Papercrete

Engineering Research Report

To the greatest degree possible, all reasonable and proper mixing, sampling and testing procedures were followed to produce the data in this report. Since papercrete is a new material, there are no written mixing and sampling standards so in some cases it was necessary to follow common sense methods rather than prescribed procedures. Any anomalies involving sample preparation are described under Section I. Observations. The tests described in Section II were performed under the supervision of Dr. Apostolos Fafitis, with the Fulton School of Engineering at Arizona State University, in the engineering laboratory. While everything possible was done to produce valid results, the data in this report should be considered a guide to the basic properties of papercrete rather than numeric absolutes. One reason for this is the issue of homogeneity of materials. Even though we used newsprint to make our samples in order to introduce as few variables as possible, we cannot state with absolute certainty that newsprint is the same throughout the country. It is difficult to maintain homogeneity from mix to mix - never mind across the entire country or world. Stringent homogeneity may not even be an issue, but until more testing is done, it has to at least be taken into account. In the interest of absolute transparency, there are a few compressive test results, which seem anomalous to us. If you study the tables carefully, you will find some results, which do not seem to track well with others. Maybe the test results are flawed or perhaps there was a problem with the mix. We can't explain some of these results and it will take repeated tests of samples from a single mix to find out if the test was wrong or the mix varied. Formulas and methods evolve and change as we learn more, and any material can be dangerous if mixed or installed improperly. Therefore, we must begin with this disclaimer.

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Section I. Preparation of Mixes For Compressive Strength Tests & Observations Before Testing

150 gallons of paper pulp was prepared comprised of 94 lbs of paper and enough water to make 150 gallons of mix. The additional components listed below were blended with the paper pulp in a mortar mixer and placed in two forms of one cubic foot each. While wet, a divider was placed in each form, dividing them into halves, providing a total of four samples of each mix. Tests 1-29 were poured on November 30, 2004. Most measures were accurate to .2 oz (two tenths of an ounce), but some measurements were difficult. The crushed glass, which was obtained at a recycling facility, was slightly wet. However, when a measured volume was dried, it occupied the same space as the slightly wet sample - so volume measurement was used rather than weight. The Styrofoam material was so light that it could easily be changed in density by light compression. Representative samples were taken from the top of the bag being careful to avoid compression. The paper mill sludge came mixed with various sized wood chips and rocks. Any chips or rocks over an inch in size were removed by hand before weighing and mixing. The measurements were accurate, but volume and weight measurements were used based on ease of handling of the materials. Gallons of dry materials were weighed to provide some description of the density of the material. The clay we used came from sandy soil sifted through a number 4 - 1/4 inch screen. A shake test and "worm" test indicated it to be about 35% clay. We retained small amounts of all materials except the paper mill sludge for reference *

Since there is not enough horizontal space on the page to fully explain each mix right next to the test results, the components of each sample mix are listed below and the test results are listed in Section II. Observations and explanations of any sampling difficulties or alterations are listed after the table below.

Test Constituents Proportions Measures
Other lb/in2

1.	Paper/Portland	1-1	9.4 lb Portland	4k 265g	
2.	Paper/Portland	1-2	18.8 lb Portland	8k 530g	
3.	Paper/Portland	1-3	28.2 lb Portland	12k 790g	
.					1 gal Sand -
4.	Paper/Portland/Sand	1-1-5gal	9.4 lb Portland, .5 gal sand	4k 265g, 7lb 9.7oz , 3k 450g	13lb 12.3oz
5.	Paper/Portland/Sand	1-1-10gal	9.4 lb Portland, 1 gal sand	4k 265g,13lb 12.3oz, 6k 245g	3k 450g
6.	Paper/Portland/Sand	1-1-15gal	9.4 lb Portland 1.5 gal sand	4k 265g,	
7.	Paper/Portland/Fly Ash	1-.7-.25	7 lb Portland, 2.4 lb Fly Ash	3k 175g, 1k 90g	Type"F"
8.	Paper/Portland/Fly Ash	1-.6-.30	6.6 lb Portland, 2.8 lb Fly Ash	2k 995g, 1k 270g	15-25%
9.	Paper/Portland/Fly Ash	1-.5-.35	6.1 lb Portland, 3.3 lb Fly Ash	2k 770g, 1k 495g	Reco.
10.	Paper/Port./Rice Hull Ash	1-.7-.3	6.6 lb Portland, 2.8 lb Rice Ash	2k 995g, 1k 270g	
11.	Paper/Port./Rice Hull Ash	1-.6-.4	5.6 lb Portland, 3.8 lb Rice Ash	2k 545g, 1k 725g	
12.	Paper/Port./Rice Hull Ash	1-.5-.5	4.7 lb Portland, 4.7 lb Rice Ash	2k 135g, 2k 135g	
13.	Paper/Portland/Styrofoam	15% Sty	12.75glpulp,21.6lbPort,2.25glSty.	9k 800g, 5.7oz, 140g	
14.	Paper/Portland/Styrofoam	20% Sty	12.75glpulp, 21.6lbPort,3 gal Sty	9k 800g, 7.1oz, 200g	
15.	Paper/Portland/Styrofoam	25% Sty	12.75gal pul,21.6lbPort,3.75g Sty	9k 800g, 9.3oz, 260g	
			(Using 2.3bags as base Port./yd.)		
16.	Sludge/Port./Fly *	1-.7-.25	7 lb Portland, 2.4 lb Fly Ash	3k 175g, 1k 90g	14.1 lbs
17.	Sludge/Port./Fly	1-.6-.30	6.6 lb Portland, 2.8 lb Fly Ash	2k 995g, 1k 270g	To allow
18.	Sludge/Port./Fly	1-.5-.35	6.1 lb Portland, 3.3 lb Fly Ash	2k 770g, 1k 495g	For wet wood.
					Start 10 water
19.	Paper/Portland/Glass	1-1-5gal	9.4 lb Portland, .5 gal Glass	4k 265g, (crushed glass-damp-	14lb 1.6oz
20.	Paper/Portland/Glass	1-1-10gal	9.4 lb Portland, 1 gal Glass	4k 265g, no accurate weight)	6k 400g
21.	Paper/Portland/Glass	1-1-15gal	9.4 lb Portland 1.5 gal Glass	4k 265g,	
					Clay-
22.	Paper/Clay** 70/30	0%Port	10.5g pulp, 4.5 gal clay	0 Port. , 57lb, 1.9oz	12lbs 11.7oz/gal
23.	Paper/Portland/Clay	1 bag mix	10.5g pulp, 9.4lbsPort, 4.5g clay	4k 265g 57lb, 1.9oz, 57lb, 1.9oz	5k, 770g
24.	Paper/Portland/Clay	2 bag mix	10.5g pulp, 18.8gPort, 4.5g clay	8k 530g 57lb, 1.9oz, 57lb, 1.9oz	
25.	Paper/Portland/Lime	1-.5-.5	4.7lb Portland, 4.7 lb Lime	2k 135g	
26.	Paper/Portland/Lime	1-1-1	9.4lb Portland, 9.4 lb Lime	4k 265g	
27.	Paper/Portland/Lime	1-1.5-1.5	14.1lb Portland, 14.1 lb Lime	6k 409g	

28.	Newspaper pulp alone***		15 gallons of newspaper pulp		
29.	Mixed paper pulp alone***		15 gallons of mixed paper pulp		
	Poured 2/23/05 Hammermilled tests. ****		All 1:2 Paper: Portland -10 cups of water		
30.	1/8 inch grind	1:2	"		
31.	3/16 inch grind	1:2	"		
32.	1/4 inch grind	1:2	"		
33.	3/8 inch grind	1:2	"		
34.	1/2 inch grind	1:2	"		
35.	5/8 inch grind	1:2	"		
36.	Clyde T. Curry Poured 2/13/05	Per yard	105 lbs of hammer milled cardboard fiber exclusively 185 lbs of portland cement Type I & II (2 Sacks) 180 lbs of fine plaster sand (2 Sacks) 12 cubic feet of styrofoam reground beads (25 % of mix) 1/2 lb. of TSP-PF dry powder detergent 180-200 gallons of PH neutral hard water (mineral laden)		
37.	Zach Rabon Poured on 2/5/05	Per yard	Mix pending.		
38.	Paper/Port/Fly ash/Sand	200 gal	100lbs/94lbs/30lbs/5gallons sand	Poured 4/6	
39	Paper/Port/Fly ash/Sand	200 ga	90 lbs newsprint 10 lbs cardboard	Poured 4/6	
	Paper above 10 percent cardboard		94 lbs Port/30 lbs fly ash/5 gal sand		
40	SRP Printing paper	.7	100lbs/94lbs/30lbs/5gallons sand	Poured 4/19	
41	Mixed waste paper	1/2 batch	50lbs/47lbs/15lbsfly/2.5 gal sand	Poured 4/19 - Lex's micer	
42.	Paper/Port/Fly ash/Sand	,7	100lbs/94lbs/30lbs/2.5gallons sand	Poured 4/19/05	
60.	Cardboard Pour 3/17/05	.7 yard	1 bag Portland, 30 lbs fly ash		
	REBAR TESTS				
1	Single block				
2	Single block - same as 1				
3	Double block - straight				
4	Double block - angle				
5	Double block - grouted				
	.1 lb = 1.6 oz				
	.2 lb = 3.2 oz				
	.3 lb = 4.8 oz				
	.4 lb = 6.4 oz				
	.5 lb = 8.0 oz				
	.6 lb = 9.6 oz				

	.7 lb = 11.2oz				
	.8 lb = 12.8 oz				

Observations Before Testing

Tests 13-15 – The Styrofoam tests seemed to settle and shrink slightly less than the other samples and to cure faster.

* Tests 16-18 - The paper mill sludge tests varied significantly from what was originally planned. Much more sludge was needed than was available and much less water was required in the mix. As soon as mixing began, it was evident that 10 gallons of water would be far too much. We stopped adding water after the initial five-gallon bucket was added. Even this amount of water made the mix far too soupy so we added a total of 3.5 batches (14.1 lbs. each) of the sludge. The mix was then very similar to conventional concrete and worked well. However, after using that much sludge we didn't have enough left to mix the two additional tests described above - so we combined tests 17 and 18. We combined the Portland cement and fly ash, and added the rest of the sludge, which comprised of two batches each (14.1 lbs.) plus the leftover sludge -13 lbs. 11 oz. Having learned from the initial mix that comparatively little water was needed, we added it in one gallon increments until the mix was workable. This required 4 gallons.

** Tests 22-24 – The clay tests were accurately measured and followed our mixing procedure. However, it was quite evident within a few hours of setting that this clay could have been mixed with a far greater proportion of papercrete slurry. Sample 22, made without binder, was not ready to tip on edge when almost all other samples were (see below). The clay samples were at first very dense and closer to classic adobe than papercrete. Note: As of December 1st, the clay samples began to dry rapidly and lose water weight.. They now appear to be clay and paper rather than classic adobe.

*** Tests 28-29 – The samples made with newspaper and mixed paper alone (without binders) took much longer to set. All samples were poured on Saturday, October 30, 2004. All samples, except 22 and 28-29, were tipped on edge on Tuesday, November 2,

2004. Those, which could not be tipped on edge had no binder with the exception of 22, which had clay. Sample 22 was carefully tipped on edge one day later than the other samples. It was observably weaker than the others.

**** Tests 30-35 -- The hammer mill tests were intended to compare the strength of various grinds of hammer milled waste paper blocks to blocks made with newsprint. To conserve on testing resources, we will test only Samples 30 (1/8"), 33 (5/16") and 35 (5/8"). While this observation may have little scientific value, Sample 33 exhibited the least deformation (shrinkage). All Samples were made the same way.. About nine ounces of paper was combined with double the amount of Portland cement and 10 cups of water. All were mixed for close to three minutes in a five-gallon can with a mortar-mixing blade in an electric drill. The mix was then placed in a 3 3/4" inch wooden form. Since the weather was so damp, the form was taken inside to dry. On the second day, the Samples were removed from the form. On the third day, small fans were set up to hasten the drying process. The samples were allowed two weeks to dry. The strength of these Samples will be compared to each other and to the results of Test 2, which was newsprint mixed 1:2 with Portland cement.

Tests 30-35 measured the strength of different grinds of hammer milled paper in order to determine if gauge of grind had any effect on strength. To conserve on testing resources, it was decided to submit samples 30, 32 and 35. If any unexpected results should occur, the other samples could be tested.

Sample 36 was a block from Clyde T. Curry, who is experimenting with fast curing chemicals and needed to know if they were having any effect on strength.

Sample 37 was a block from Zach Rabon in Mason, Texas - new formula.

Sample 40 - Printing trimmings. About twenty percent shrinkage. Tip on edge time about four days rather than next day with newsprint. Tried a forty percent mix with newsprint which worked much better, but a 50-50 or 1:1 mix with newsprint would probably work best.

Sample 41 - Mixed waste paper. Since a percentage of this mix was already newsprint, the shrinkage and tip time were not as extreme as the print trimmings in Sample 40, but a larger percentage of newsprint should be used. The shrinkage was more than newsprint and it took somewhat longer to dry enough to tip up.

WEATHER (Tests 1-29)

The weather during the pouring and drying period was unusually wet for Arizona. The ground where the samples were poured was still damp from a prior rain, and there were two light rains and 10-12 days of overcast weather in the three weeks following the pour. Daily observations of the samples indicated that those mixed with Portland cement dried faster and shrank less than those without, however all samples took considerably longer to dry than (reported) in the summer months. The two samples made without binder, the newspaper and mixed paper, could not be turned on edge until the third week of November.

On the 18th of November it was observed that the clay samples were changing color to a light beige. They were also losing weight. Of all the samples, the clay and the paper mill sludge samples shrank and slumped the least. They also were the densest and heaviest leading to the assumption that their thermal properties would not be very desirable. The tradeoff seems to be mass vs. good insulation properties.

On the 21st of November, with another winter storm threatening, all blocks were moved and stacked on a concrete pad under a small covered overhang. Blowing rain could still reach them but a falling rain would not. This was deemed necessary because of the frequent rains had slowed the drying time of all the samples. The newspaper and mixed paper blocks were handled for the first time. They held together but were still very wet.

It is now the 11th of December. All samples are dry externally and quite strong - with the exception of the sample made with rice hull ash. It is still soft to the touch. Either rice hull ash simply doesn't work as a pozzolan or the amount of Portland cement mixed with the rice hull ash wasn't sufficient. If time permits, we will try making additional samples with a greater percentage of Portland cement. Update 4/10/05 - This almost certainly occurred because of lack of Portland. All tests seem to indicate that most of the strength tracks Portland content. However, fiber type and sand content have a role as well.

Samples 11-13, Rice Hull Ash and 28,29, Paper Without Binder were not submitted to Arizona State for testing in order to conserve testing resources. As stated above, the Rice Hull Ash did not appear to work very well and samples 28,29 were considered to be unnecessary since any form of paper block will have to contain binder. So 24 samples were submitted to ASU on February 4th for testing.

Samples 38, 39 Noticed that light hand compression and addition of more material within 20-30 minutes after pour, results in much less honeycombing and shrinkage. Samples were somewhat more difficult to remove from forms, but remained nearly 100 percent square in curing.

Sample 60 Cardboard shrank slightly more and retained water for much longer than newsprint and kept the light brown color. However, upon drying, the material seemed to exhibit much more strength. Clyde Curry reports adding 10 percent cardboard to newsprint results in greater strength. It appears that adding longer fibers to the mix adds strength.

Section II. Laboratory Testing

1. Scope

The scope of this project is mainly focused on the compressive properties of Papercrete, a new material made of waste paper, cement, and water. In addition to the compressive properties, a limited number of preliminary tests are performed. The objective of these tests is to gain some insight on other properties such as creep, pull and thermal.

2. Objectives

2.1 Determine a working Young's modulus (E) of the different samples in order to choose the ideal mixture that has the higher stiffness and lower deformation.

2.2 Study the deformation (creep) behavior of the selected samples under the application of constant load applied for a long period of time.

2.3 Determine some thermal properties such as thermal conductivity (K), and thermal resistance (R).

2.4 Determine the bond characteristics of the material by doing pull-out test.

3. Compressive Test

3.1 Experimental Setup

In theses tests an increasing uniaxial compressive load was applied at constant speed, uniformly distributed in order to develop the stress vs strain curve and determine determine the stiffness of the material. The following testing procedure was used for the compression test:

- Since some samples had irregular faces, they were made flat by using normal commercial mortar (Figure 1). In this way, the applied load is distributed uniformly.

Figure 1.- Papercrete sample with mortar on one face

- The mortar was allowed to cure for seven days. The samples were tested under uniaxial compressive force using a 100ton-compression machine (Figure 2). The loading rate at the displacement control mode was 0.35 in/min, and all samples were loaded up to approximately 10 kips, unloaded, and reloaded to approximately 15 kips.
- Two aluminum plates were used to distribute uniformly the load given by the machine to the sample.

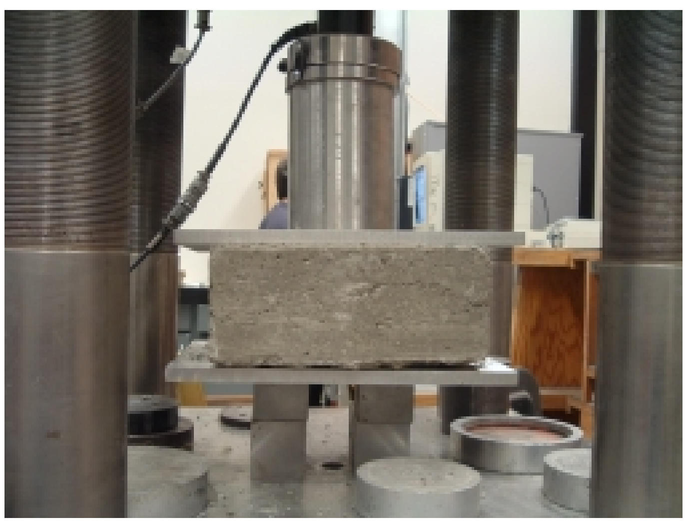


Figure 2.- Compression test

- Failure was defined by deformation criteria rather than load because the compressive force magnitude does not drop. The material is not brittle, and it does not exhibit descending branch in the stress-strain curve.
- It was found that at 15 kips the deformation was excessive, rendering the material useless.

3.2 Results

The data collected from the compression tests ware used to develop two graphs for each sample. The first graph is Load vs Deformation, and the second one is Stress vs Strain. The stiffness or elastic modulus of the material (E) is the slope of the Stress vs Strain graph. A trend line was applied using Microsoft Excel in order to get the right value of the slope of the curve (Figure 3). Note that the material is non-linear, and as a result there is no Elastic (Young's) Modulus. A working Young's Modulus is an approximate value obtained from the stress-strain curves, and which can be used as an index to characterize the compressive behavior up to some stress. In practice, the allowable compressive stress is expected to be at about this level. The softer part of the curve (Figure 3), is probably due to irregularities of the surfaces of the specimens.

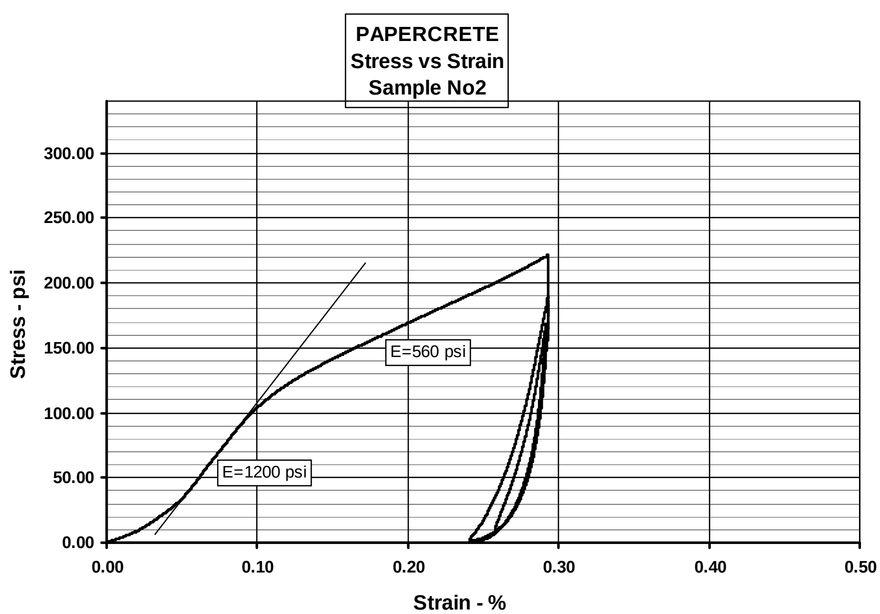


Figure 3.- Stress vs Strain graph

A first group of twenty three samples of different mix proportions of recycled paper and cement were tested under uniaxial compressive force on March 1st, 2nd, and 3rd and the results are tabulated in Table 1:

Table 1 : Papercrete Samples (1st group)
Summary results

	Sample	Material	Proportions	Elastic Modulus 1	Elastic Modulus 2
1	Sample1	Paper/Portland	1-1	600 psi	200 psi
2	Sample2	Paper/Portland	1-2	1200 psi	560 psi
3	Sample3	Paper/Portland	1-3	2000 psi	860 psi
4	Sample4	Paper/Portland/Sand	1-1-5gal	800 psi	285 psi
5	Sample5	Paper/Portland/Sand	1-1-10gal	700 psi	330 psi
6	Sample6	Paper/Portland/Sand	1-1-15gal	590 psi	280 psi
7	Sample7	Paper/Portland/Fly Ash	1-.7-.25	950 psi	260 psi
8	Sample8	Paper/Portland/Fly Ash	1-.6-.30	420 psi	190 psi
9	Sample9	Paper/Portland/Fly Ash	1-.5-.35	400 psi	200 psi
10	Sample13	Paper/Portland/Styrofoam	15% Sty	1200 psi	700 psi
11	Sample14	Paper/Portland/Styrofoam	20% Sty	1430 psi	490 psi
12	Sample15	Paper/Portland/Styrofoam	25% Sty	860 psi	490 psi
13	Sample16	Sludge/Port./Fly	1-.7-.25	1390 psi	
14	Sample1718	Sludge/Port./Fly	1-.6-.3	2700 psi	
15	Sample19	Paper/Portland/Glass	1-1-5gal	470 psi	200 psi
16	Sample20	Paper/Portland/Glass	1-1-10gal	570 psi	250 psi
17	Sample21	Paper/Portland/Glass	1-1-15gal	700 psi	230 psi
18	Sample22	Paper/Clay	0%Port	1394 psi	620 psi
19	Sample23	Paper/Portland/Clay	1 bag mix	855 psi	390 psi
20	Sample24	Paper/Portland/Clay	2 bag mix	1375 psi	670 psi
21	Sample25	Paper/Portland/Lime	1-.5-.5	400 psi	170 psi
22	Sample26	Paper/Portland/Lime	1-1-1	570 psi	230 psi
23	Sample27	Paper/Portland/Lime	1-1.5-1.5	660 psi	250 psi

A second group of six samples was tested on April 5, 3rd and the results are tabulated in Table 2:

Table 2: Papercrete Samples (2nd group)
Summary results

	Sample	Material	Proportions	Elastic Modulus 1	Elastic Modulus 2
24	Sample30	1/8 inch grind	1:2	1550 psi	-
25	Sample33	3/8 inch grind	1:2	2000 psi	-

26	Sample35	5/8 inch grind	1:2	1200 psi	-
27	Sample36	Clyde T. Curry: Poured 2/13/05	Per yard	1250 psi	100 psi
28	Sample37	Zach Rabon:Poured on 2/5/05	Per yard	3000 psi	800 psi
29	Sample60	Cardboard Pour 3/17/05	.7 yard	220 psi	-

A third group of five samples was tested on May 17th, and the results are tabulated in Table 3:

Table 3: Papercrete Samples

Summary results

	Sample	Material	Proportions	Elastic Modulus 1	Elastic Modulus 2
30	Sample38	Paper/Port/Fly ash/Sand	200 gal	1200 psi	100 psi
31	Sample39	Paper/Port/Fly ash/Sand	200 gal	900 psi	120 psi
32	Sample40	SRP Printing paper	0.7	1500 psi	270 psi
33	Sample41	Mixed waste paper	1/2 batch	1300 psi	-
34	Sample42	Paper/Port/Fly ash/Sand	0.7	2100 psi	220 psi

All the Load vs Deformation and Stress vs Strain graphs as well as the sample detailed descriptions may be found in Appendix I.

3.3 Conclusions

- When the samples were capped, all of them absorbed a lot of water very quickly. However, no apparent change in the samples after the seven day curing period was observed.
- During the compression test, the stress-strain curve is monotonically increasing and the sample starts packing rather than disintegrating. For that reason, deformation is the criterion for failure.
- The Stress vs Strain graphs suggest that, papercrete is a ductile material that can sustain large deformations (Figure 5).

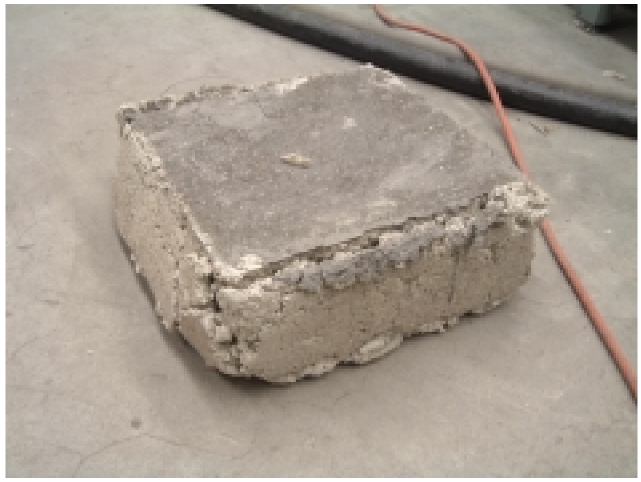


Figure 5.- Papercrete sample after testing

- Cement plays an important role in the compressive strength and behavior. Specimens with higher proportion of cement exhibit larger Young’s Modulus.
- As pointed out, the stress-strain curves exhibit a softer segment at the beginning (Figure 3). This is probably because of the inherent irregularities of the specimens due to shrinkage.
- It is believed that, in practice (for example in the construction of a wall), the self-weight of the structure will apply a moderate pressure which will bring the stress at the level of the working Young’s Modulus which will be used in design.

4. Pull Out Test

4.1 Experimental Setup

This test is used to measure the bond capacity of a material by applying an increasing force to extract a corrugated steel bar that was previously driven. The following testing procedure was used for the Pull Out Test:

- The pull-out samples were prepared by driving a corrugated steel bar in the middle of a block of Papercrete. Two different kinds of samples were tested. The single one has one block, and the second one has two blocks. Cement was used to join blocks, and, in some samples, some cement was put to fill the empty spaces between the steel bar and the block (Figure 6).

Figure 6.- Pull Out sample with two blocks.

- The sample is subjected to an increasing load in order to pull out the steel bar by using a 100ton-compression machine (Figure 7). The loading rate at the displacement control mode was 0.35 in/min, and a steel cap was used to apply the load on the bar to avoid it moves during the test.

Figure 7.- Pull Out Test (double block)

- In the same way as the compression test, failure was defined by deformation criteria rather than load because the pulling force magnitude does not drop immediately. After reaching the pulling force its maximum value, it starts decreasing slowly due to the friction between the steel bar and papercrete. Since the steel bar is a corrugated one, the force does not decrease immediately due to the bar wrinkles or folds.

4.2 Results

The data collected from the pull-out test were used to develop a Load vs Deformation graph for each sample. From this graph, we can obtain the maximum load (Pmax) that the sample can sustain before the corrugated steel bar and the papercrete block start sliding between each other (Figure 8).

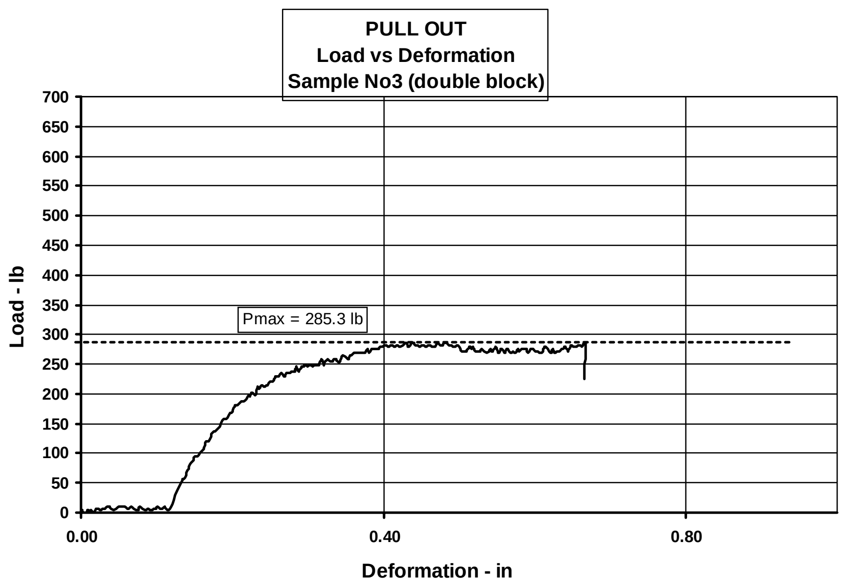


Figure 8.- Load vs Deformation

Five samples were tested on May 17th, and the results are tabulated in Table 4:

Pull out test
Summary results

	Sample	Type	Pmax (lbs)
1	Sample1	single	60.4
2	Sample2	single	47.0
3	Sample3	double	285.3
4	Sample4	double	130.1
5	Sample5	double	694.0

All the Load vs Deformation graphs as well as the sample detailed descriptions may be found in Appendix II.

4.3 Conclusions

- During the pull out test, the load-deformation curve is monotonically increasing in a non-linear way until it reaches its maximum. Then it starts decreasing slowly due to the bar wrinkles or folds which prevent the opposite force (friction force) from decreasing drastically.
- All load-deformation curves exhibit a large number of peaks along them. This is because the material (papercrete) is broken and packed as the corrugated steel bar is driven by the pulling force. When the material is broken, the pulling load drops, and when the material starts packing, the load increases. This occurs hundreds of times during the entire tests.
- From the results numbers, it is noted that the results vary considerably from one to another. Since the corrugated steel bar was driven into the papercrete blocks by hammering, some factors such as perpendicularity, and packing produced by bar wrinkles or folds can make pull out results vary.
- In addition, Pmax does not vary proportionally. For example, if Pmax=40lb for a single block sample, Pmax will not be 2 times 40 for a double block sample. It will be larger. This can be due to several factors such as perpendicularity of the steel bar, state of papercrete packing after driving the steel bar, and the cement used to join blocks.

5. Creep Test

5.1 Experimental Setup

This test is used to see how a material behaves when it is subjected to a constant compressive load for a long period of time. The following testing procedure was used for the Creep Test:

- All creep samples were made by cutting papercrete blocks of approximately 3 in x 3 in x 9 in (Figure 9).

Figure 9.- Creep samples

- It was designed a special apparatus with a gage that allows us to measure vertical deformations with a sensitivity of 1/1000 of an inch. A steel bar is used to transmit and amplify a load of 60lb to a wood rod which transmits the load to the sample through two small wood plates (Figure 10).

Figure 10.- Creep Test

- Each sample is subjected to a constant load of approximately 300 lb for a relatively long period of time (approximately 2 weeks) until the increment of deformation from one day with respect to another is almost zero.

5.2 Results

The data collected from the creep test were used to develop a Deformation vs Time graph for each sample. From this graph, we can see the deformation (creep) behavior under a constant load (Figure 11). At the beginning, the material is non-linear, but, as time goes by, the curve starts getting asymptotic. To smoothen the curve, a trend line was applied using Microsoft Excel.

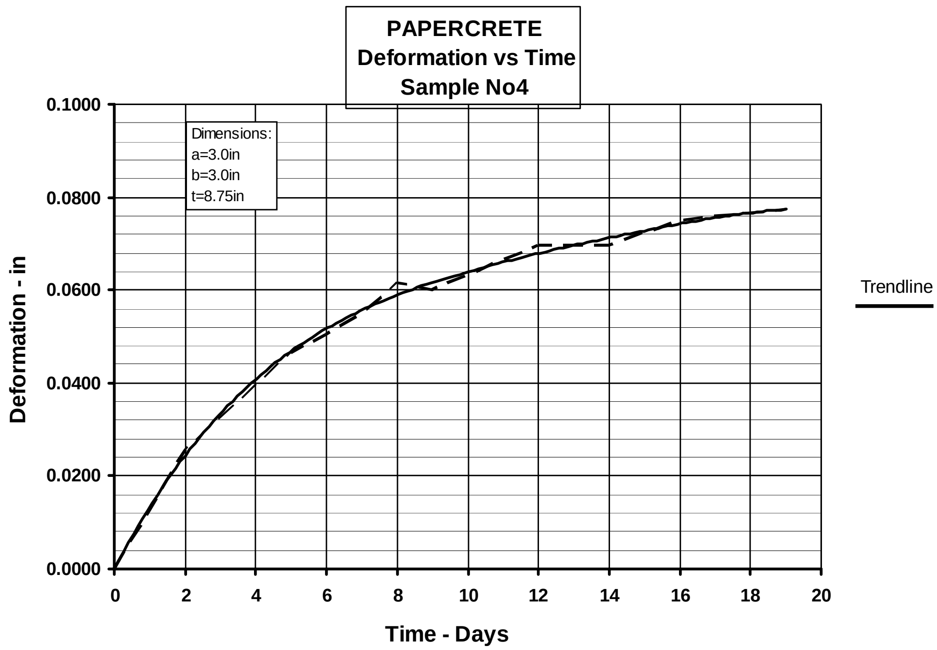


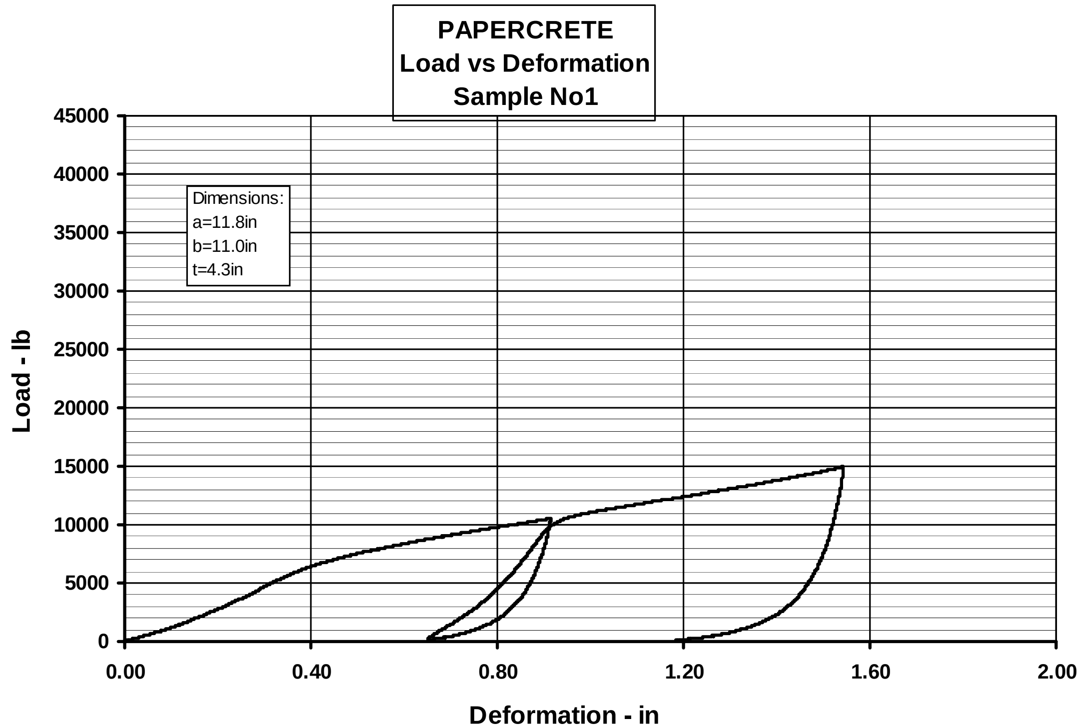
Figure 11.- Deformation-Time curve

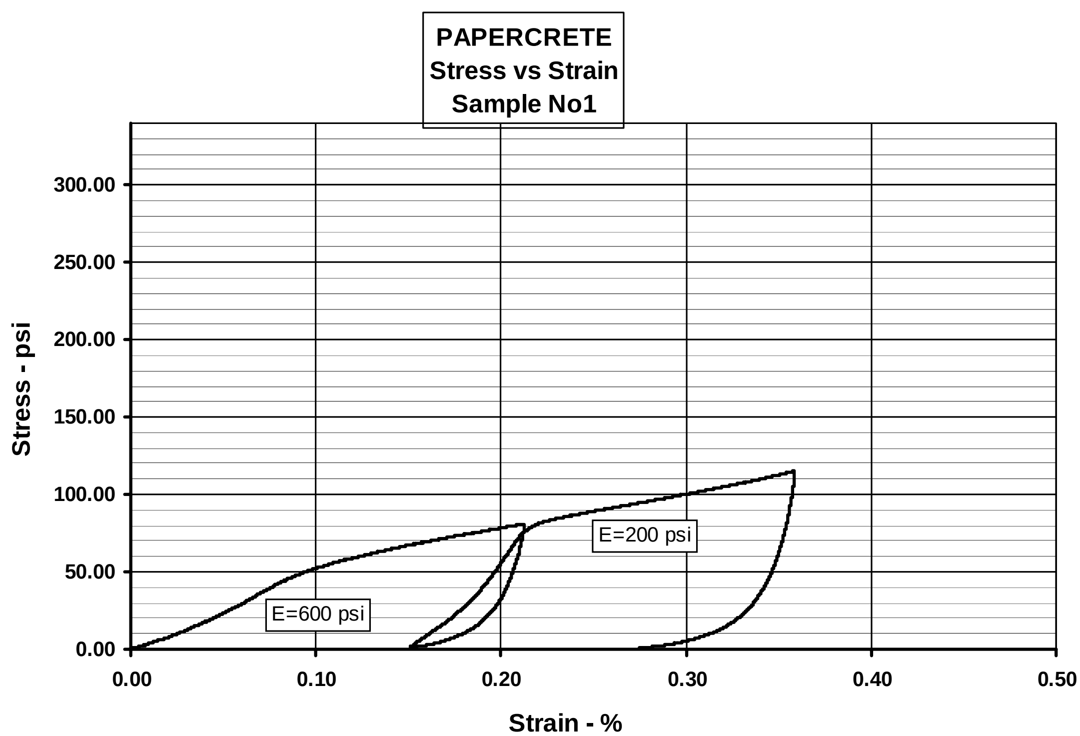
A group of six samples will be tested, and all results will be reported as soon the tests are over. So far, just one sample has been tested, and the Deformation vs Time graph as well as a table showing deformation, and strain may be found in Appendix III.

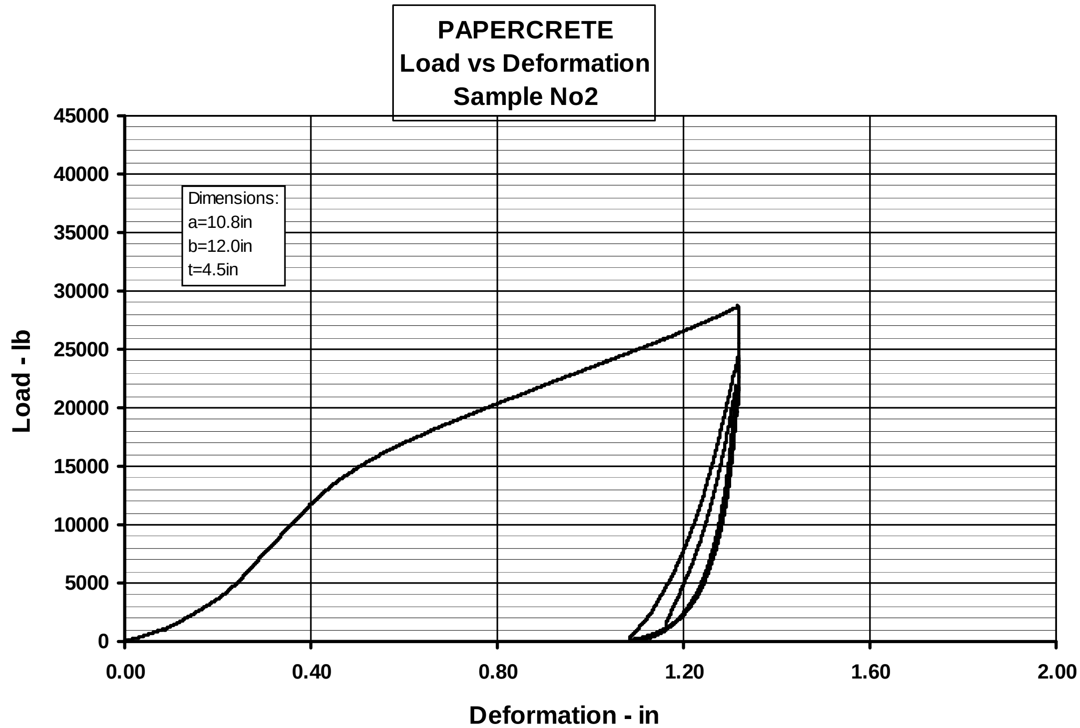
Appendix I

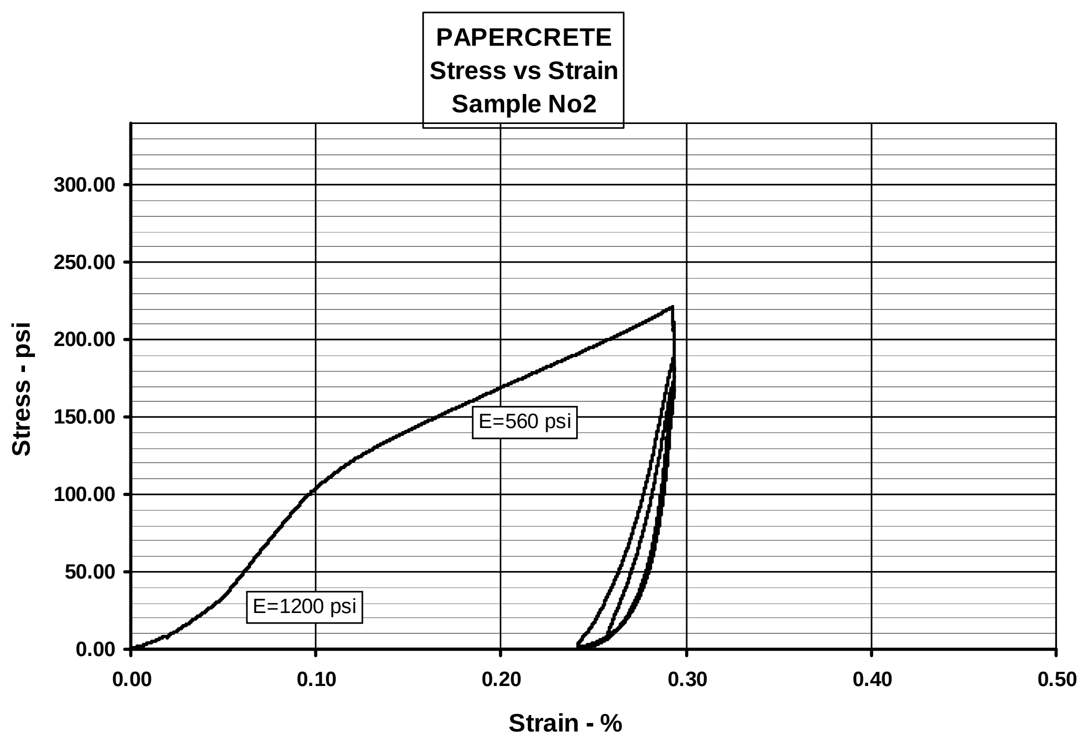
Compressive Test

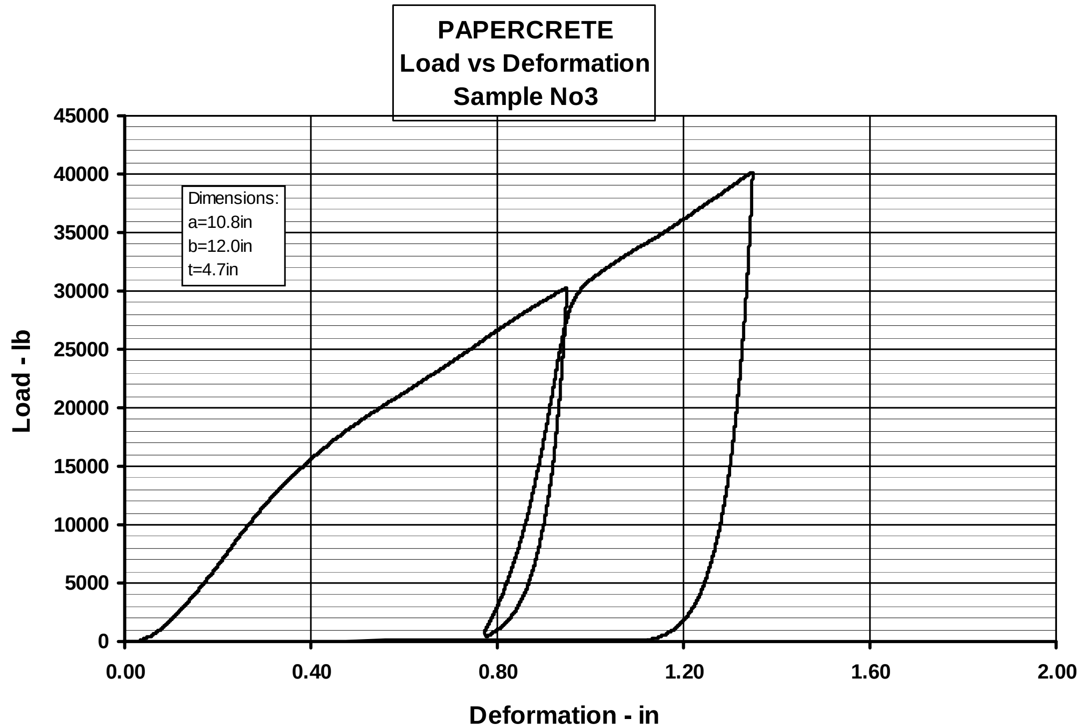
1st Group of Samples


PAPERCRETE
Load vs Deformation
Sample No1
Dimensions:
a=11.8in
b=11.0in
t=4.3in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

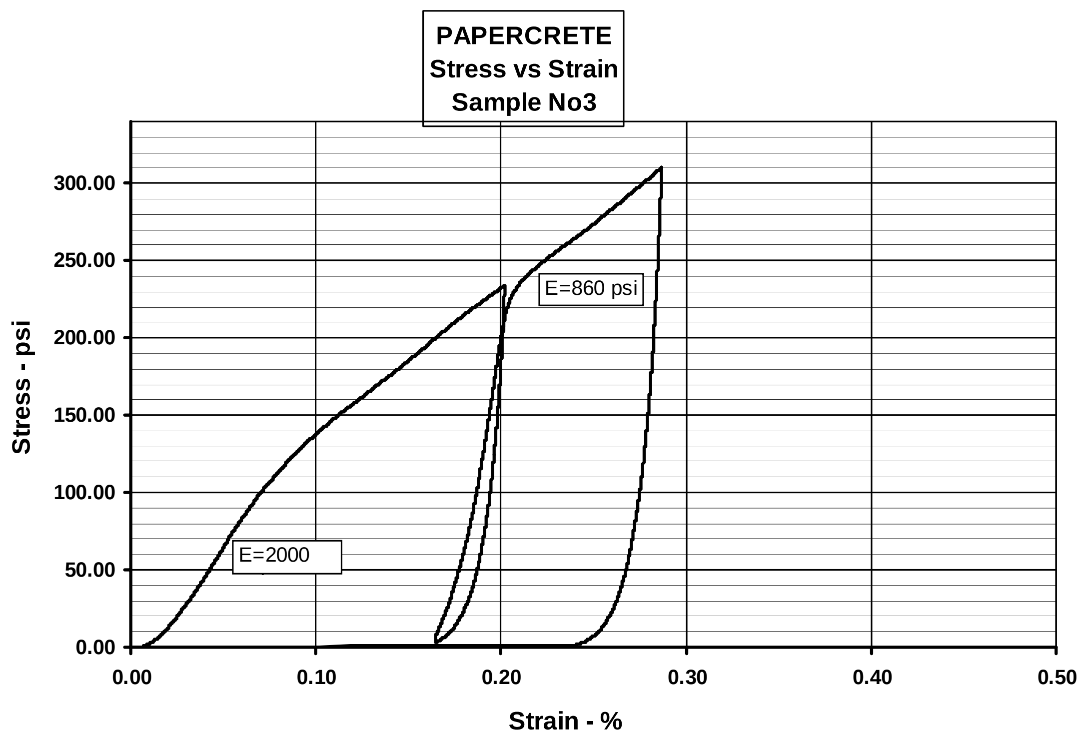

PAPERCRETE
Stress vs Strain
Sample No1
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=200 psi
E=600 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %


PAPERCRETE
Load vs Deformation
Sample No2
Dimensions:
a=10.8in
b=12.0in
t=4.5in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

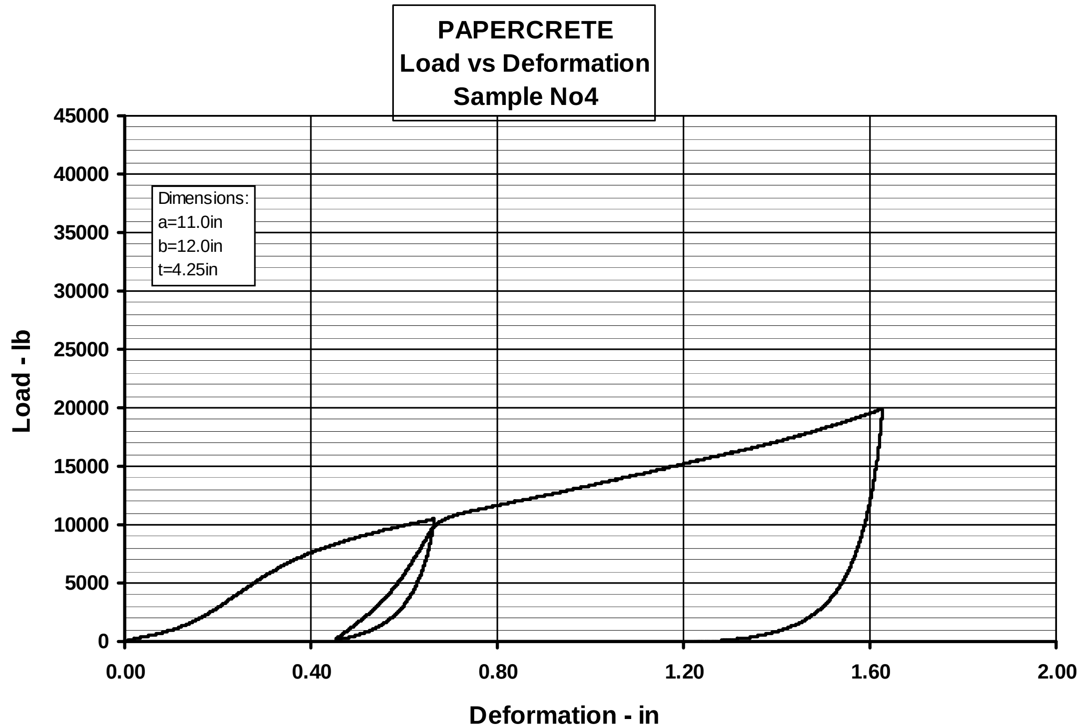

PAPERCRETE
Stress vs Strain
Sample No2
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=560 psi
E=1200 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

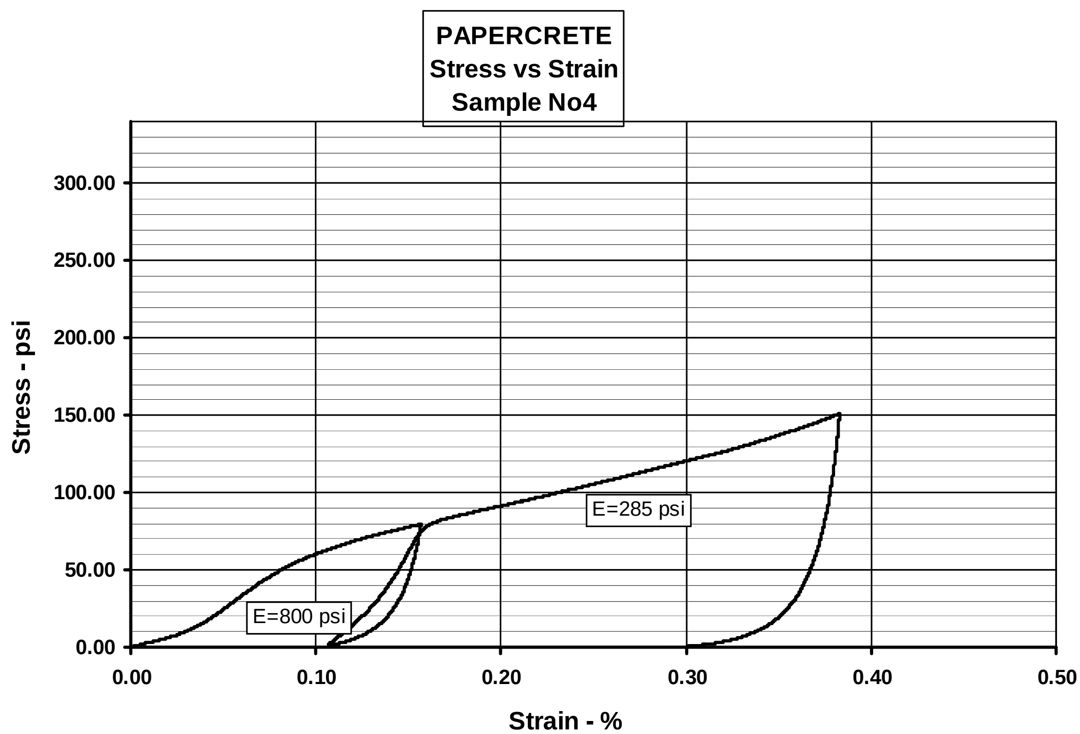


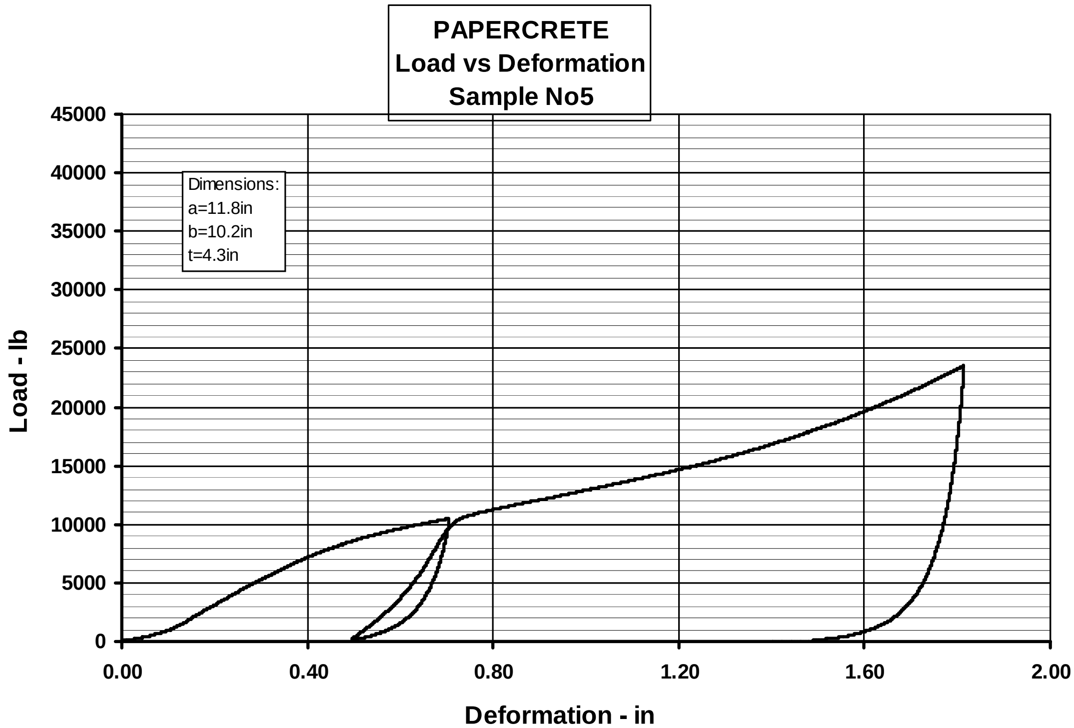
PAPERCRETE
Load vs Deformation
Sample No3
Dimensions:
a=10.8in
b=12.0in
t=4.7in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

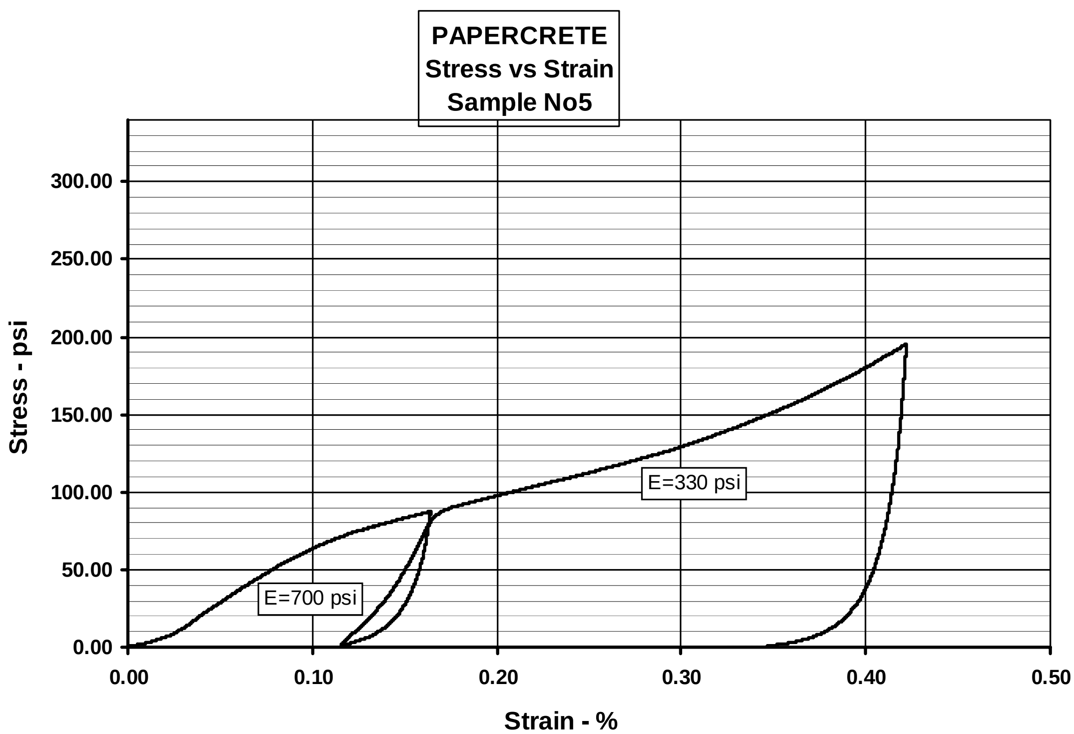


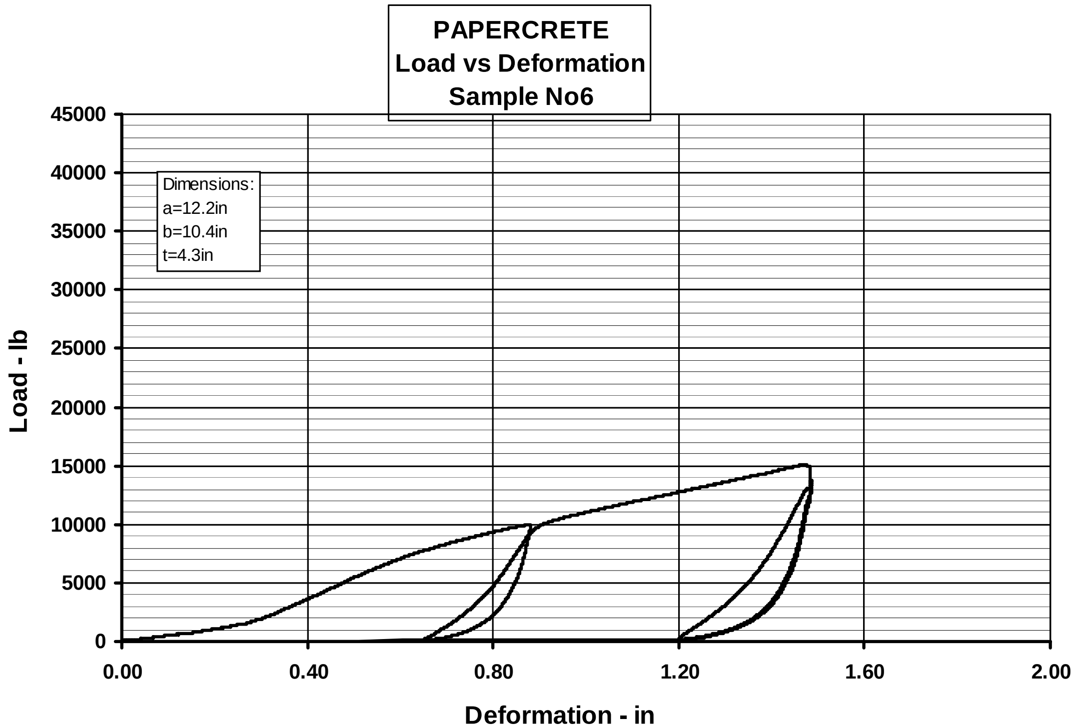
PAPERCRETE
Stress vs Strain
Sample No3
E=860 psi
E=2000
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

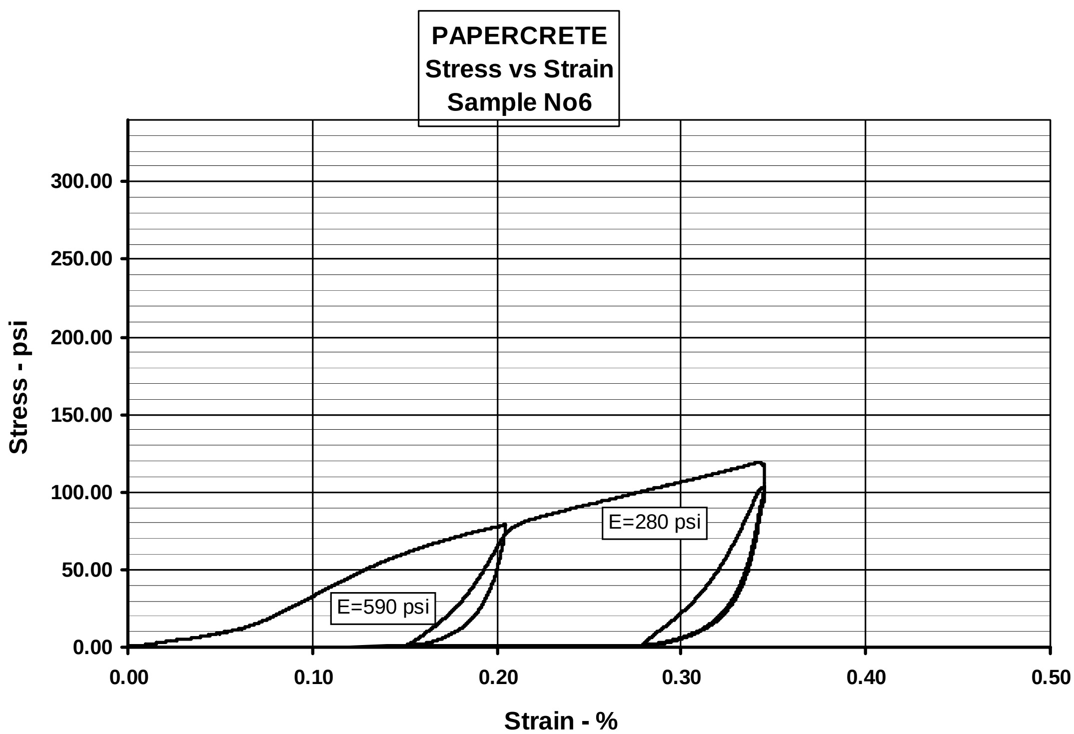

PAPERCRETE
Load vs Deformation
Sample No4
Dimensions:
a=11.0in
b=12.0in
t=4.25in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

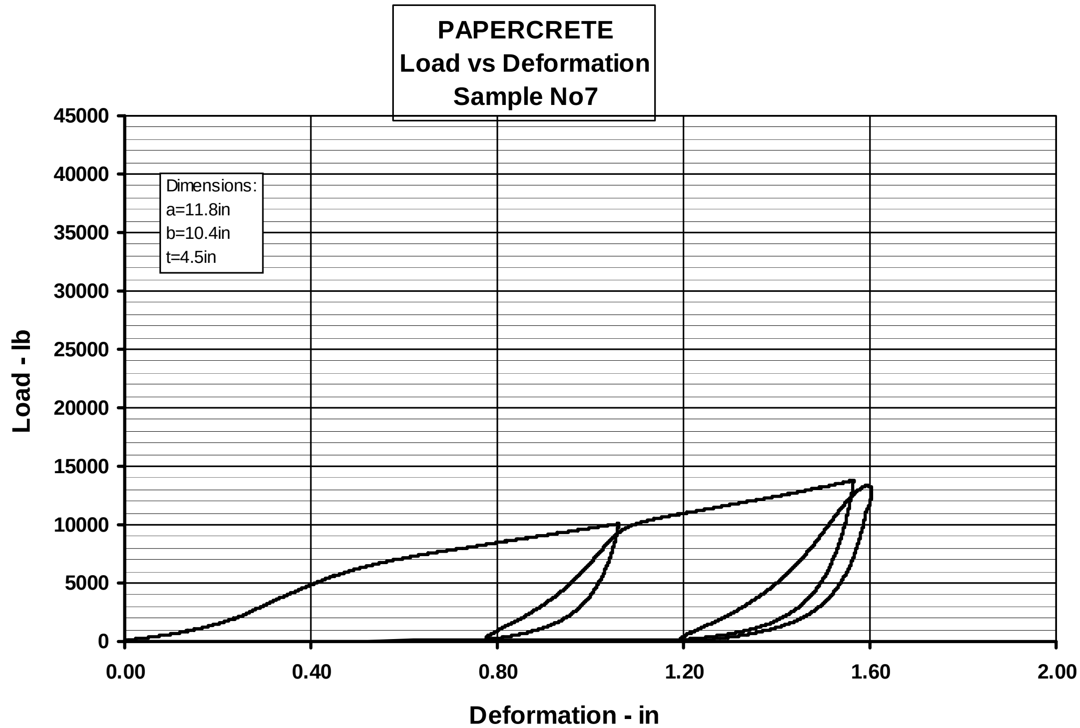

PAPERCRETE
Stress vs Strain
Sample No4
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=285 psi
E=800 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

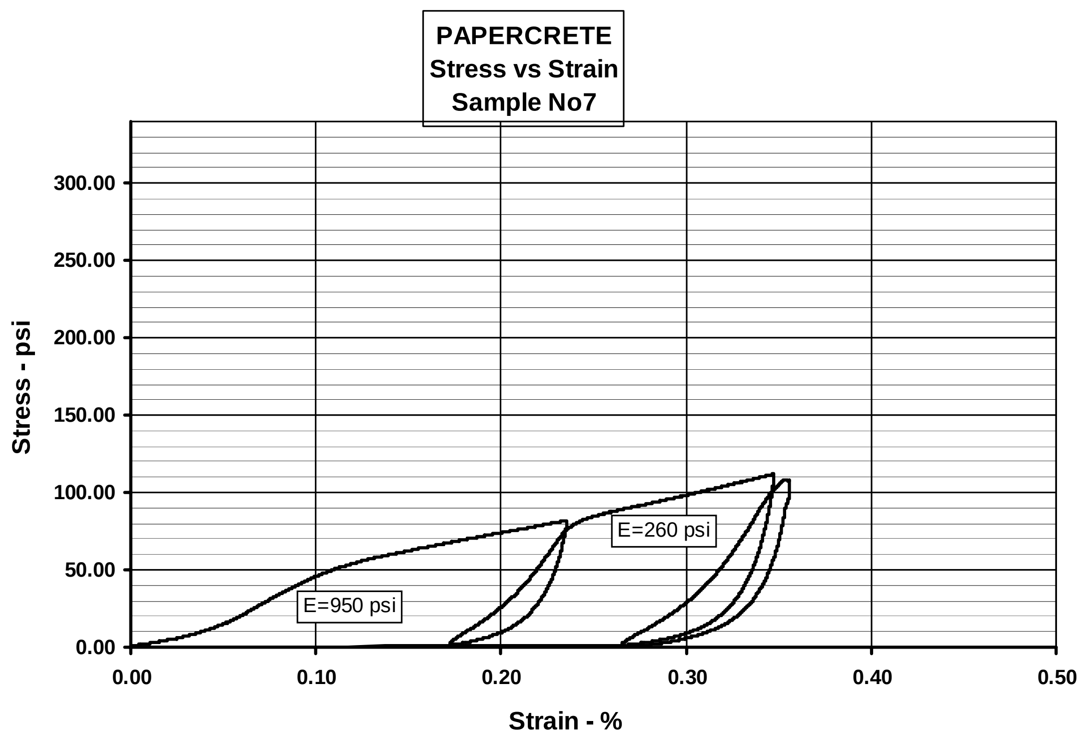

PAPERCRETE
Load vs Deformation
Sample No5
Dimensions:
a=11.8in
b=10.2in
t=4.3in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

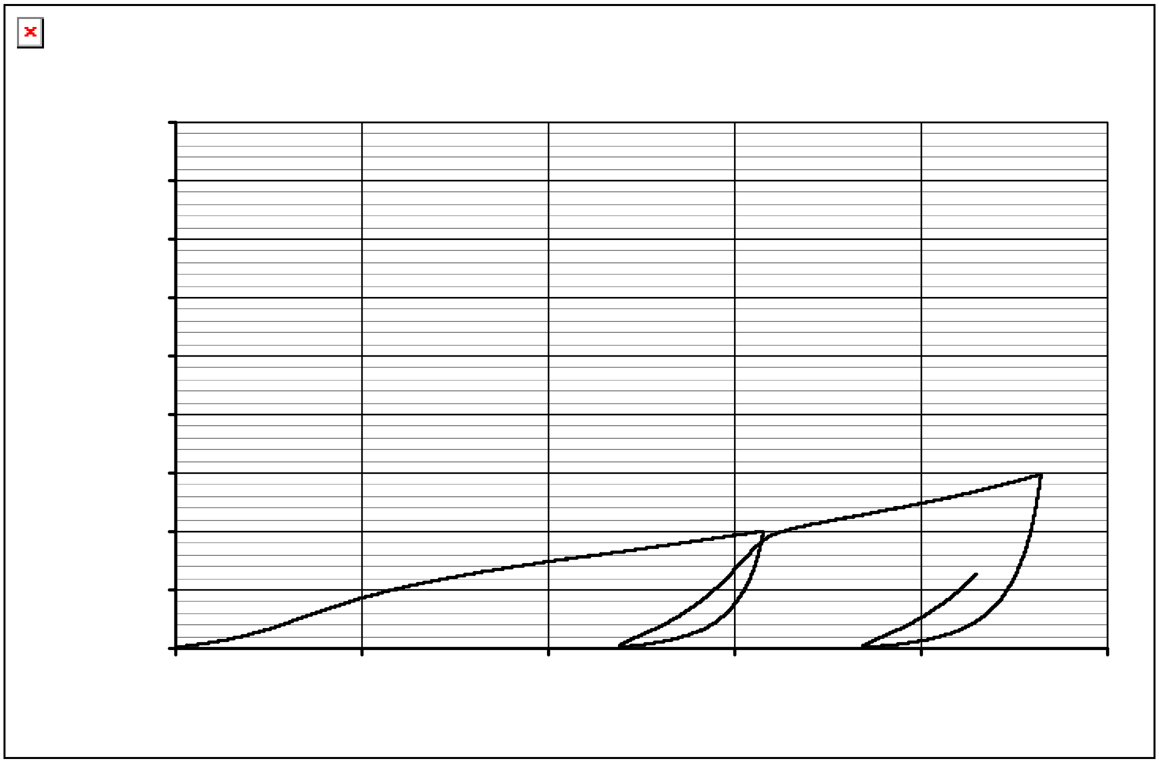

PAPERCRETE
Stress vs Strain
Sample No5
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=330 psi
E=700 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

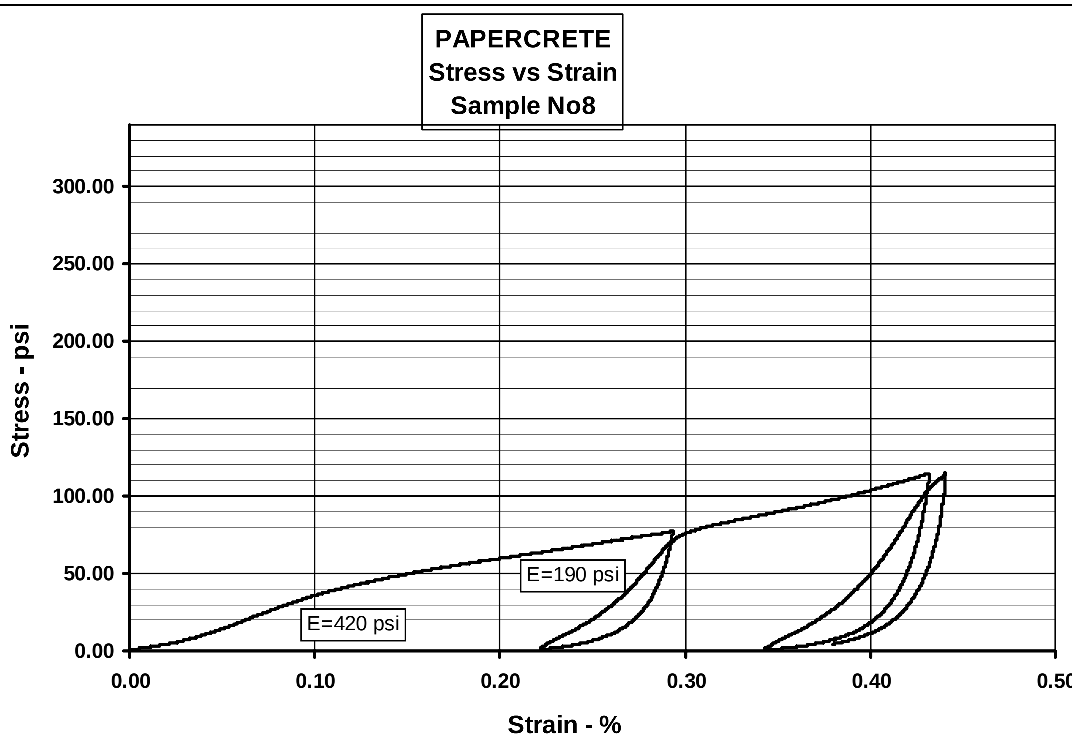

PAPERCRETE
Load vs Deformation
Sample No6
Dimensions:
a=12.2in
b=10.4in
t=4.3in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

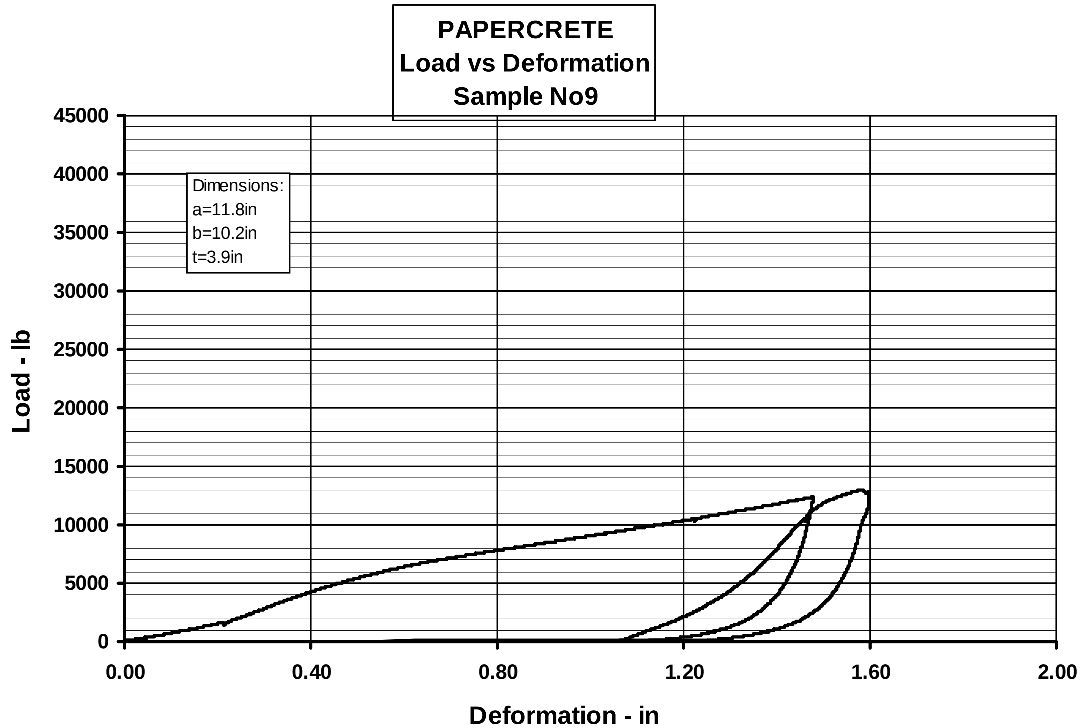

PAPERCRETE
Stress vs Strain
Sample No6
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=280 psi
E=590 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

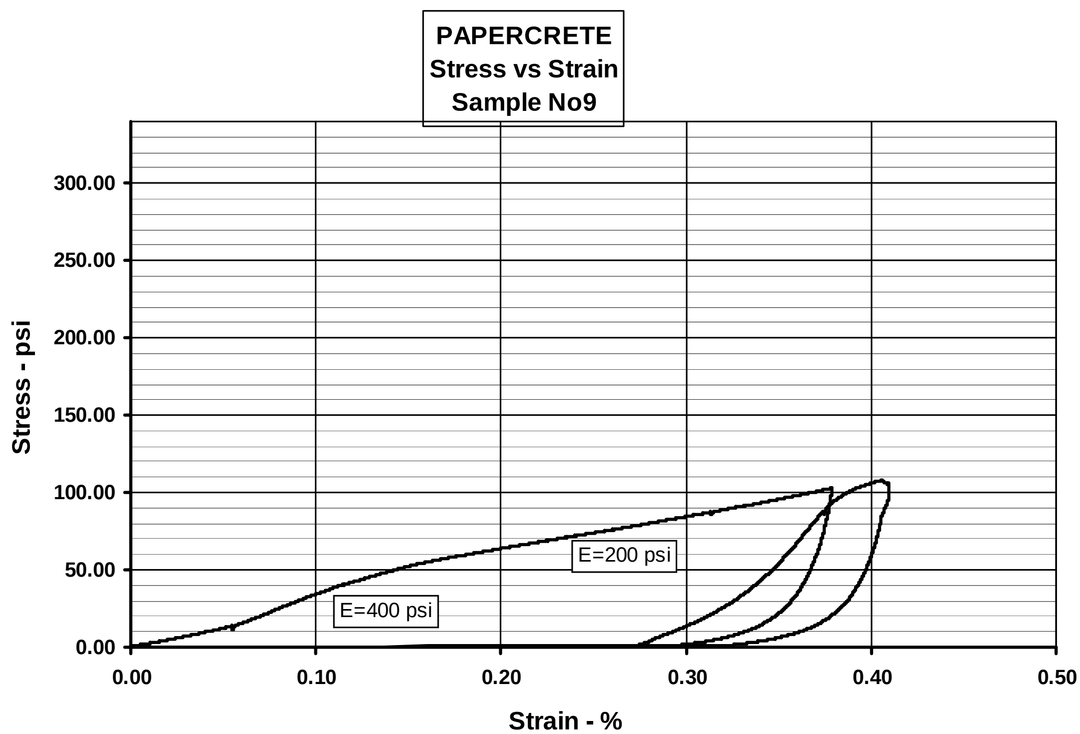

PAPERCRETE
Load vs Deformation
Sample No7
Dimensions:
a=11.8in
b=10.4in
t=4.5in
Load - lb
Deformation - in
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
0.00
0.40
0.80
1.20
1.60
2.00

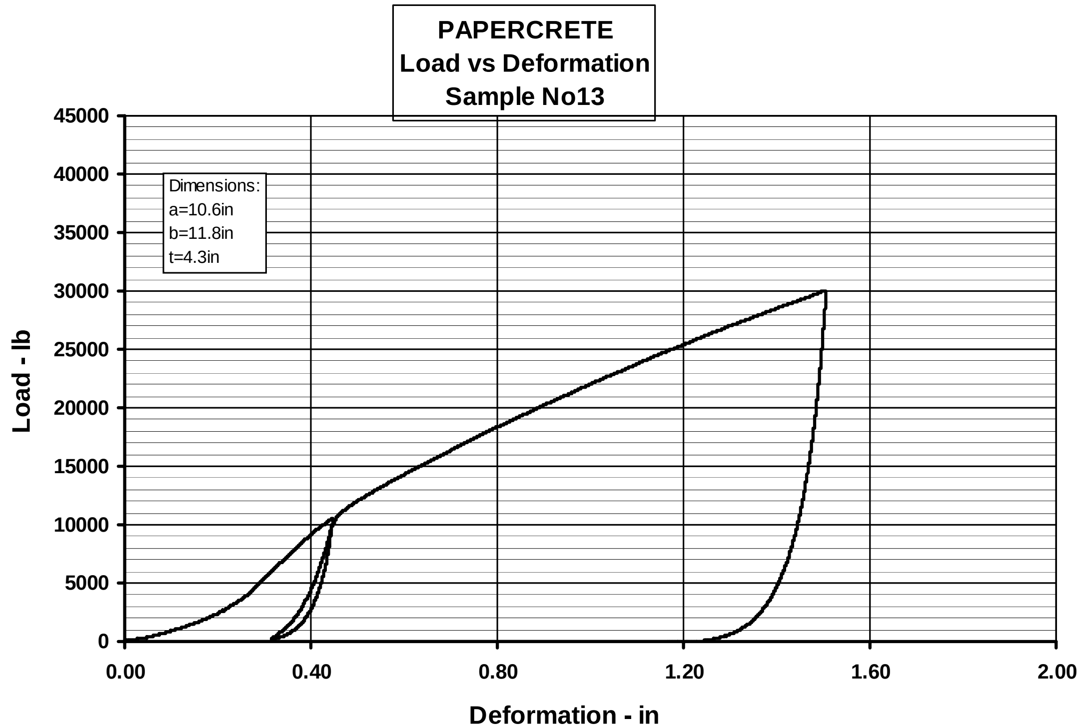

PAPERCRETE
Stress vs Strain
Sample No7
E=260 psi
E=950 psi
Stress - psi
Strain - %
0.00
50.00
100.00
150.00
200.00
250.00
300.00
0.00
0.10
0.20
0.30
0.40
0.50

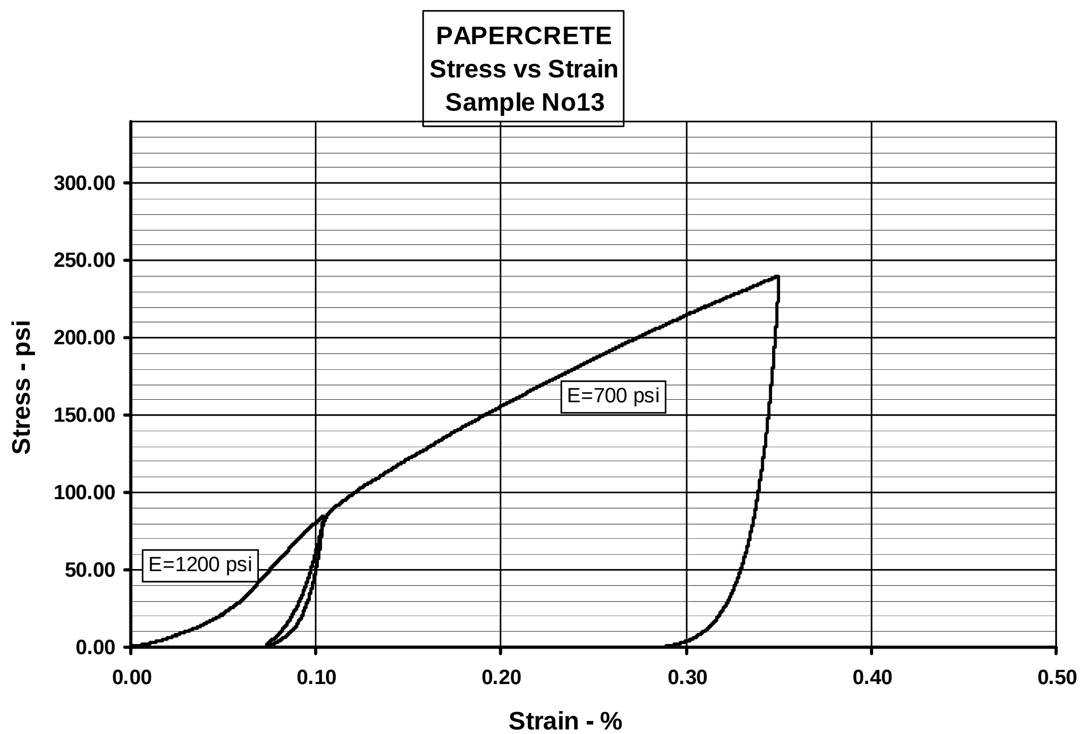


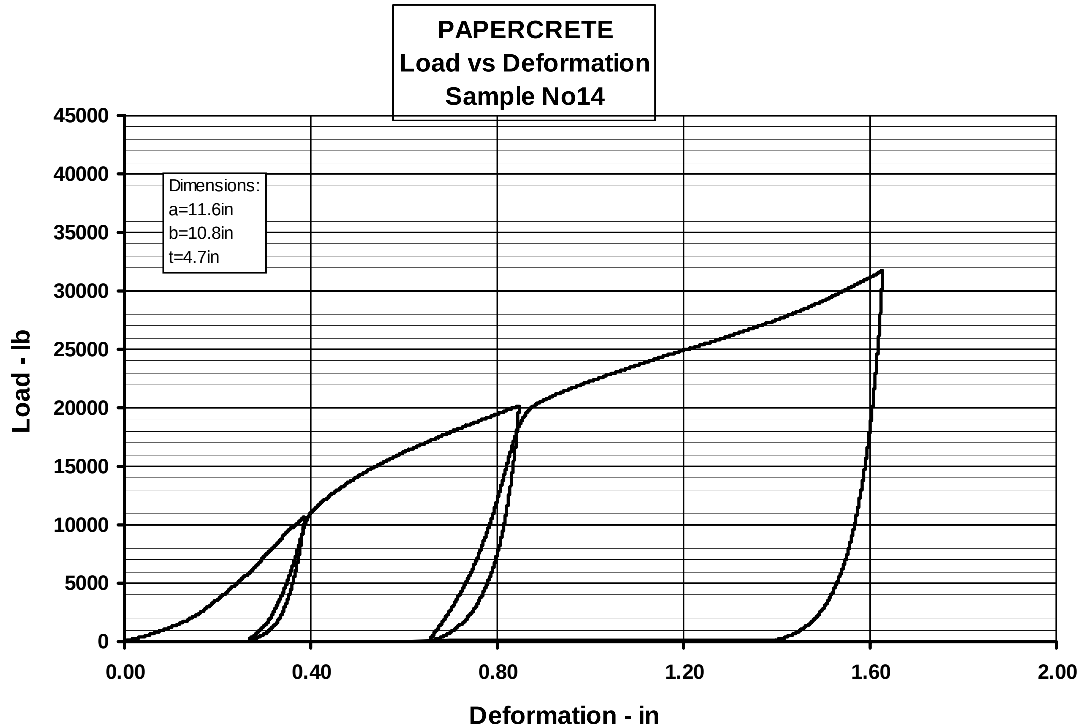

PAPERCRETE
Stress vs Strain
Sample No8
Stress - psi
Strain - %
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50
E=190 psi
E=420 psi

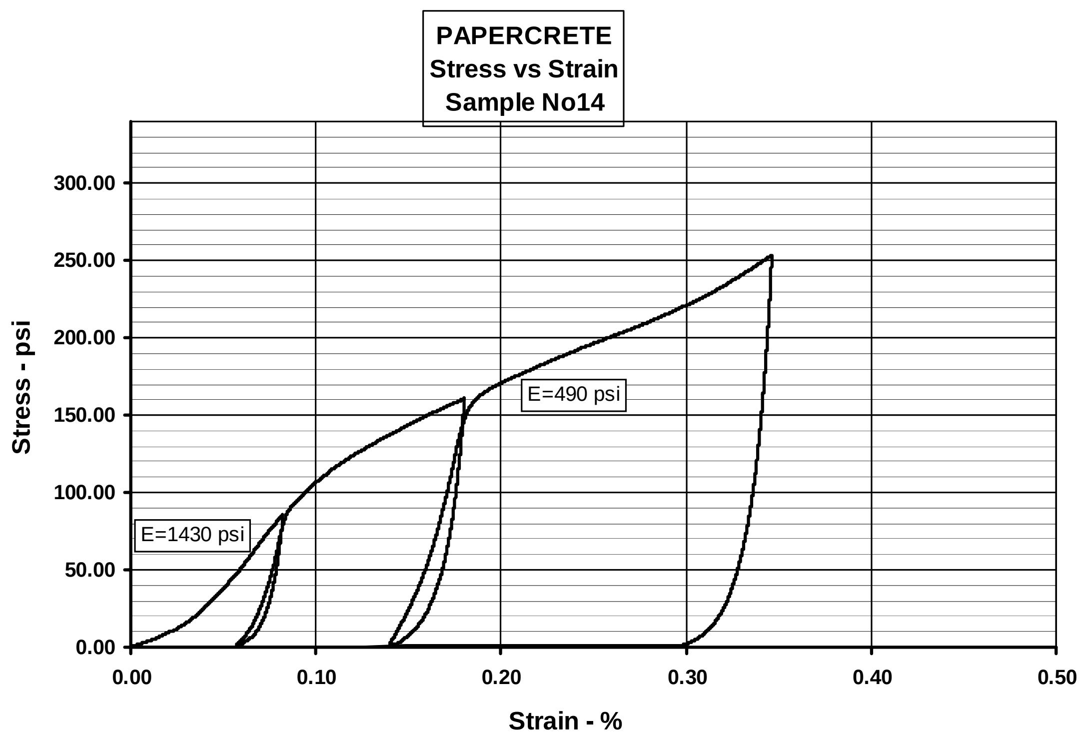

PAPERCRETE
Load vs Deformation
Sample No9
Dimensions:
a=11.8in
b=10.2in
t=3.9in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

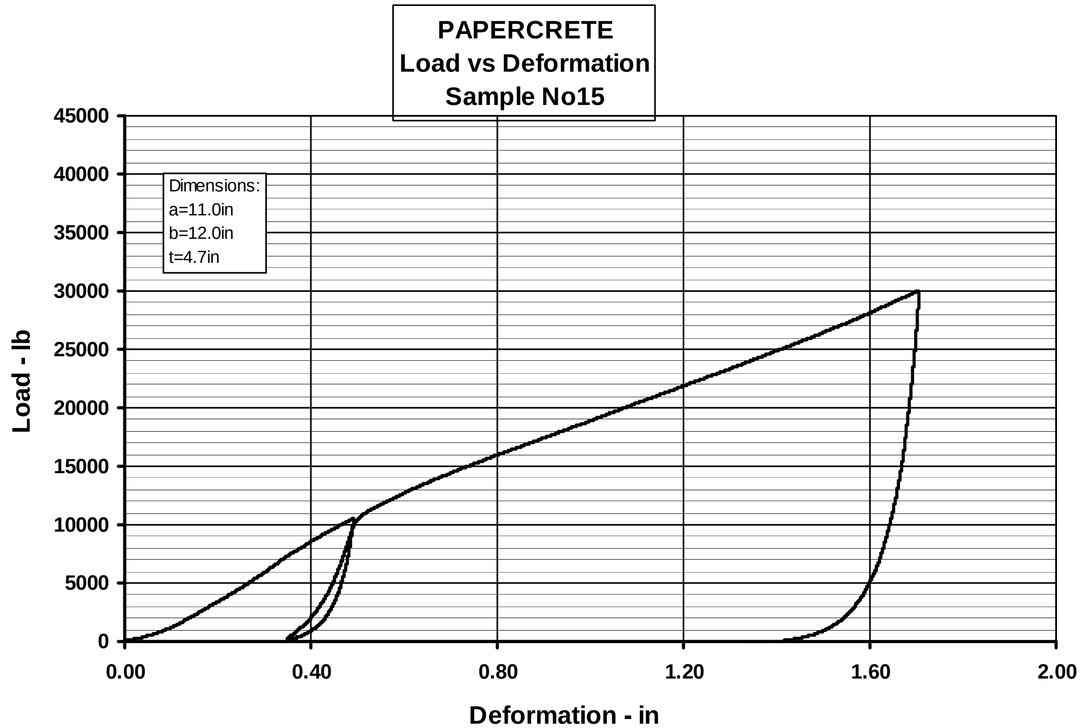

PAPERCRETE
Stress vs Strain
Sample No9
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=200 psi
E=400 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

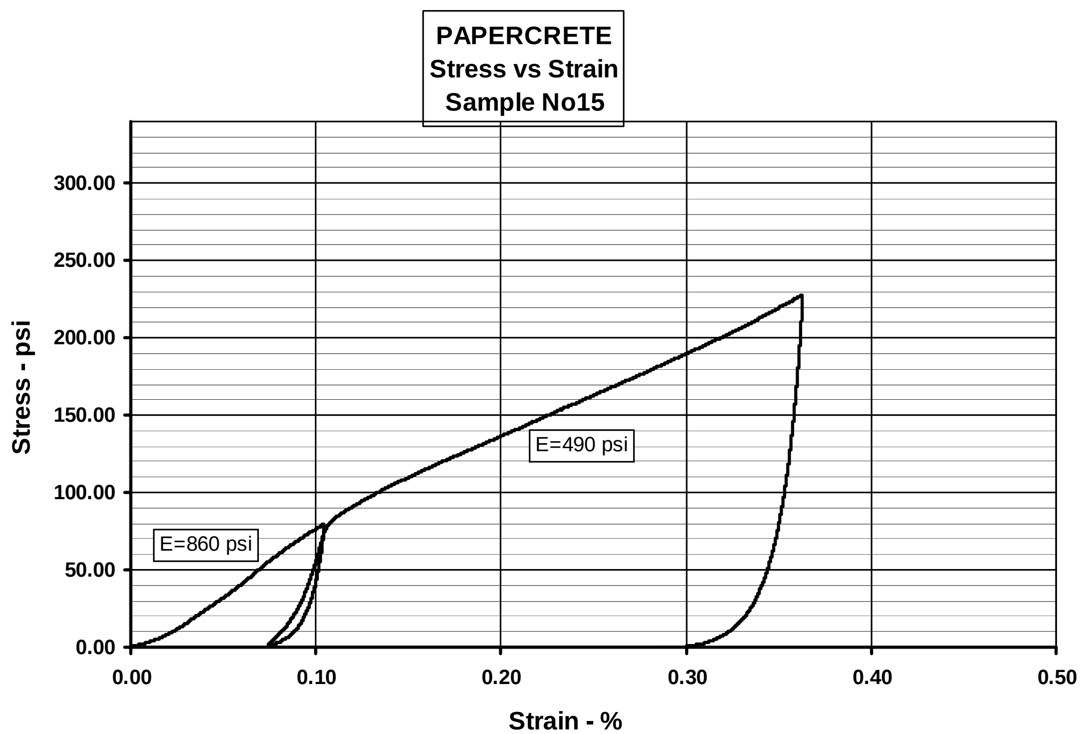

PAPERCRETE
Load vs Deformation
Sample No13
Dimensions:
a=10.6in
b=11.8in
t=4.3in
Load - lb
Deformation - in
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00

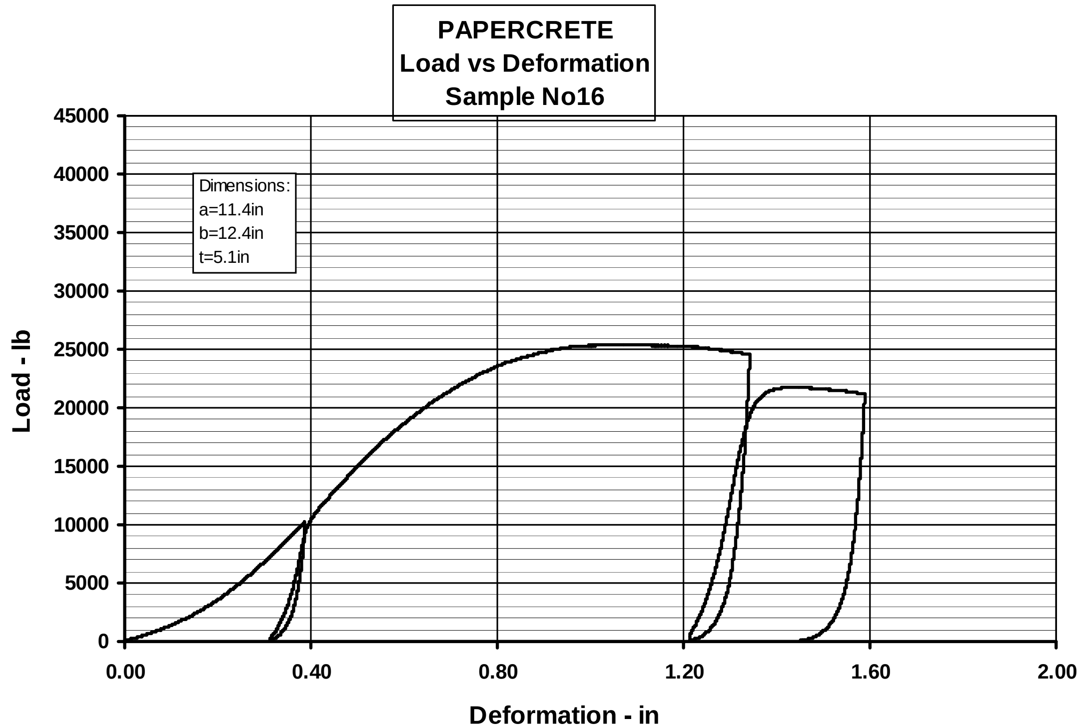

PAPERCRETE
Stress vs Strain
Sample No13
E=700 psi
E=1200 psi
Stress - psi
Strain - %
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50

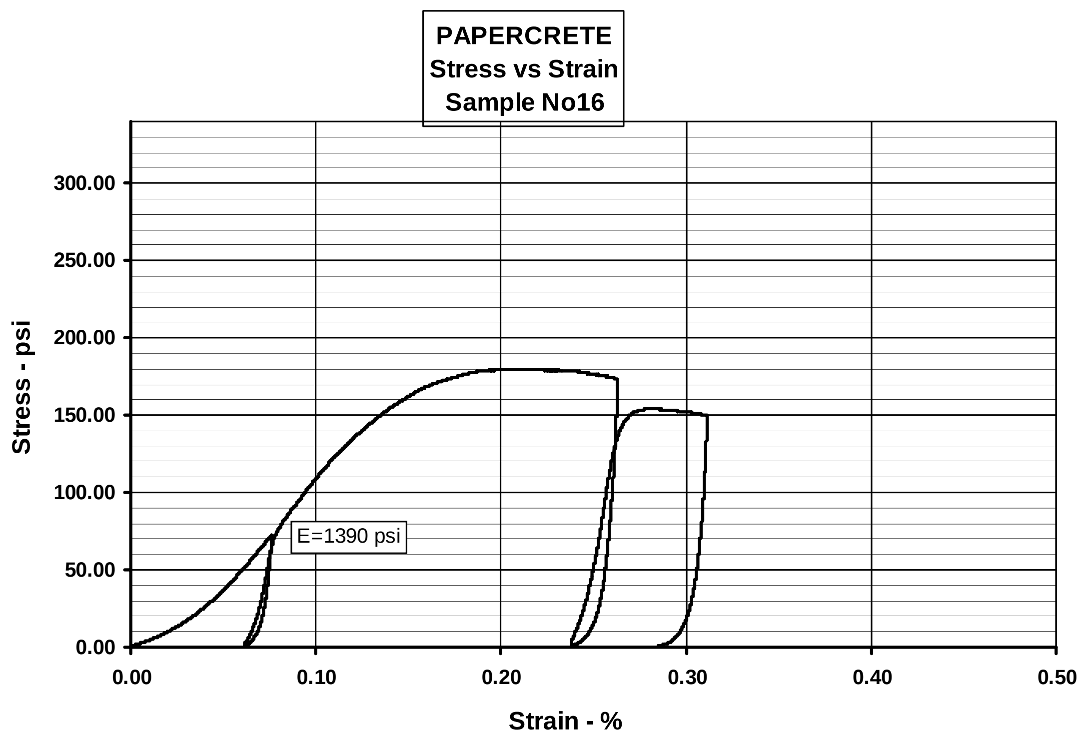

PAPERCRETE
Load vs Deformation
Sample No14
Dimensions:
a=11.6in
b=10.8in
t=4.7in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

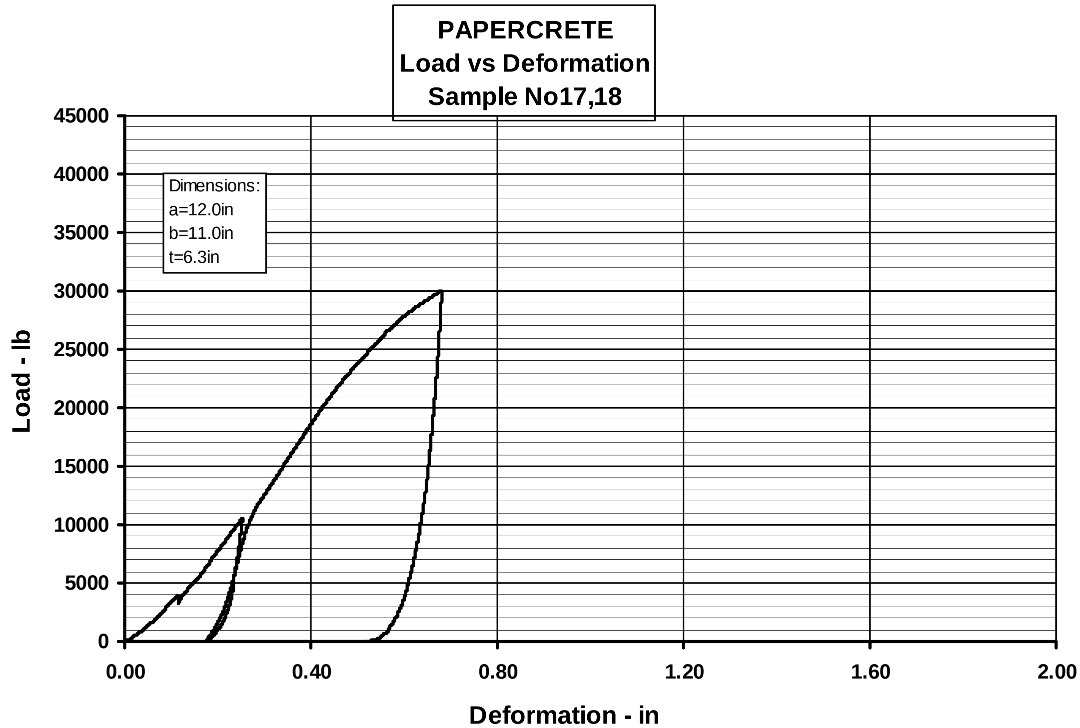

PAPERCRETE
Stress vs Strain
Sample No14
E=490 psi
E=1430 psi
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

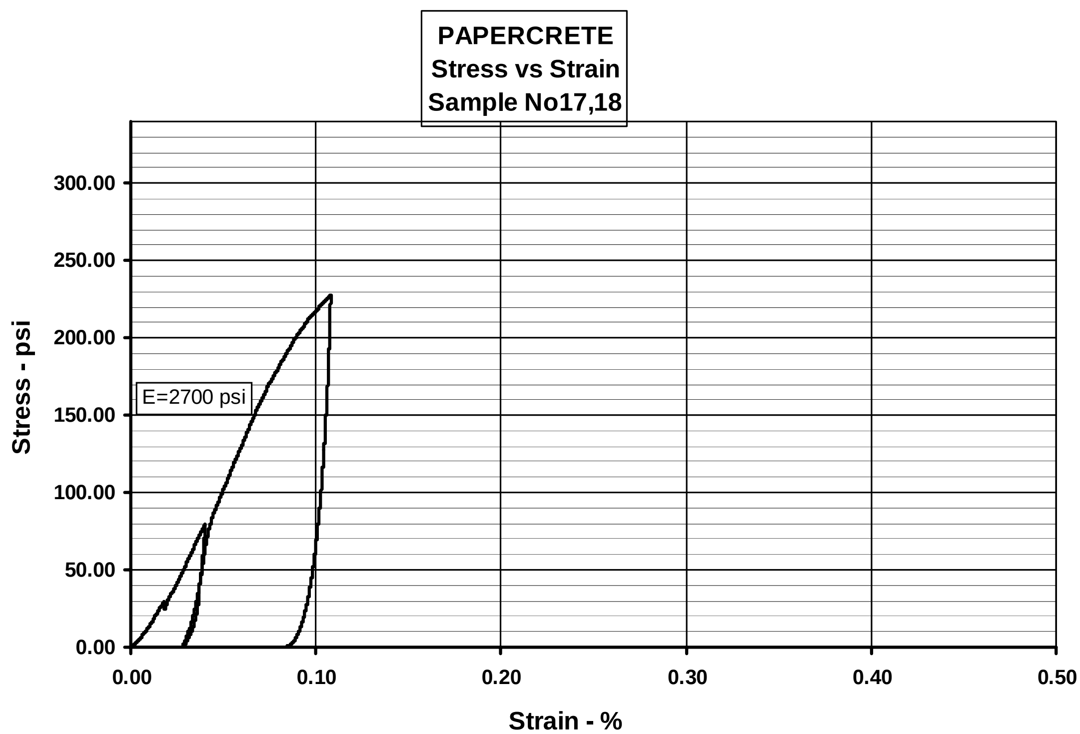

PAPERCRETE
Load vs Deformation
Sample No15
Dimensions:
a=11.0in
b=12.0in
t=4.7in
Load - lb
Deformation - in
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00

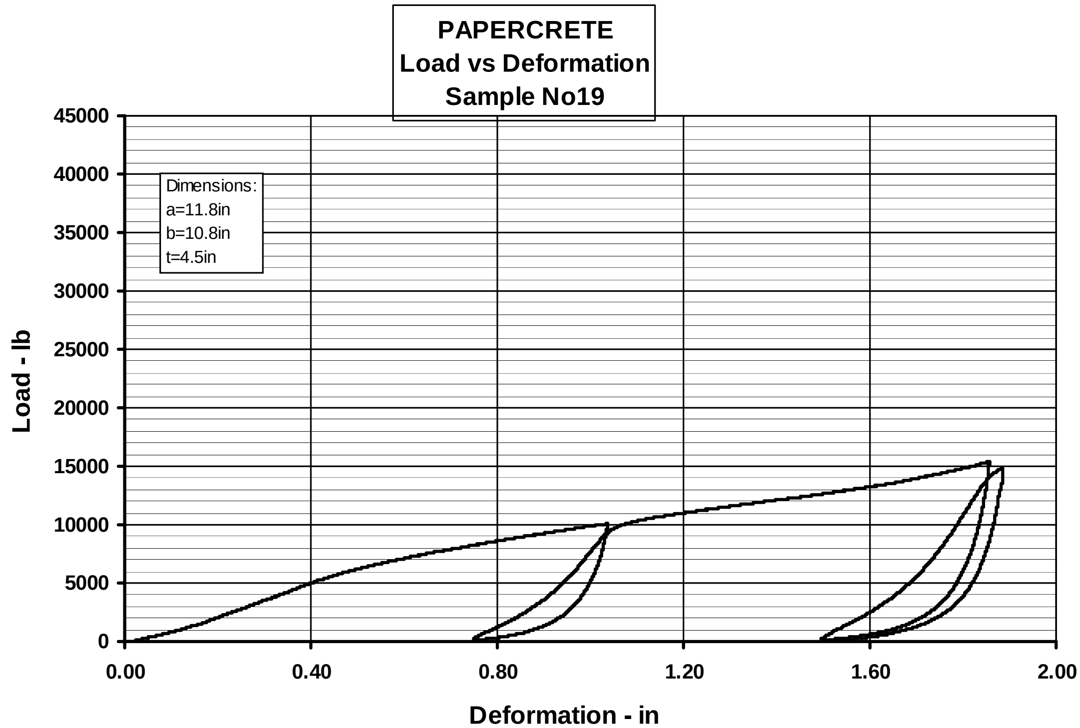

PAPERCRETE
Stress vs Strain
Sample No15
E=490 psi
E=860 psi
Stress - psi
Strain - %
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50

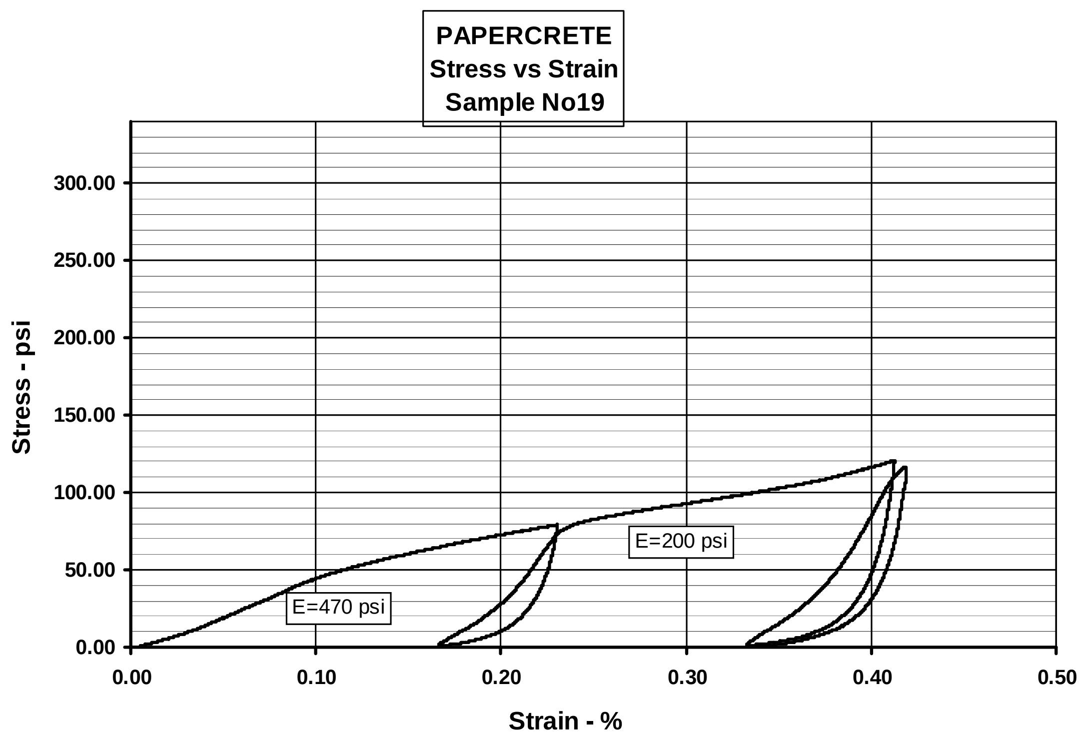

PAPERCRETE
Load vs Deformation
Sample No16
Dimensions:
a=11.4in
b=12.4in
t=5.1in
Load - lb
Deformation - in
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00

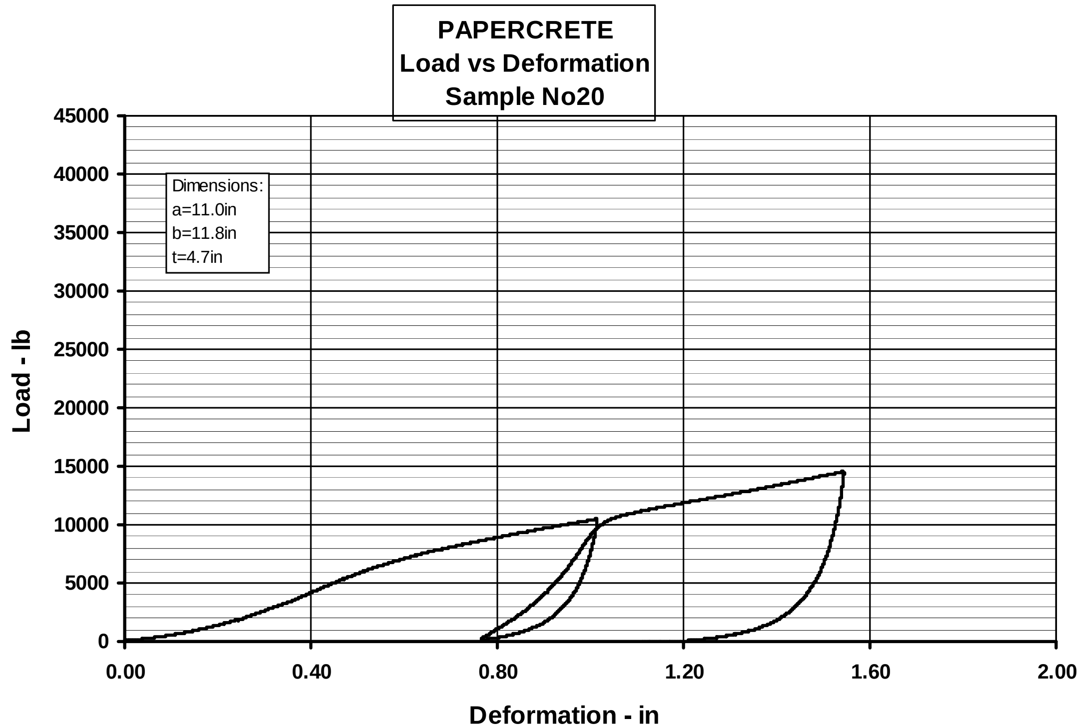

PAPERCRETE
Stress vs Strain
Sample No16
E=1390 psi
Stress - psi
Strain - %
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50

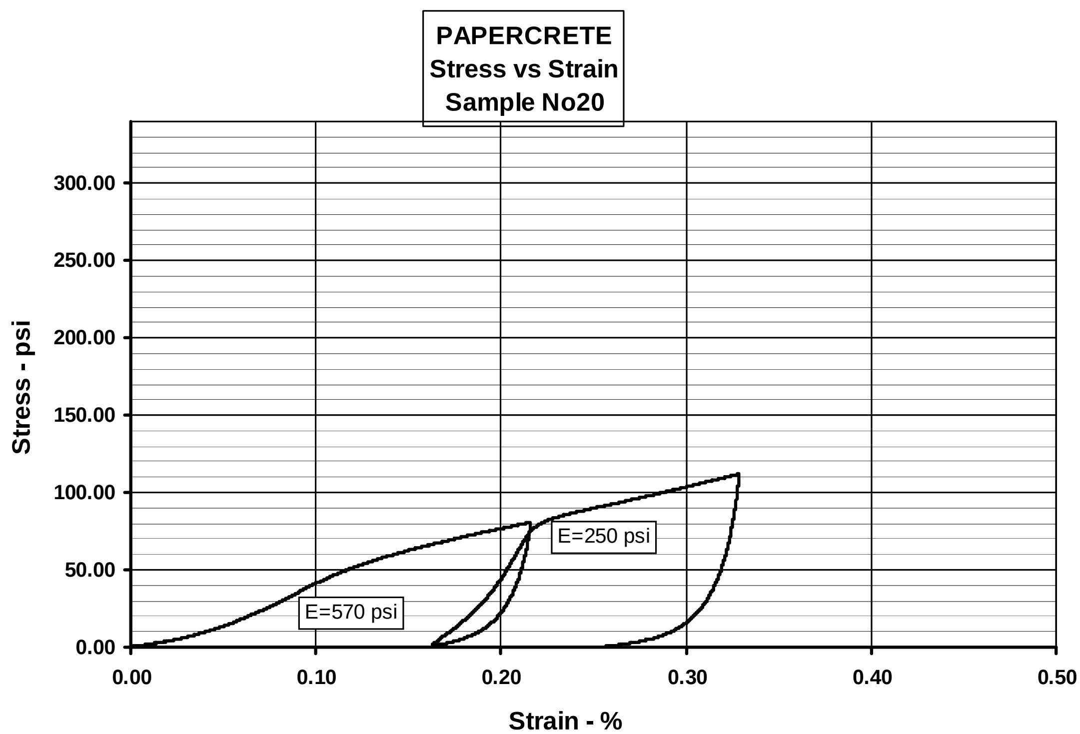

PAPERCRETE
Load vs Deformation
Sample No17,18
Dimensions:
a=12.0in
b=11.0in
t=6.3in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

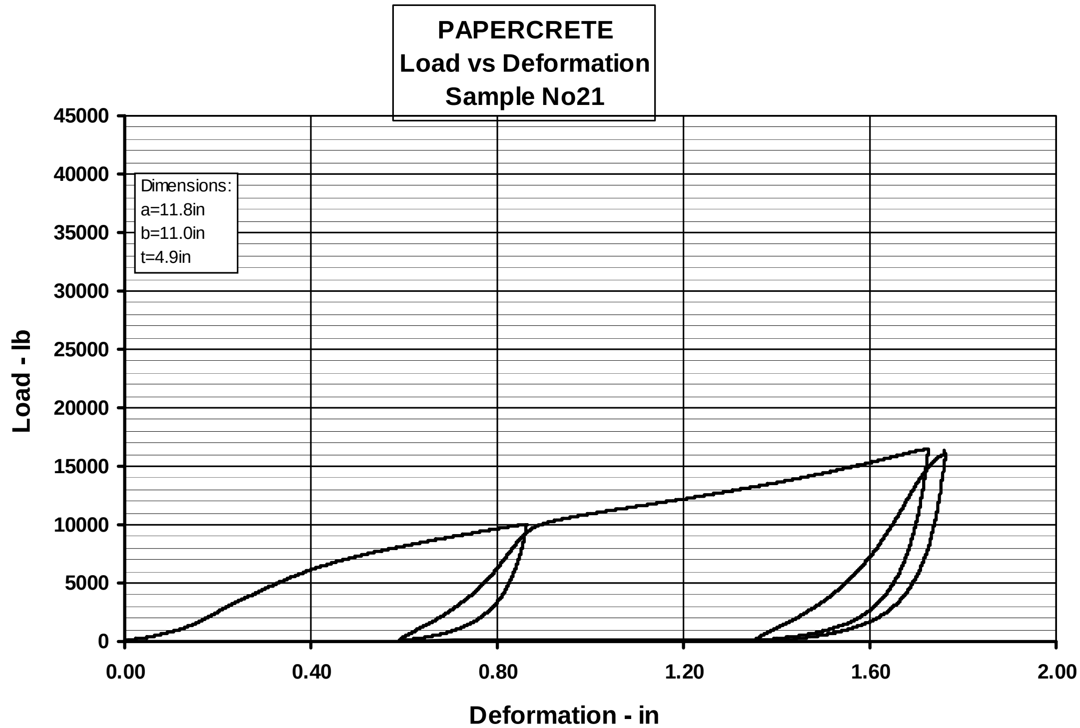

PAPERCRETE
Stress vs Strain
Sample No17,18
E=2700 psi
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

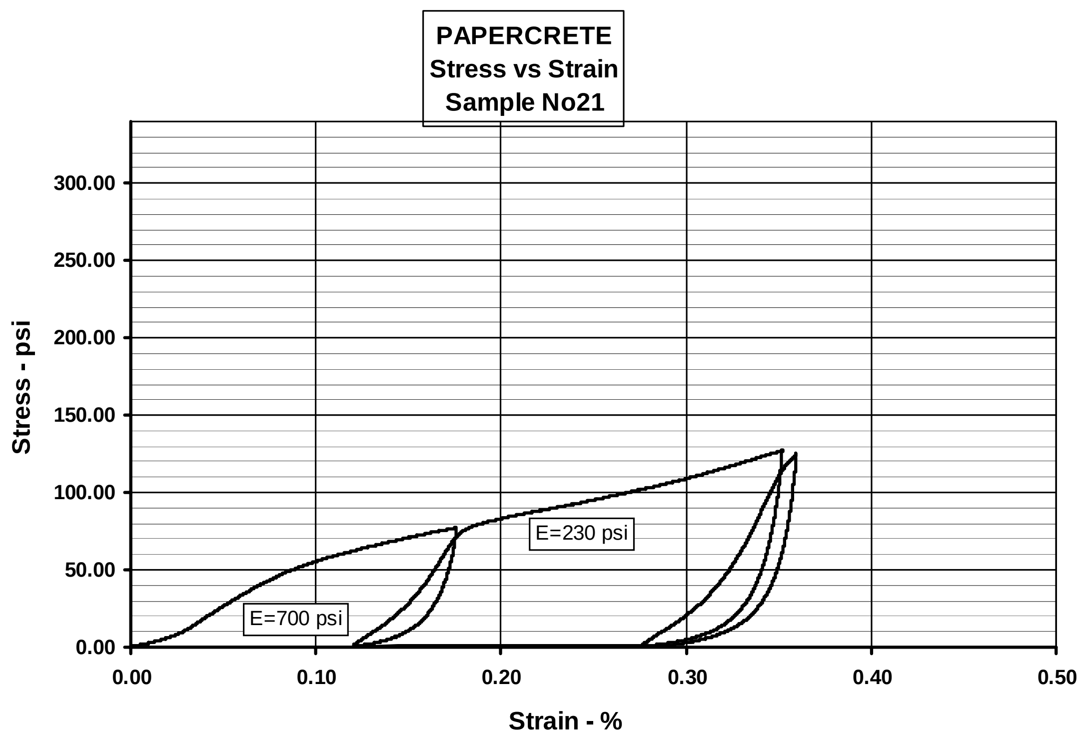

PAPERCRETE
Load vs Deformation
Sample No19
Dimensions:
a=11.8in
b=10.8in
t=4.5in
Load - lb
Deformation - in
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00

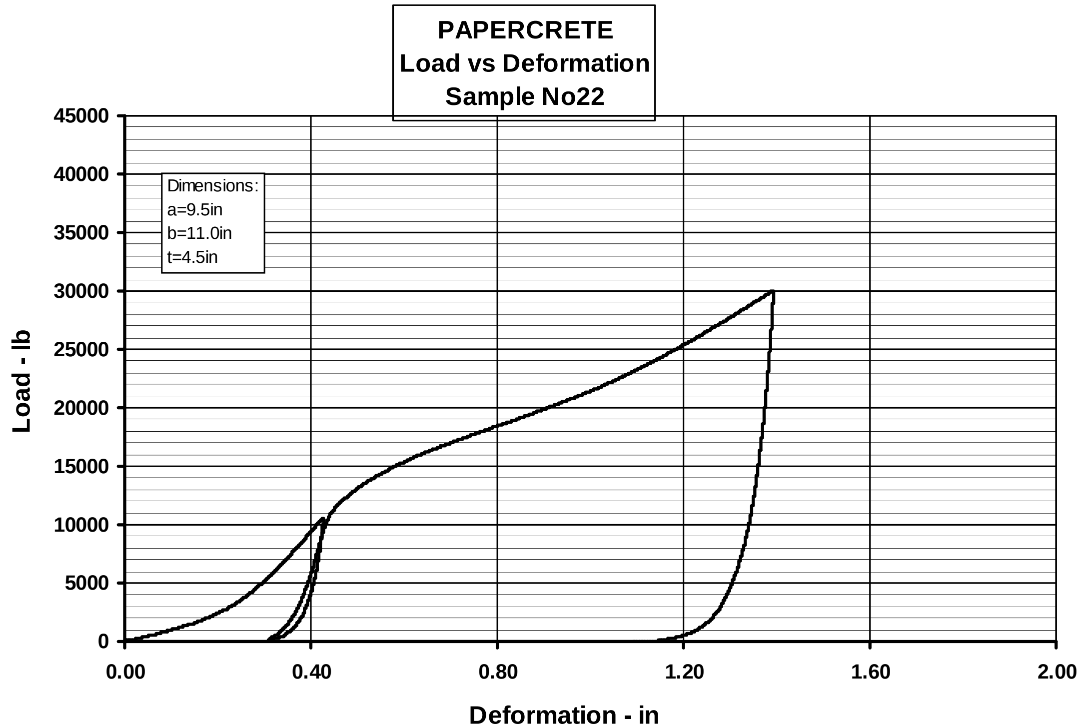

PAPERCRETE
Stress vs Strain
Sample No19
E=200 psi
E=470 psi
Stress - psi
Strain - %
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50

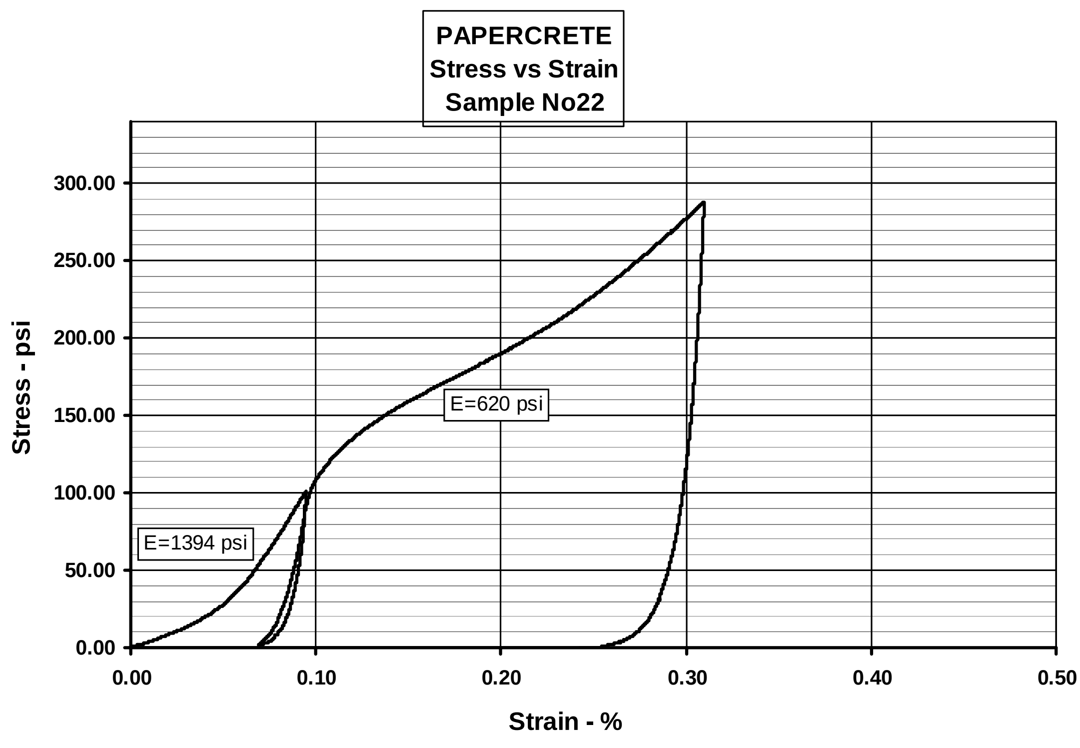

PAPERCRETE
Load vs Deformation
Sample No20
Dimensions:
a=11.0in
b=11.8in
t=4.7in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

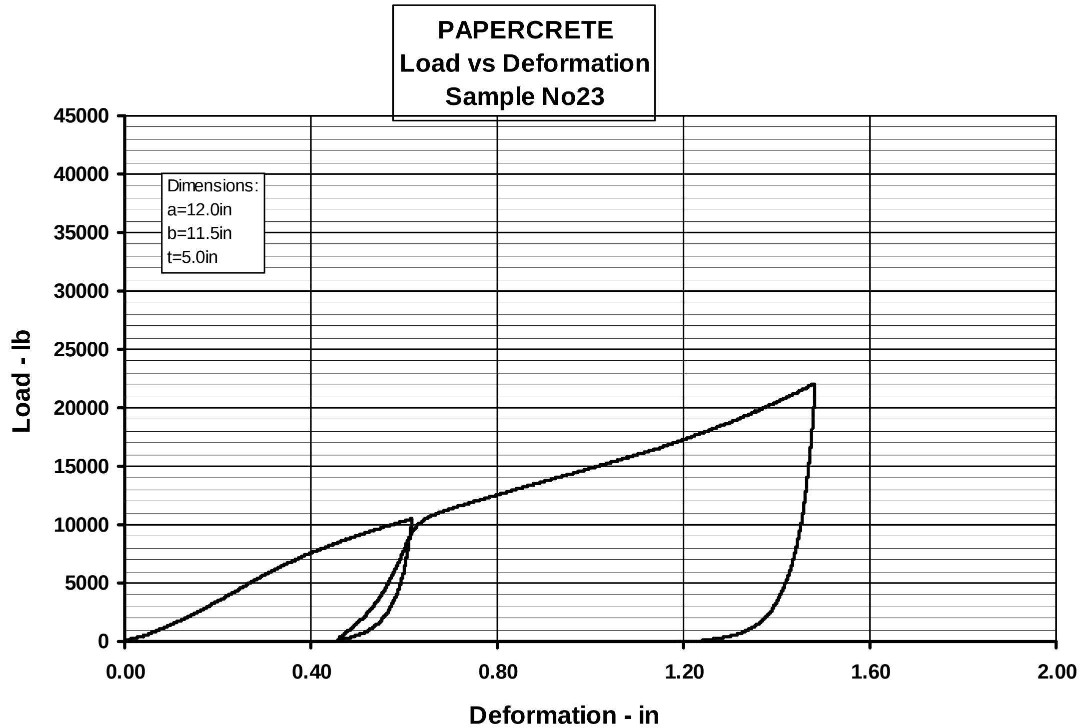

PAPERCRETE
Stress vs Strain
Sample No20
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=250 psi
E=570 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

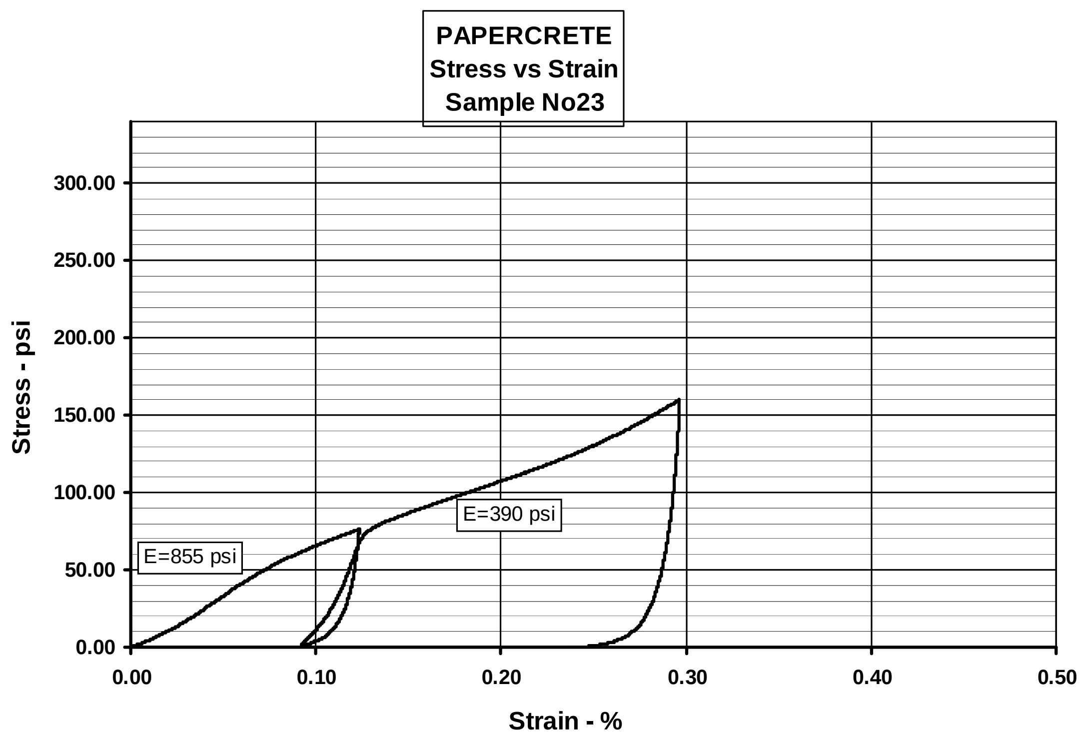

PAPERCRETE
Load vs Deformation
Sample No21
Dimensions:
a=11.8in
b=11.0in
t=4.9in
Load - lb
Deformation - in
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00

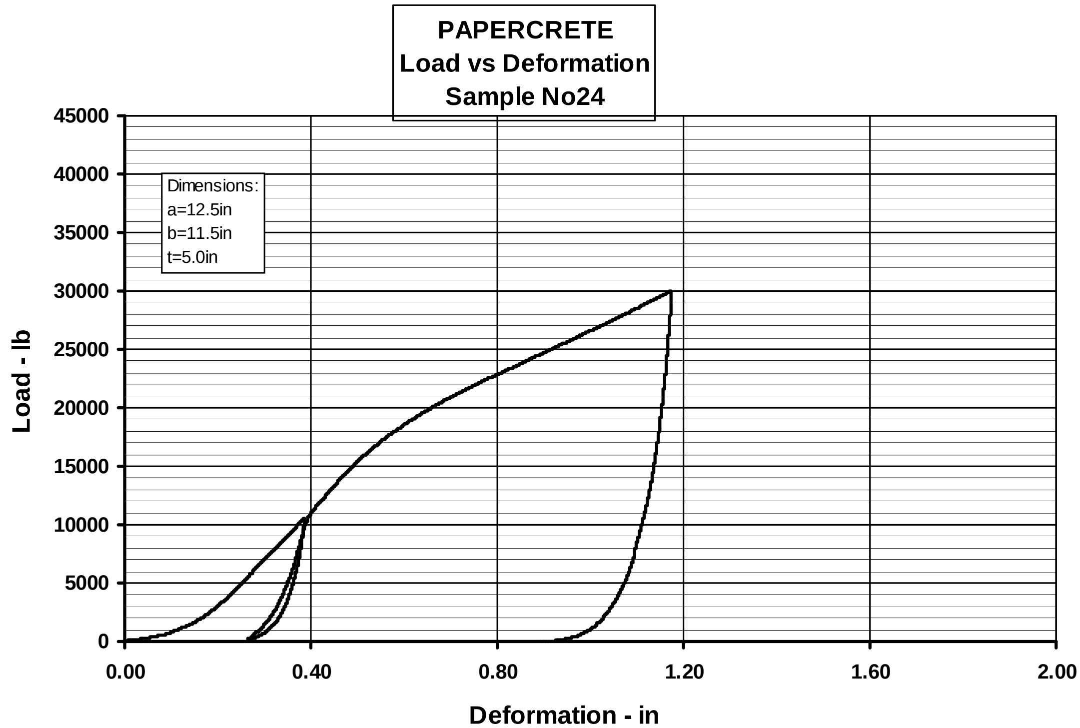

PAPERCRETE
Stress vs Strain
Sample No21
E=230 psi
E=700 psi
Stress - psi
Strain - %
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.10
0.20
0.30
0.40
0.50

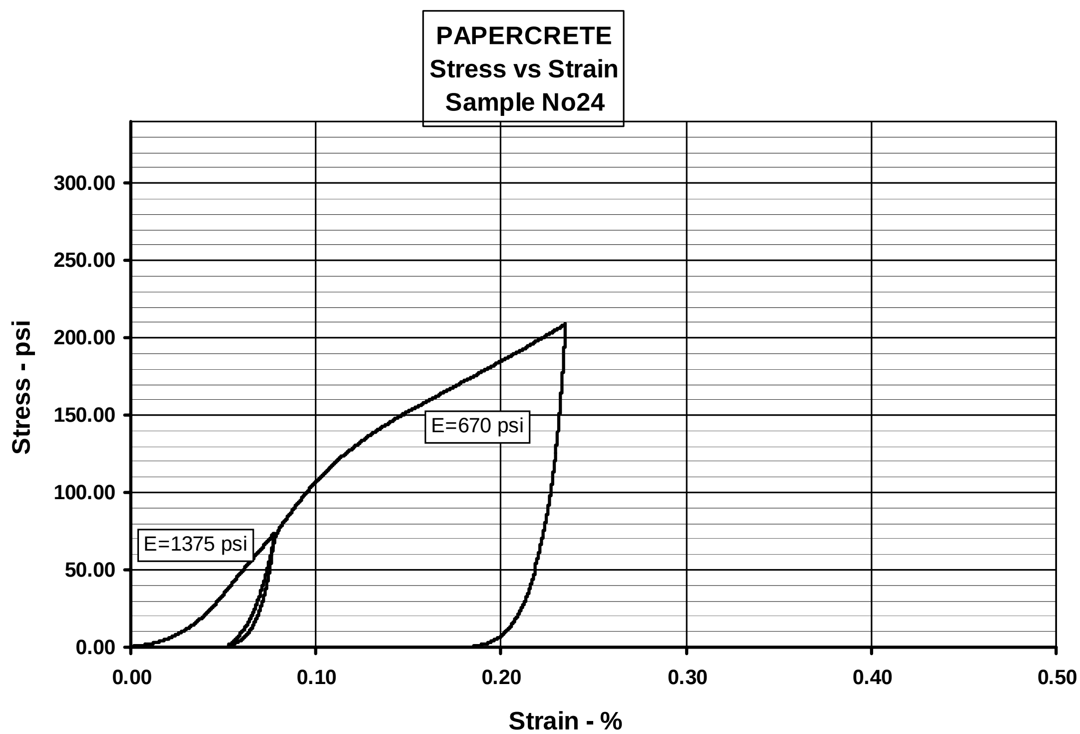

PAPERCRETE
Load vs Deformation
Sample No22
Dimensions:
a=9.5in
b=11.0in
t=4.5in
Load - lb
Deformation - in
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
0.00
0.40
0.80
1.20
1.60
2.00

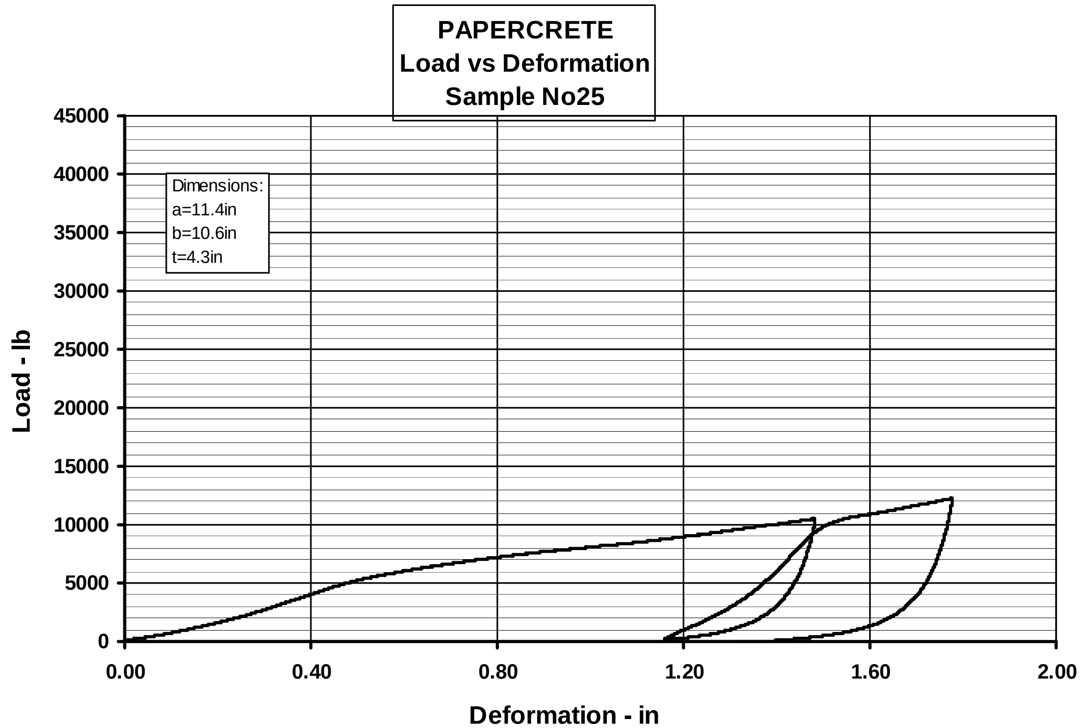

PAPERCRETE
Stress vs Strain
Sample No22
E=620 psi
E=1394 psi
Stress - psi
Strain - %
0.00
50.00
100.00
150.00
200.00
250.00
300.00
0.00
0.10
0.20
0.30
0.40
0.50

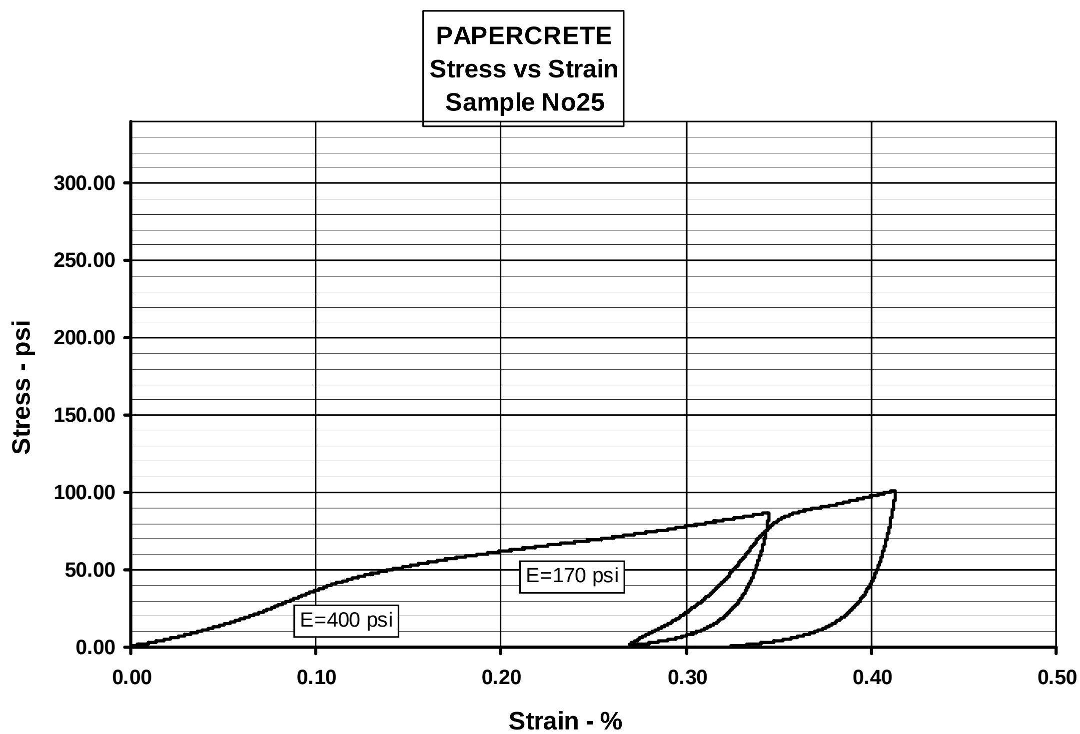

PAPERCRETE
Load vs Deformation
Sample No23
Dimensions:
a=12.0in
b=11.5in
t=5.0in
Load - lb
Deformation - in
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00

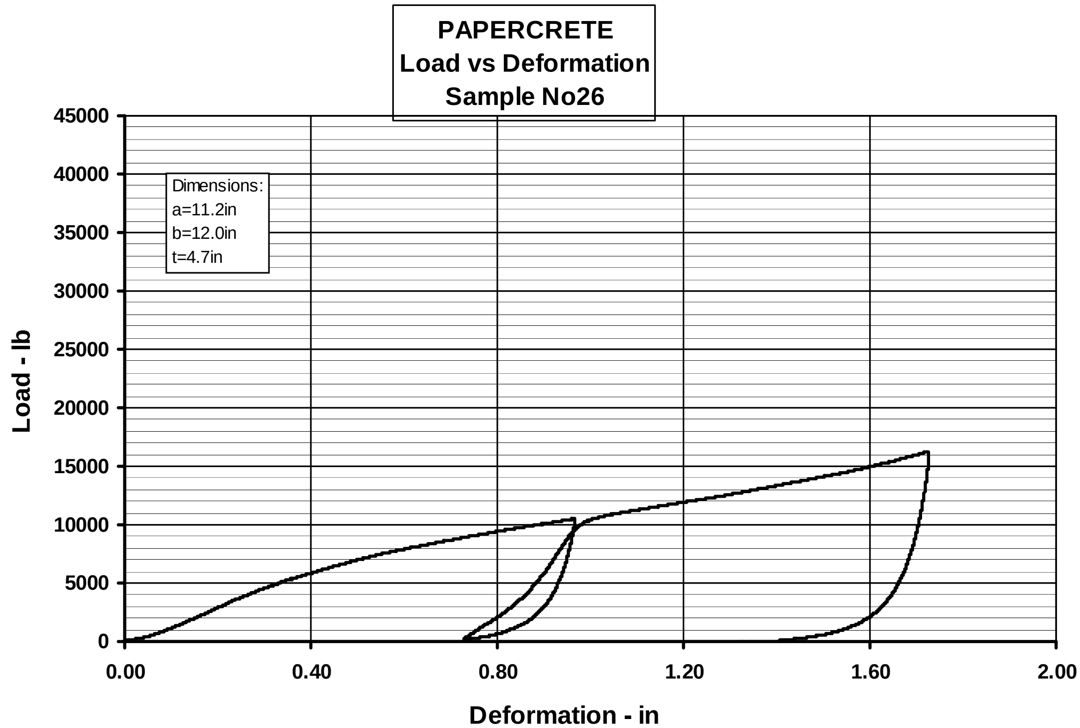

PAPERCRETE
Stress vs Strain
Sample No23
E=855 psi
E=390 psi
Stress - psi
Strain - %
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50

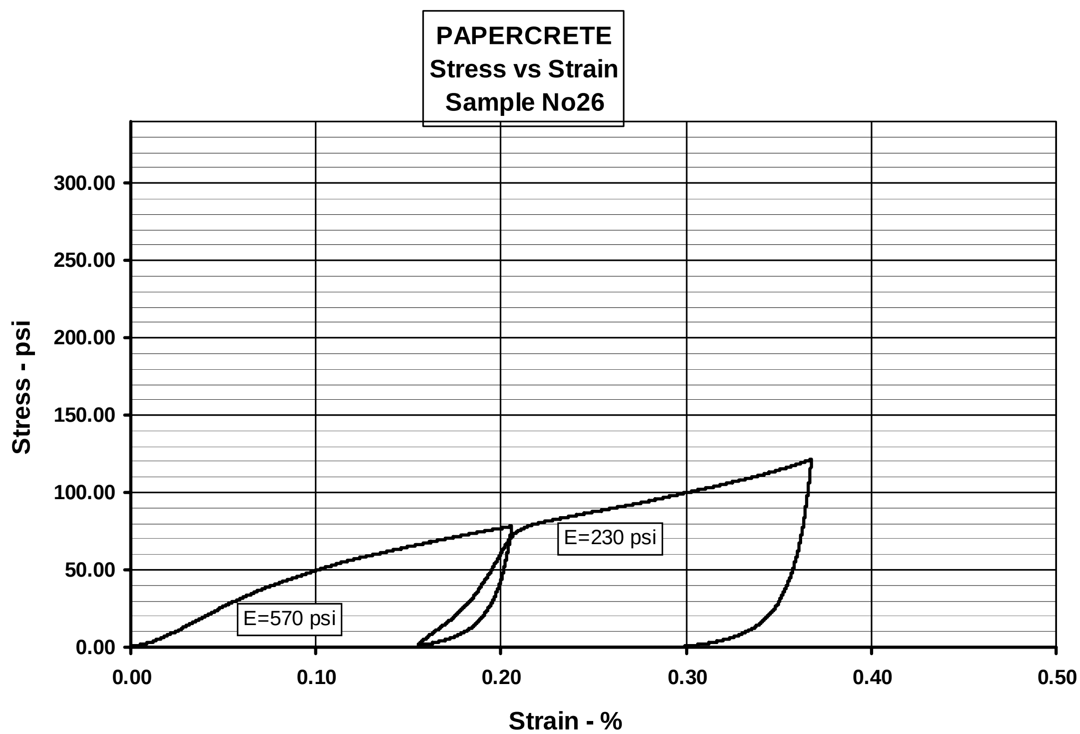

PAPERCRETE
Load vs Deformation
Sample No24
Dimensions:
a=12.5in
b=11.5in
t=5.0in
Load - lb
Deformation - in
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
0.00
0.40
0.80
1.20
1.60
2.00

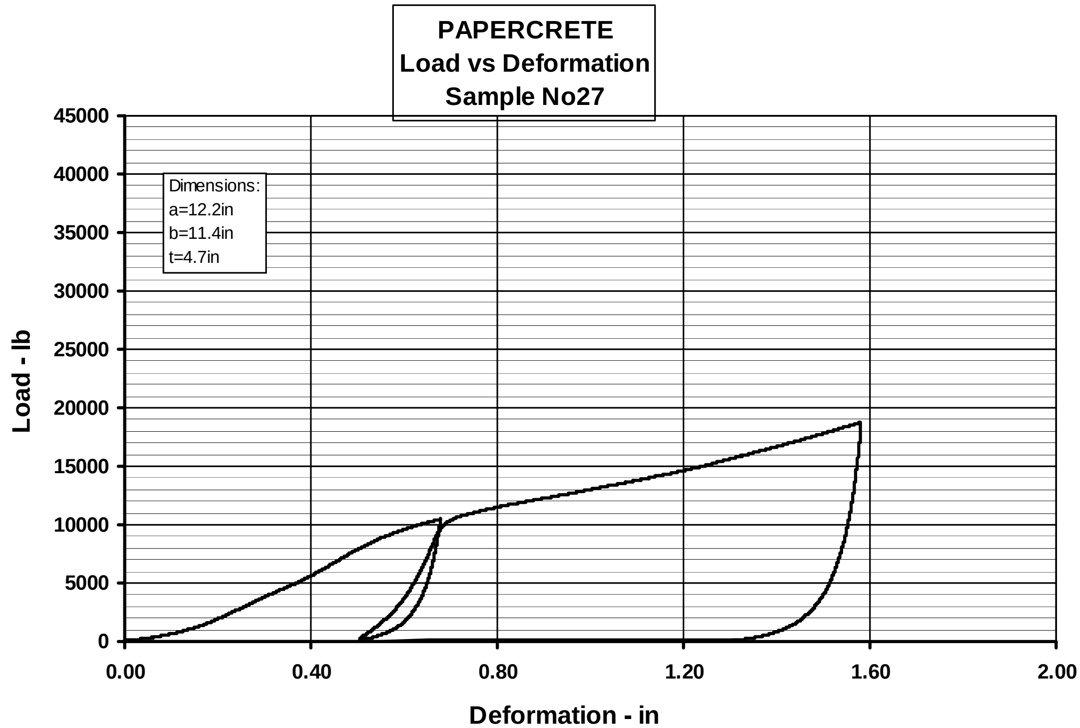

PAPERCRETE
Stress vs Strain
Sample No24
E=670 psi
E=1375 psi
Stress - psi
Strain - %
0.00
50.00
100.00
150.00
200.00
250.00
300.00
0.00
0.10
0.20
0.30
0.40
0.50

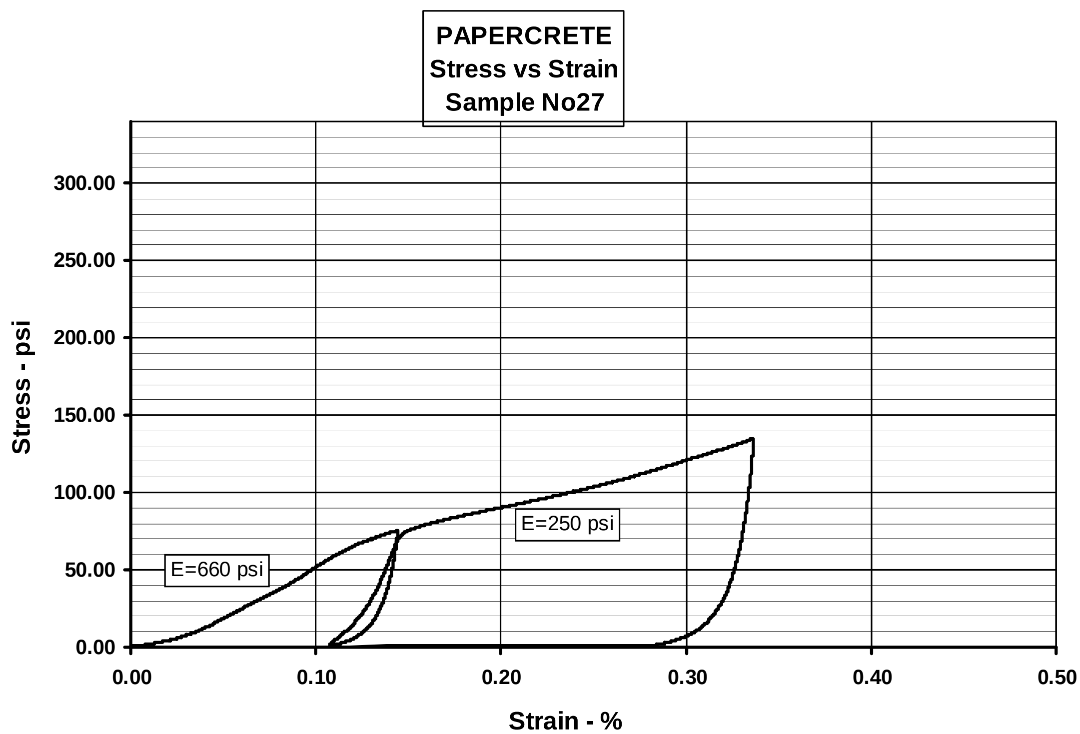

PAPERCRETE
Load vs Deformation
Sample No25
Dimensions:
a=11.4in
b=10.6in
t=4.3in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in


PAPERCRETE
Stress vs Strain
Sample No25
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=170 psi
E=400 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

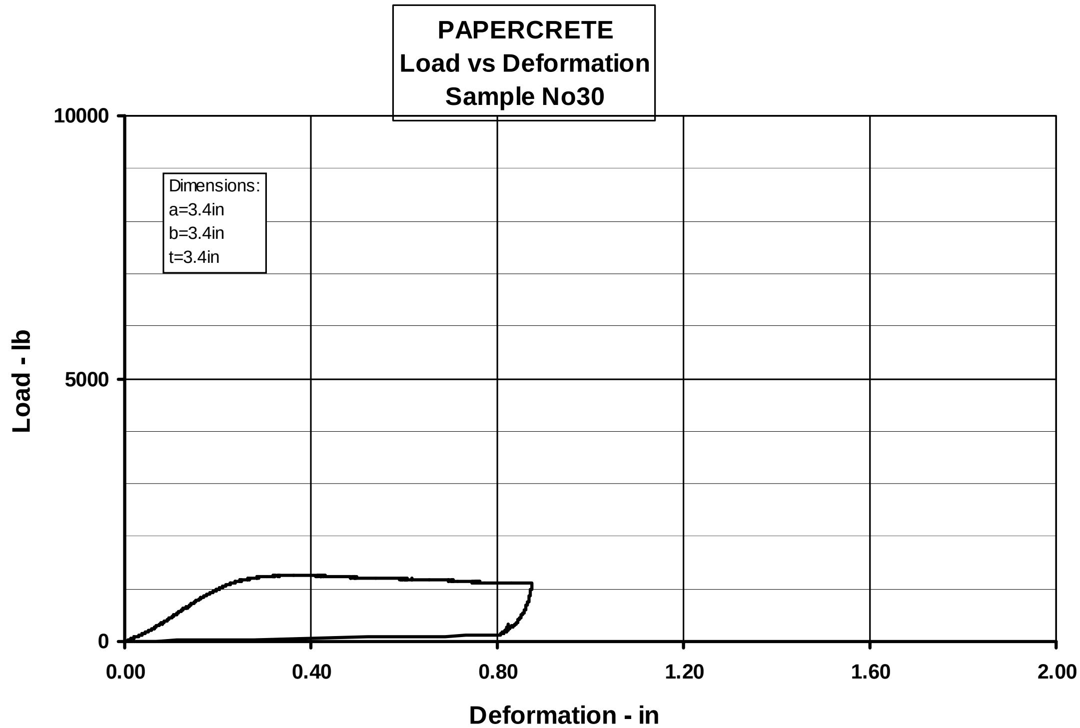

PAPERCRETE
Load vs Deformation
Sample No26
Dimensions:
a=11.2in
b=12.0in
t=4.7in
Load - lb
Deformation - in
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00

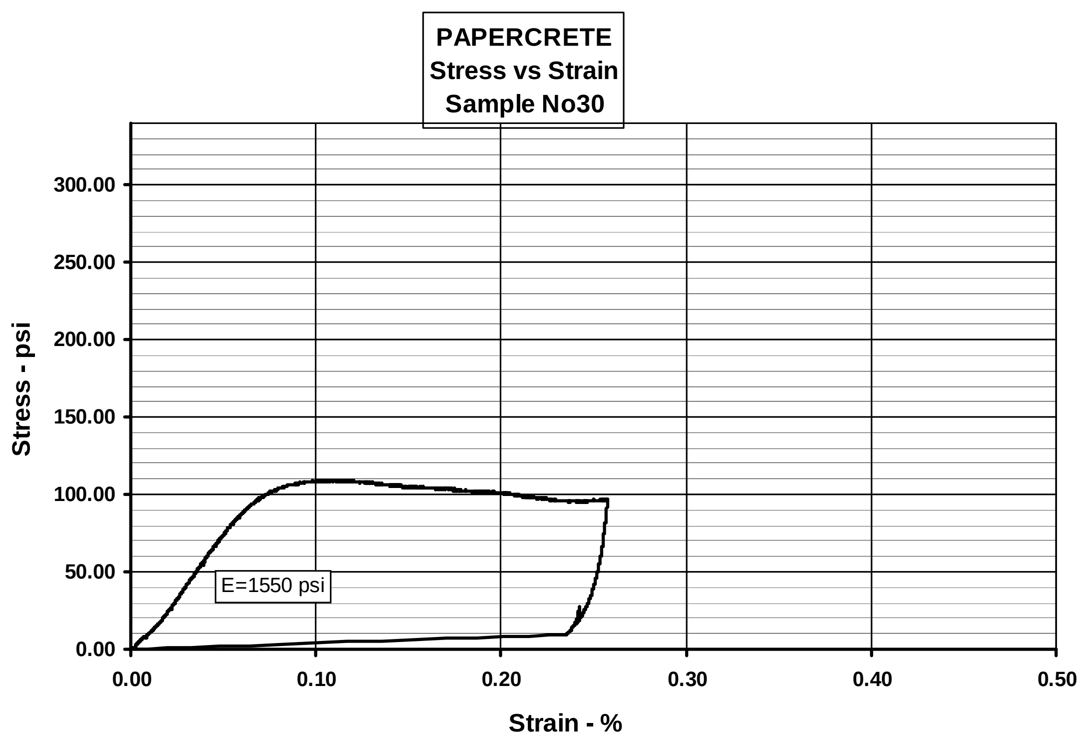

PAPERCRETE
Stress vs Strain
Sample No26
E=230 psi
E=570 psi
Stress - psi
Strain - %
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50

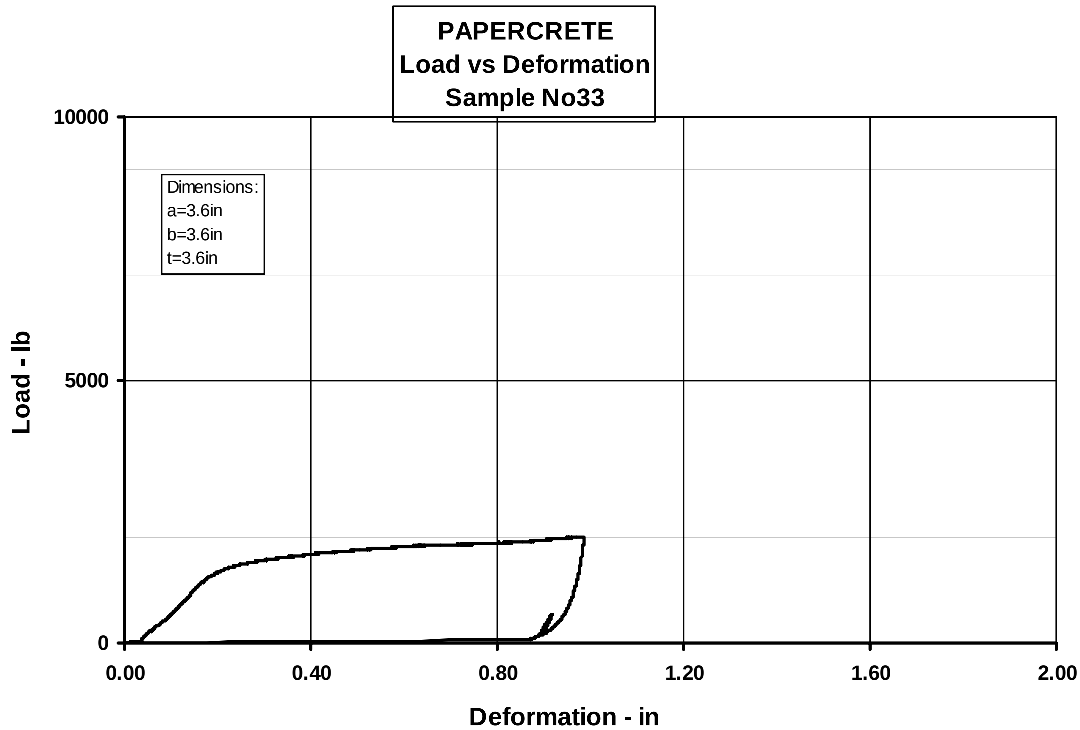

PAPERCRETE
Load vs Deformation
Sample No27
Dimensions:
a=12.2in
b=11.4in
t=4.7in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

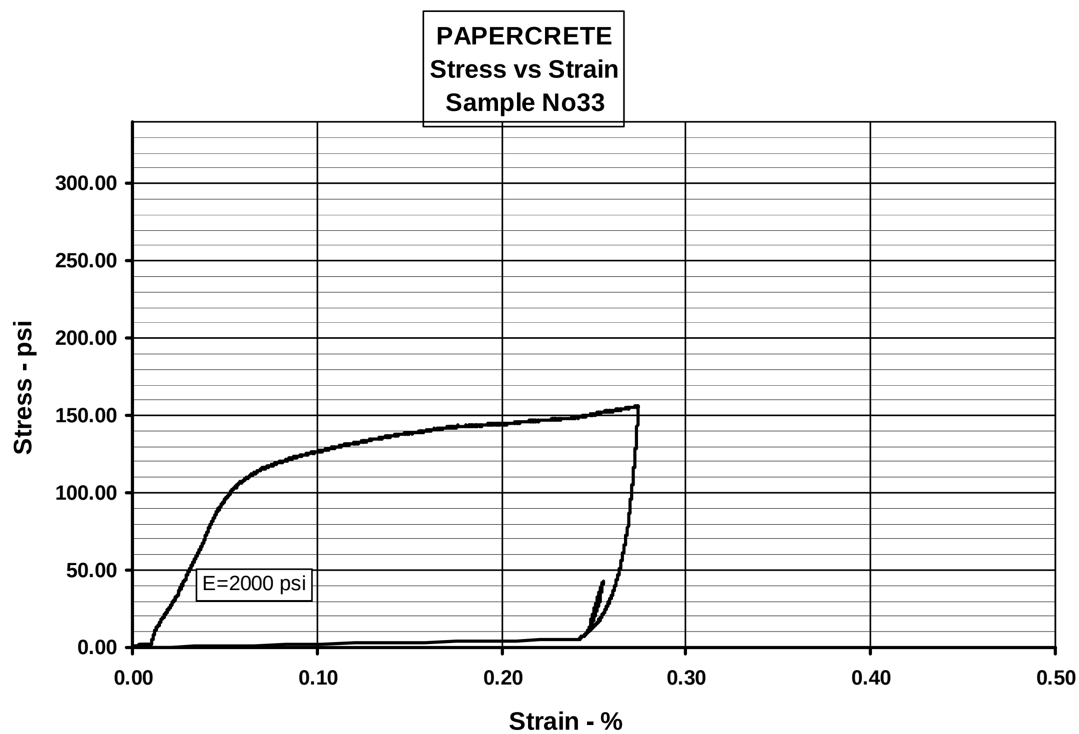

PAPERCRETE
Stress vs Strain
Sample No27
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=660 psi
E=250 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

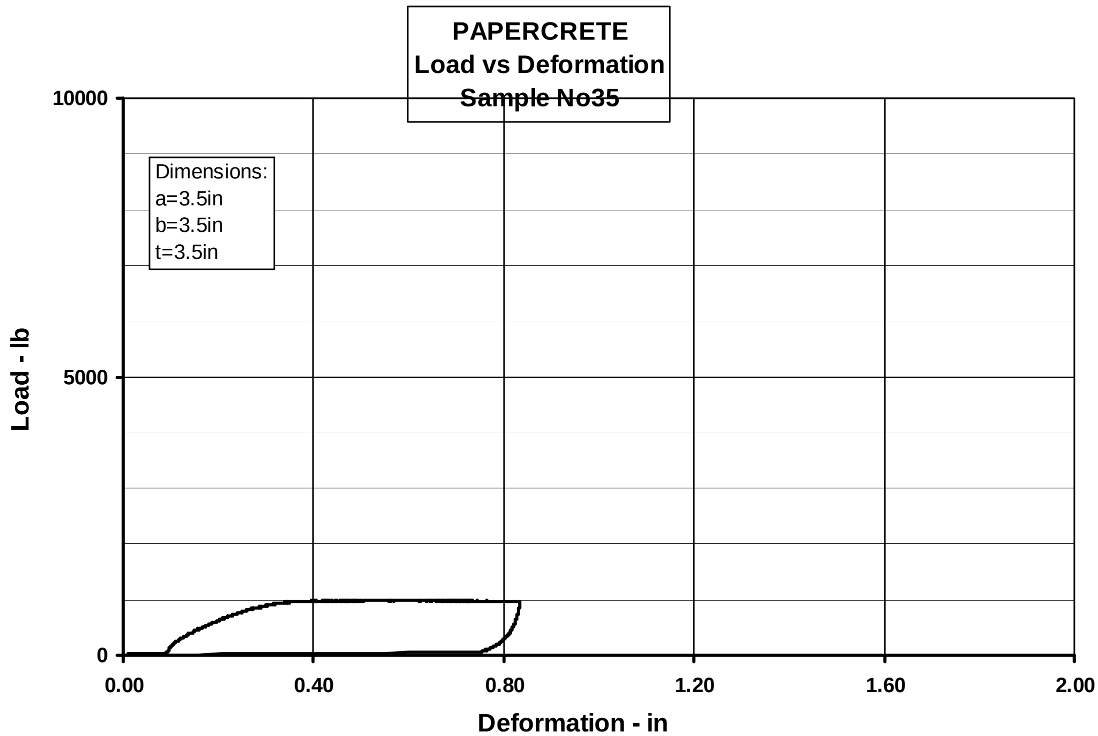
2nd Group of Samples

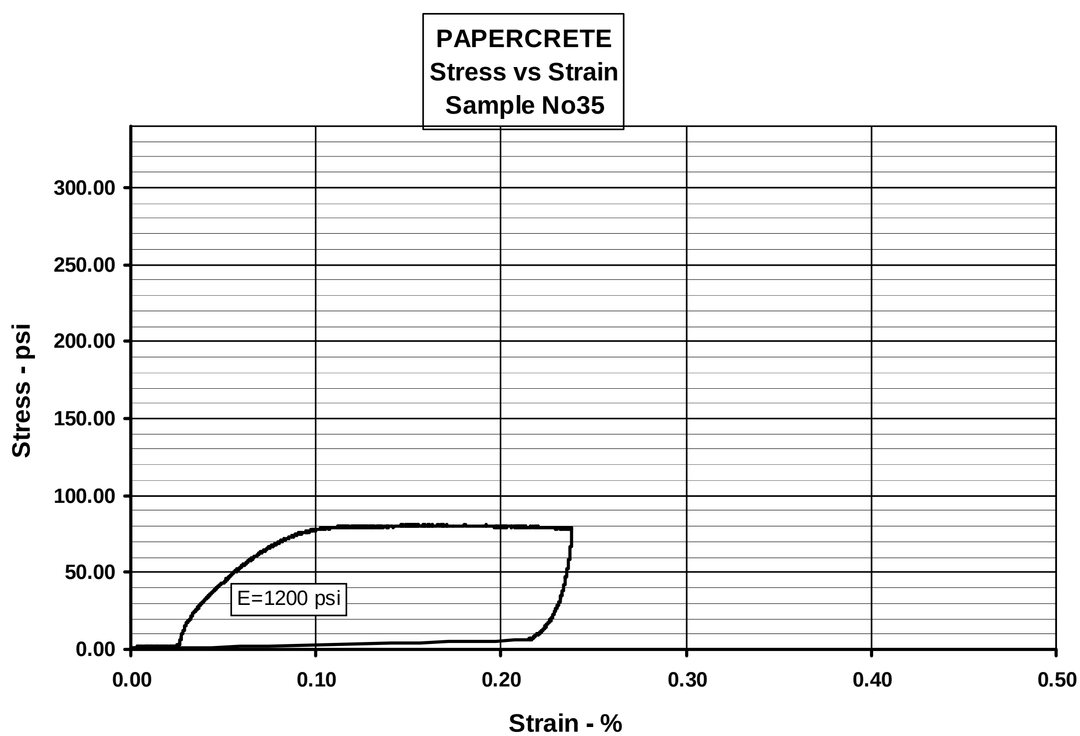

PAPERCRETE
Load vs Deformation
Sample No30
Dimensions:
a=3.4in
b=3.4in
t=3.4in
10000
5000
0
Load - lb
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

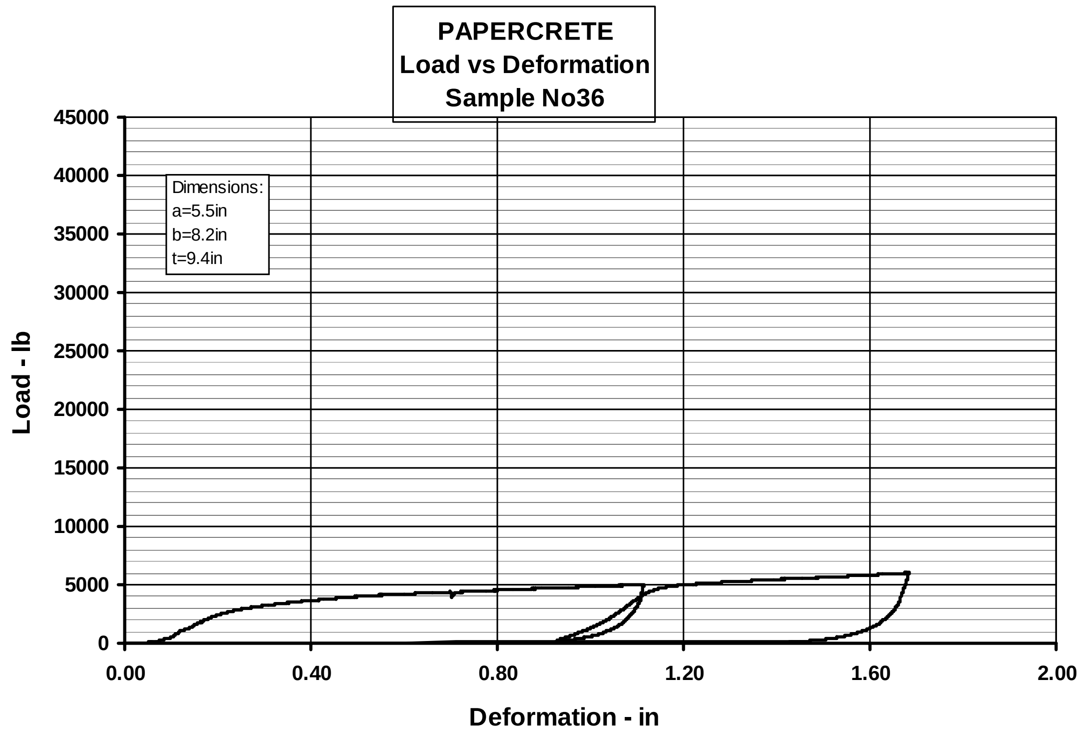

PAPERCRETE
Stress vs Strain
Sample No30
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Stress - psi
E=1550 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

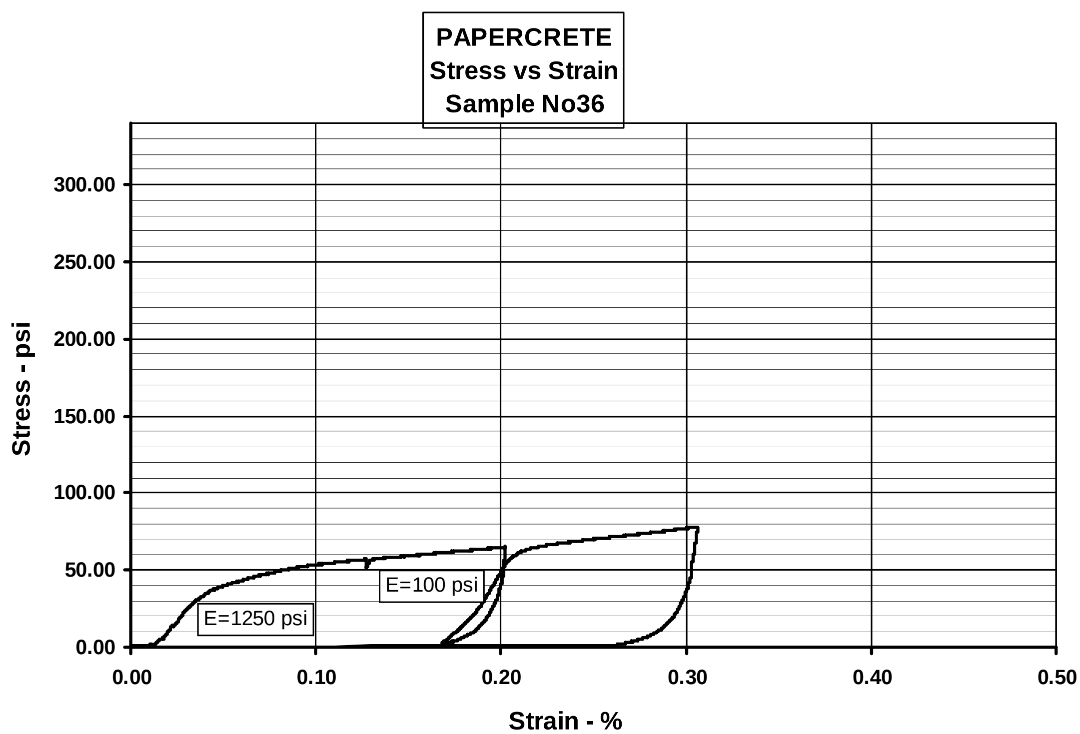

PAPERCRETE
Load vs Deformation
Sample No33
Dimensions:
a=3.6in
b=3.6in
t=3.6in
Load - lb
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

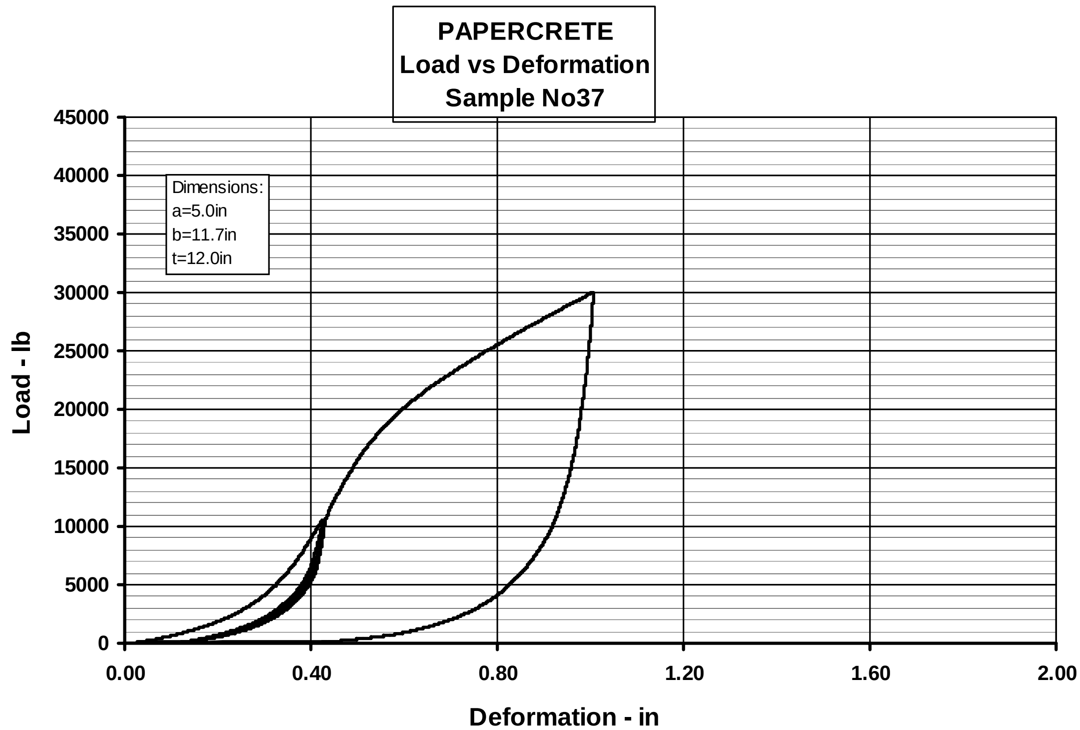

PAPERCRETE
Stress vs Strain
Sample No33
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=2000 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

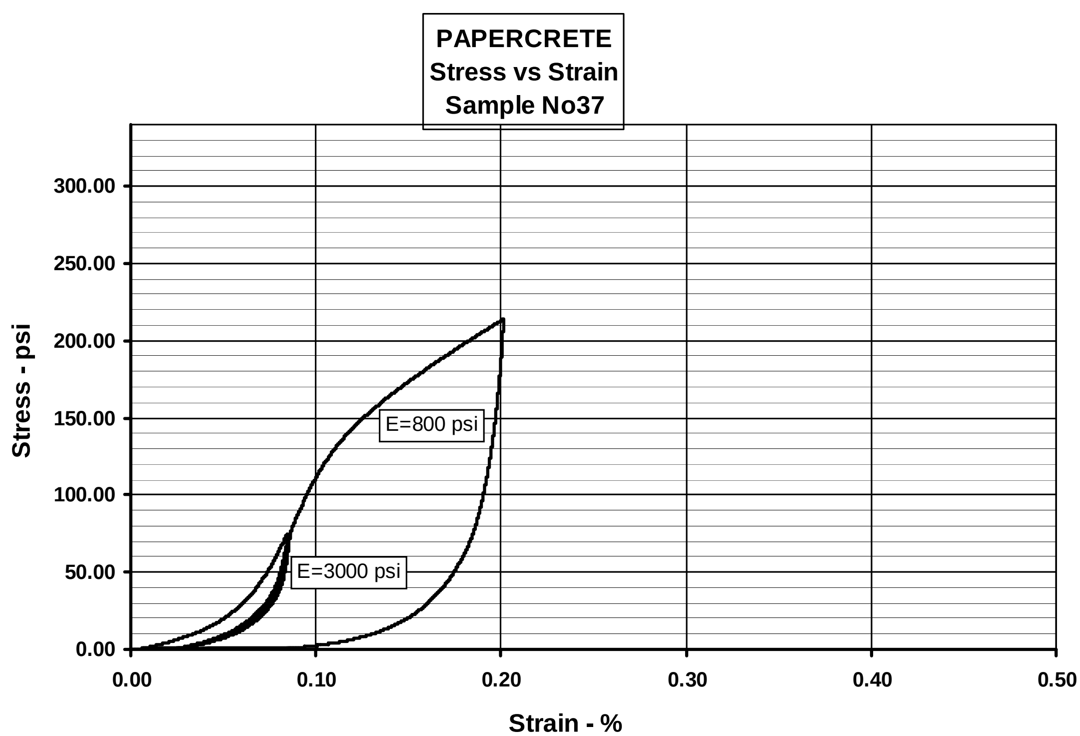

PAPERCRETE
Load vs Deformation
Sample No35
Dimensions:
a=3.5in
b=3.5in
t=3.5in
Load - lb
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

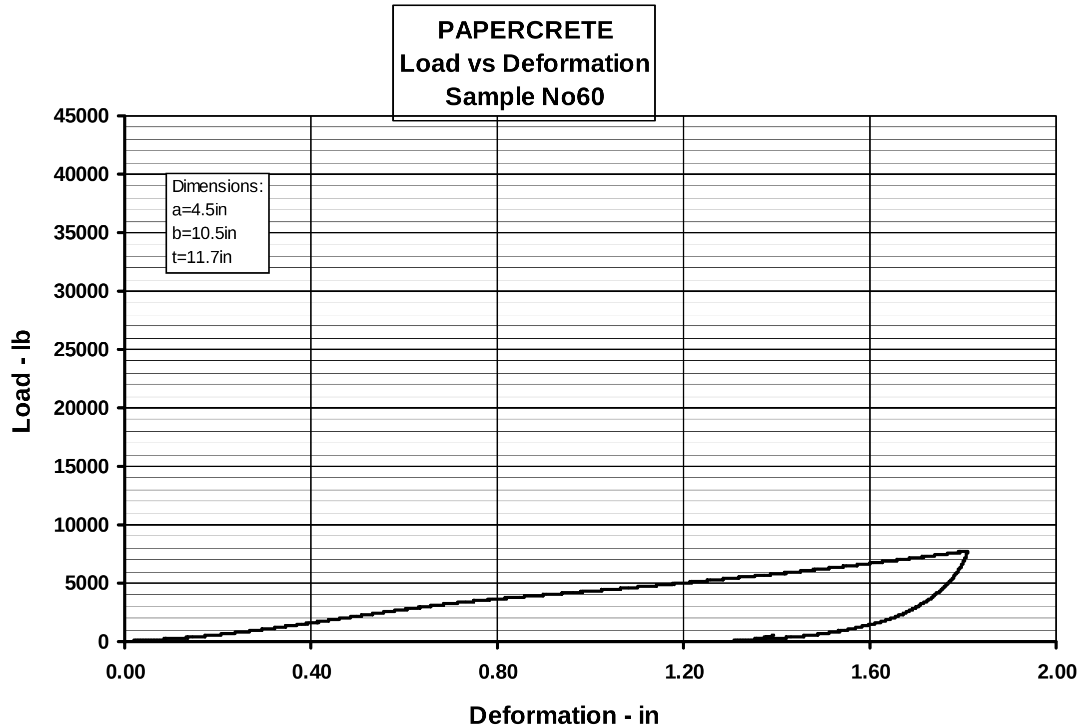

PAPERCRETE
Stress vs Strain
Sample No35
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=1200 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

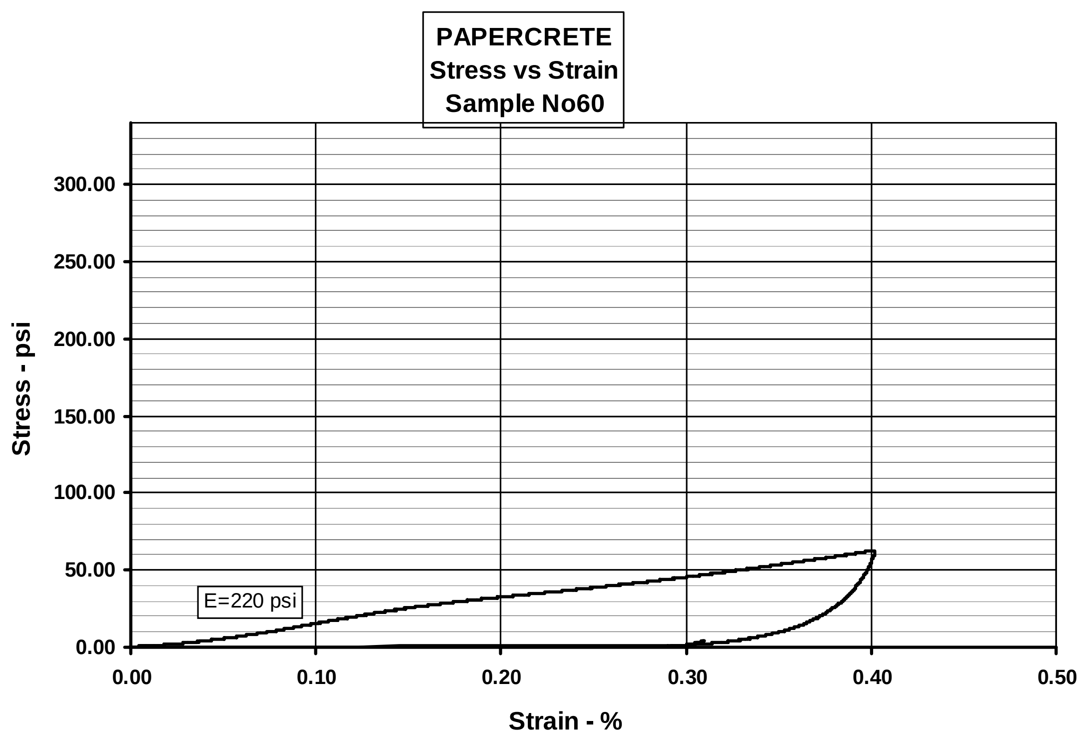

PAPERCRETE
Load vs Deformation
Sample No36
Dimensions:
a=5.5in
b=8.2in
t=9.4in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in


PAPERCRETE
Stress vs Strain
Sample No36
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=100 psi
E=1250 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

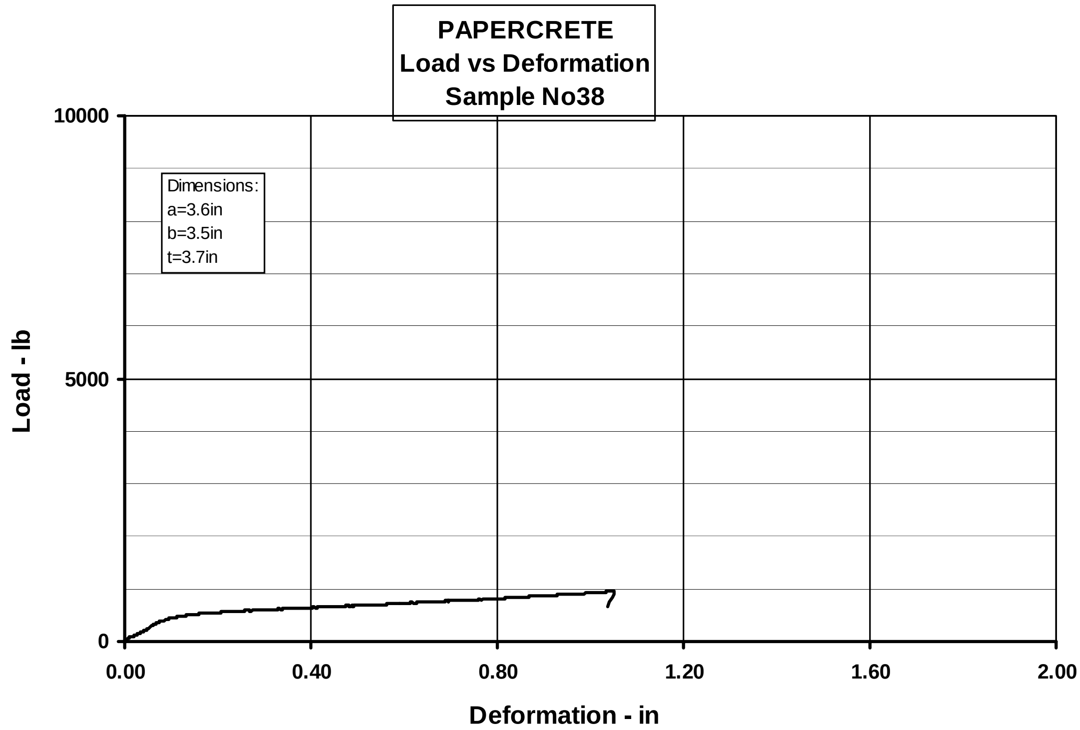

PAPERCRETE
Load vs Deformation
Sample No37
Dimensions:
a=5.0in
b=11.7in
t=12.0in
Load - lb
Deformation - in
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
0.00
0.40
0.80
1.20
1.60
2.00

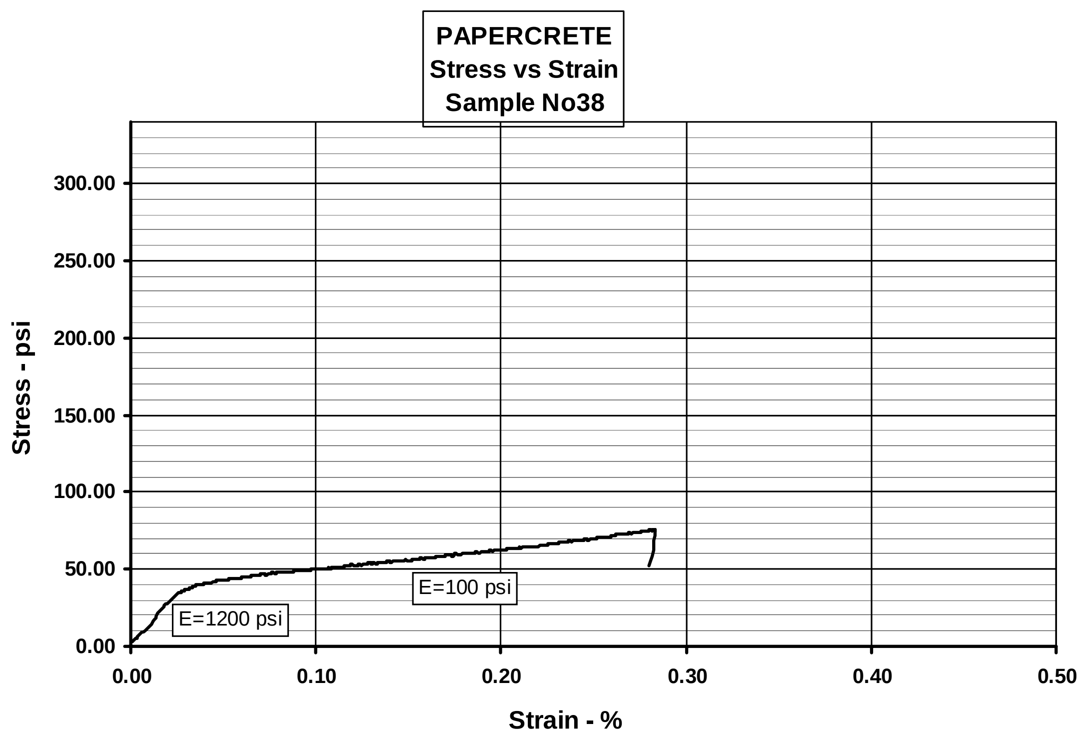

PAPERCRETE
Stress vs Strain
Sample No37
E=800 psi
E=3000 psi
Stress - psi
Strain - %
0.00
50.00
100.00
150.00
200.00
250.00
300.00
0.00
0.10
0.20
0.30
0.40
0.50

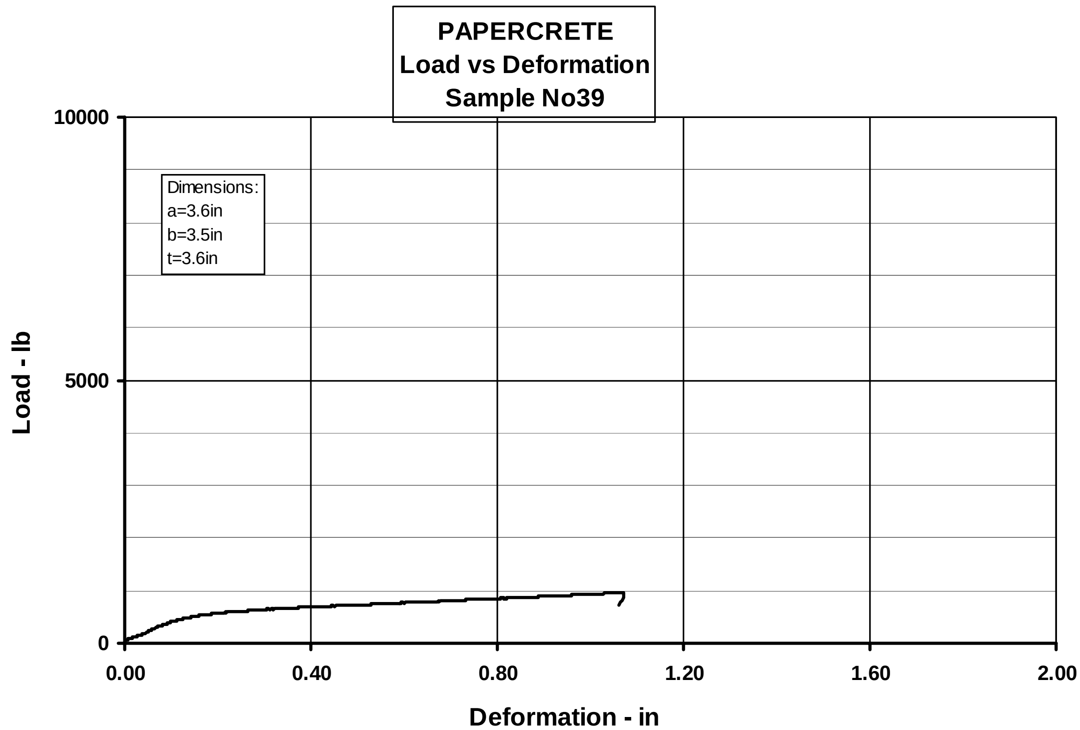

PAPERCRETE
Load vs Deformation
Sample No60
Dimensions:
a=4.5in
b=10.5in
t=11.7in
Load - lb
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

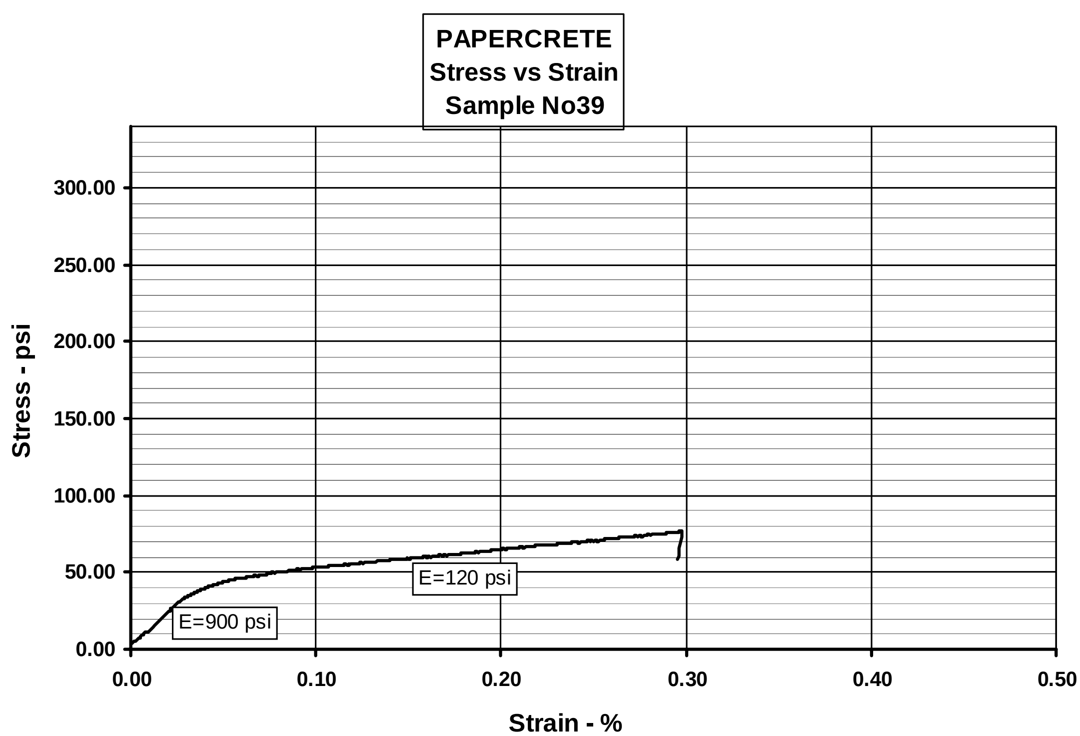

PAPERCRETE
Stress vs Strain
Sample No60
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=220 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

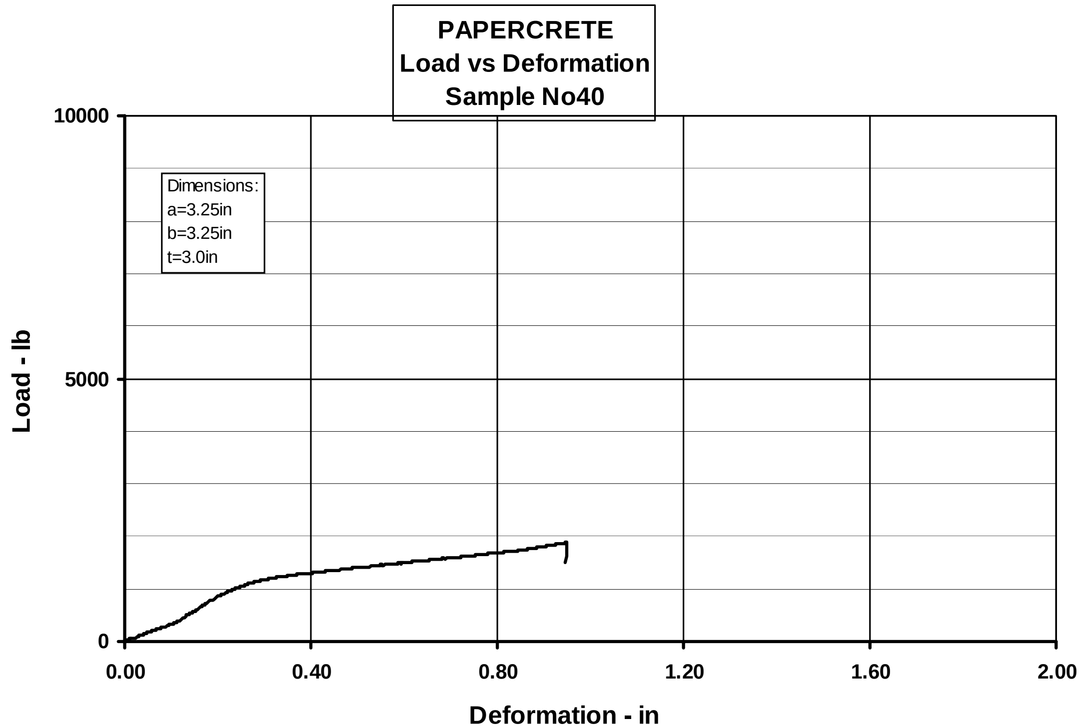
3rd Group of Samples

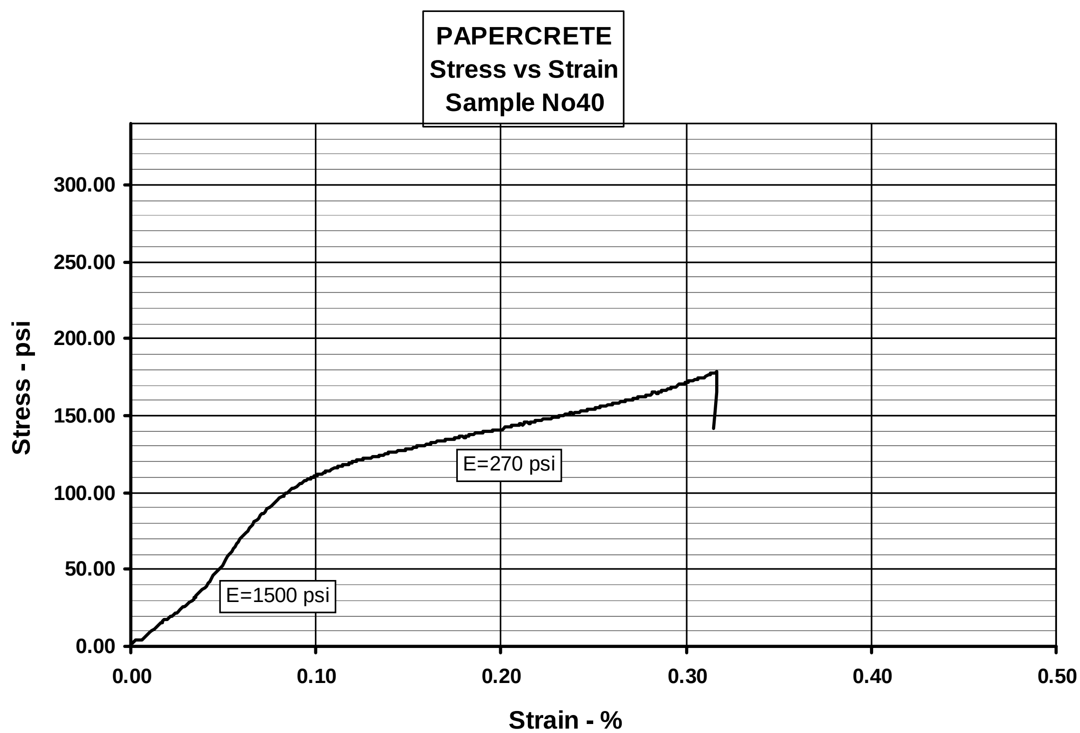

PAPERCRETE
Load vs Deformation
Sample No38
Dimensions:
a=3.6in
b=3.5in
t=3.7in
10000
5000
0
Load - lb
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

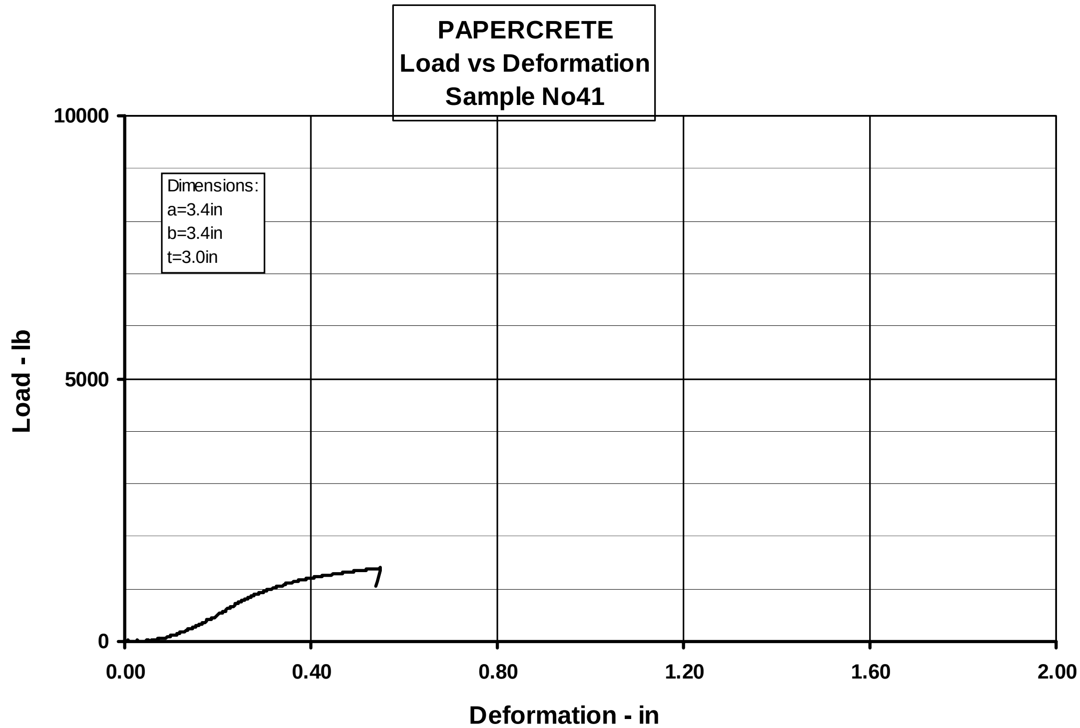

PAPERCRETE
Stress vs Strain
Sample No38
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Stress - psi
E=100 psi
E=1200 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

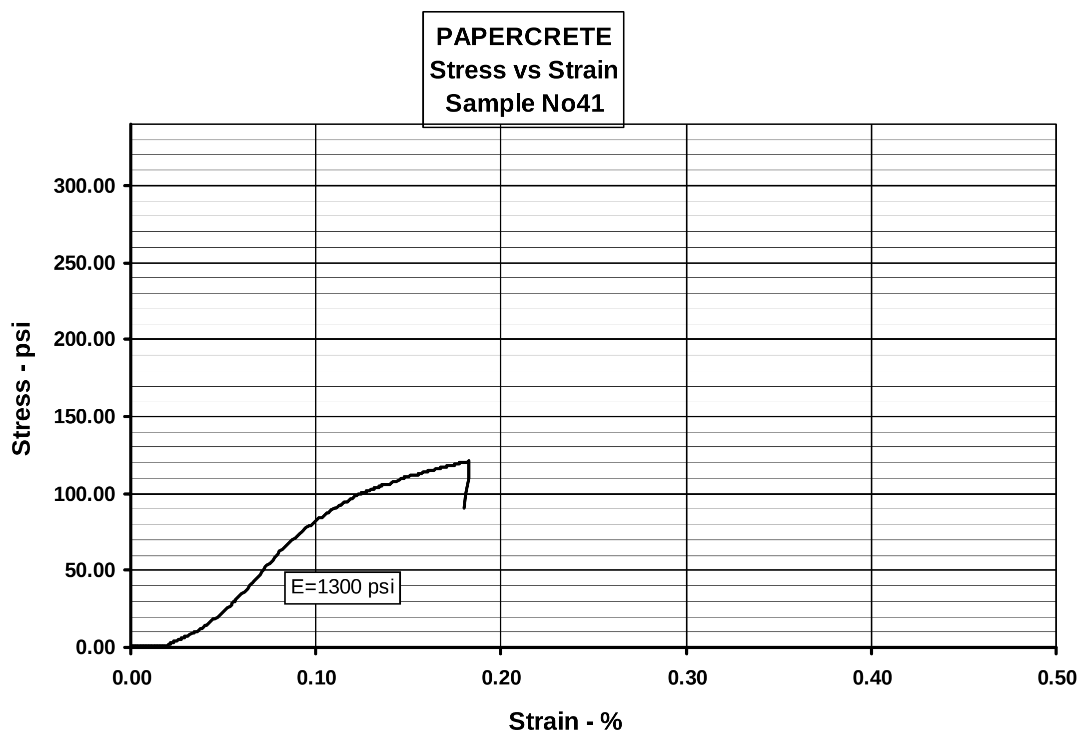

PAPERCRETE
Load vs Deformation
Sample No39
Dimensions:
a=3.6in
b=3.5in
t=3.6in
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Load - lb
Deformation - in

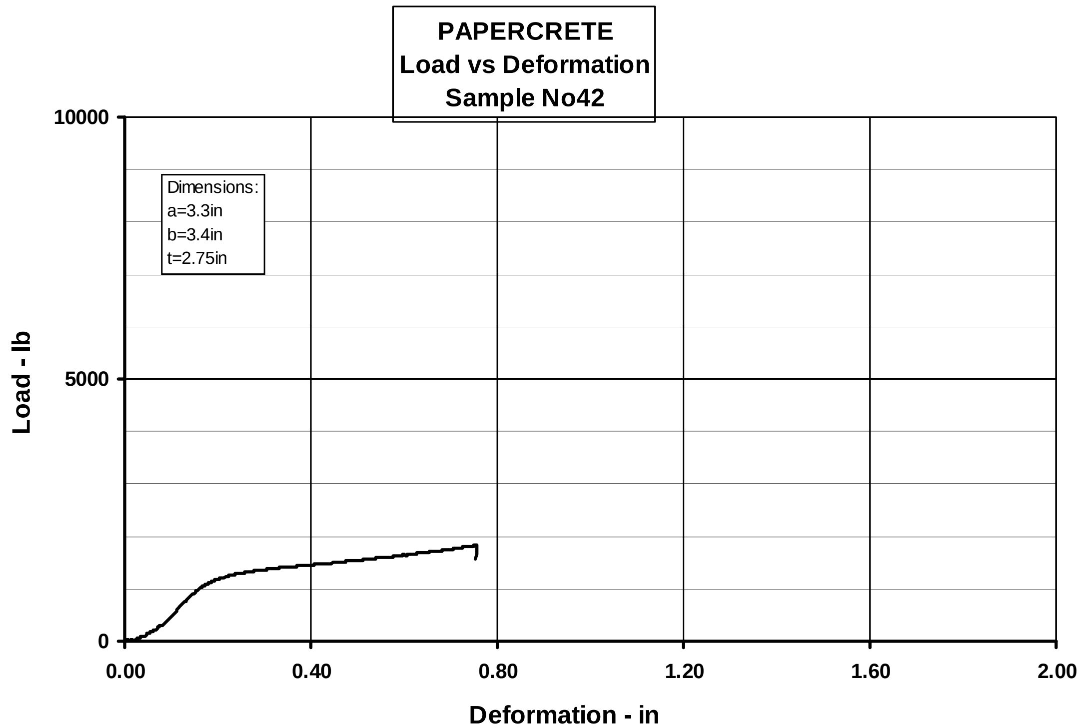

PAPERCRETE
Stress vs Strain
Sample No39
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=120 psi
E=900 psi
0.00
0.10
0.20
0.30
0.40
0.50
Stress - psi
Strain - %

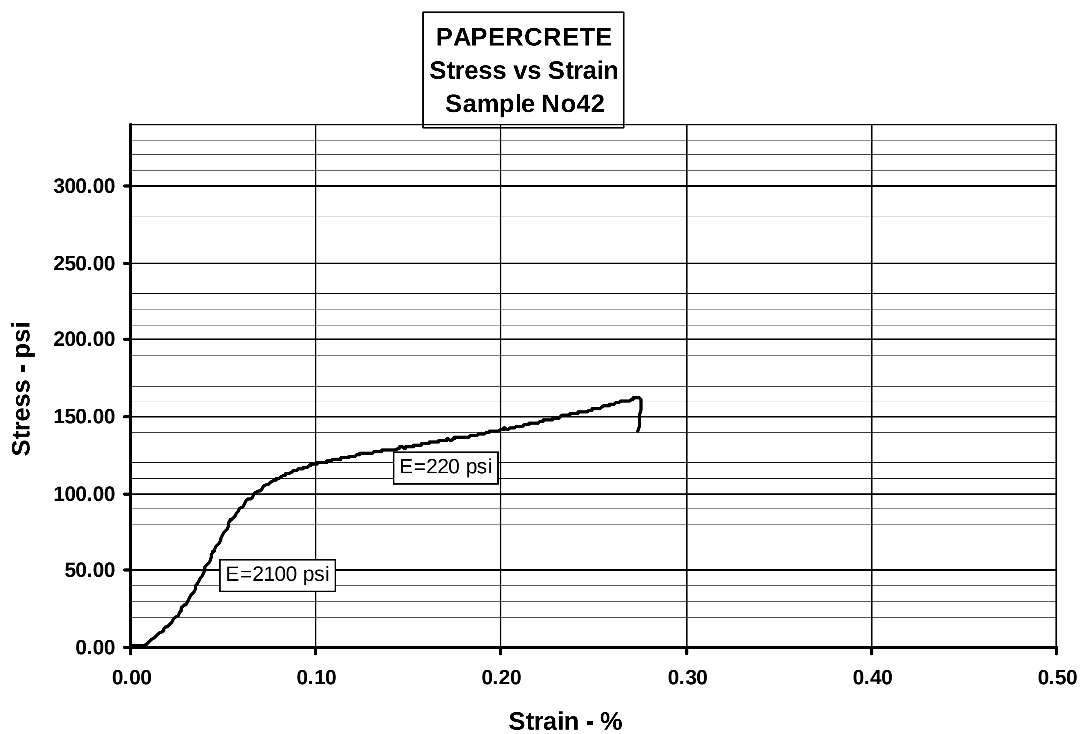

PAPERCRETE
Load vs Deformation
Sample No40
Dimensions:
a=3.25in
b=3.25in
t=3.0in
Load - lb
Deformation - in
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00


PAPERCRETE
Stress vs Strain
Sample No40
E=270 psi
E=1500 psi
Stress - psi
Strain - %
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50


PAPERCRETE
Load vs Deformation
Sample No41
Dimensions:
a=3.4in
b=3.4in
t=3.0in
Load - lb
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

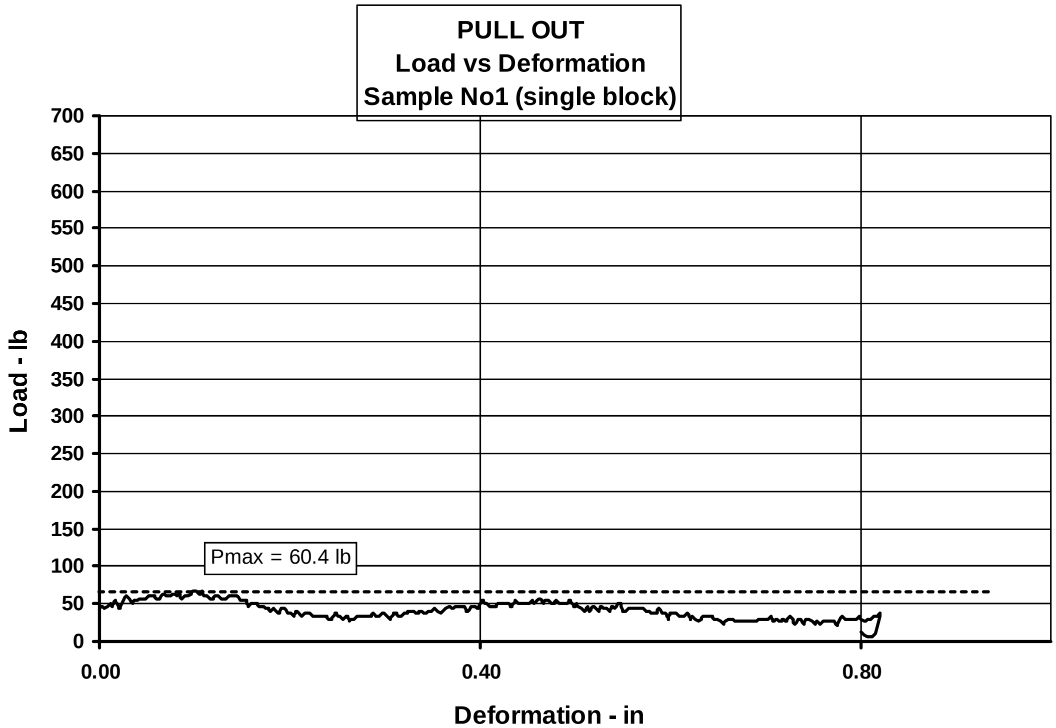

PAPERCRETE
Stress vs Strain
Sample No41
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
E=1300 psi
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

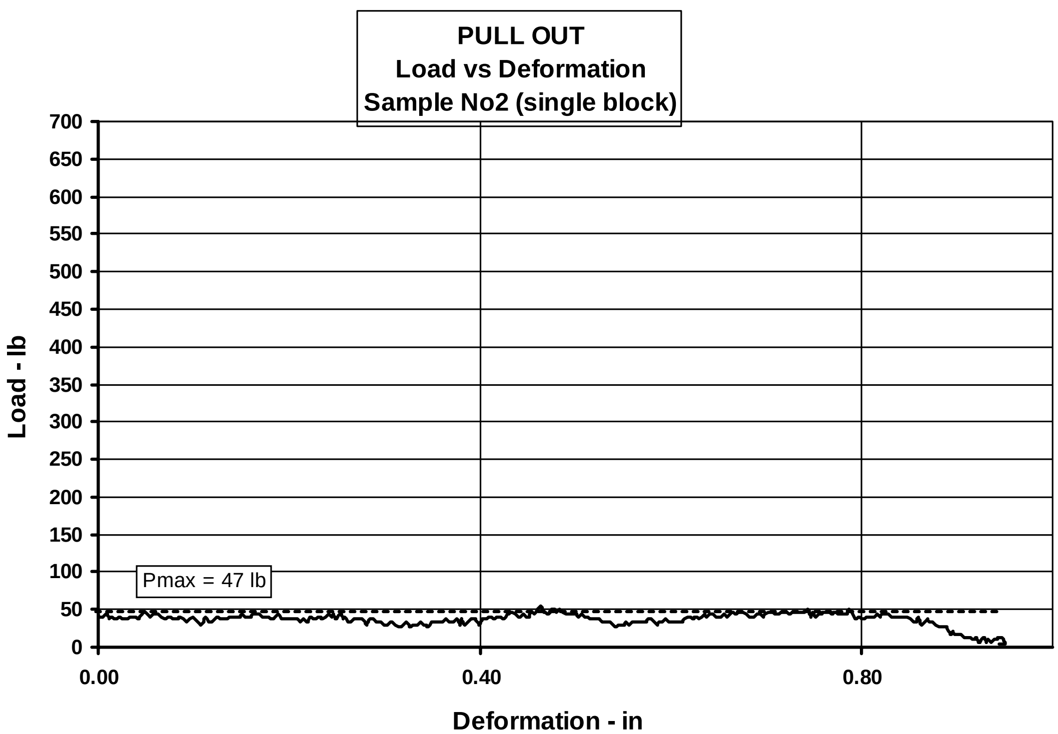

PAPERCRETE
Load vs Deformation
Sample No42
Dimensions:
a=3.3in
b=3.4in
t=2.75in
Load - lb
10000
5000
0
0.00
0.40
0.80
1.20
1.60
2.00
Deformation - in

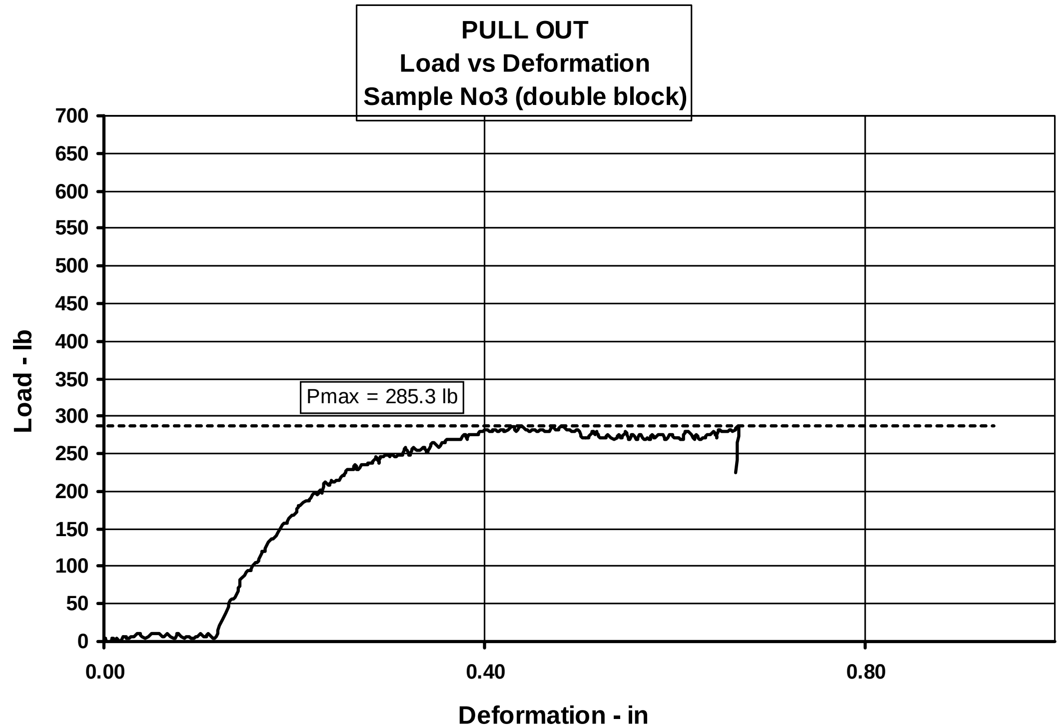

PAPERCRETE
Stress vs Strain
Sample No42
E=220 psi
E=2100 psi
Stress - psi
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0.00
0.10
0.20
0.30
0.40
0.50
Strain - %

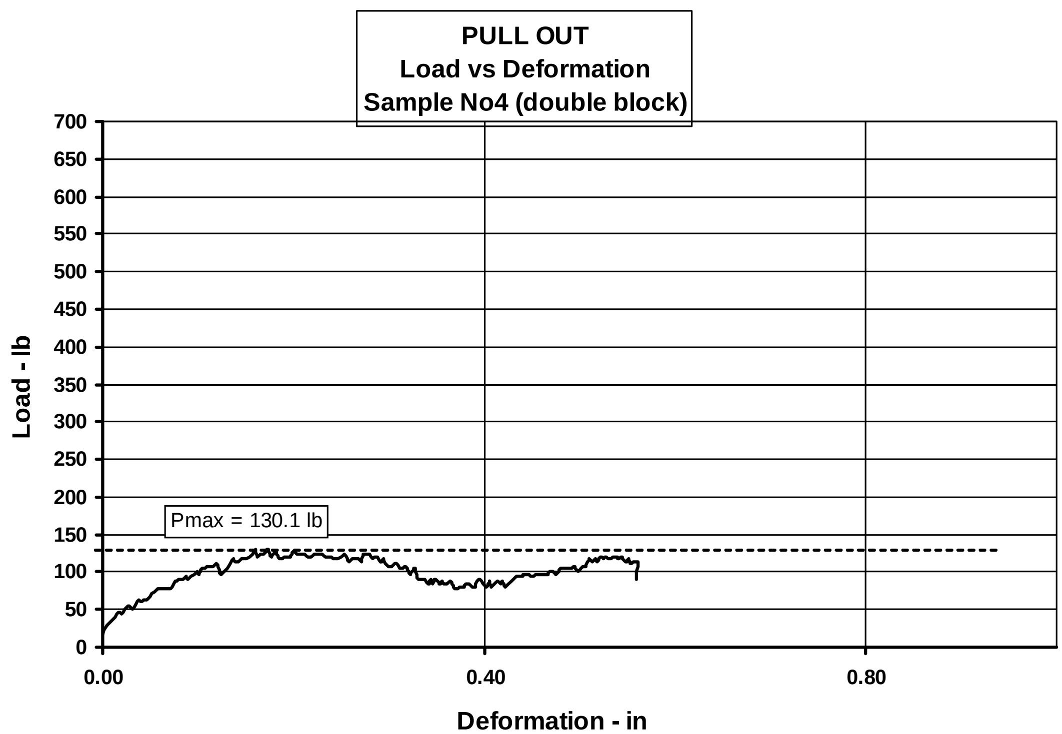
Appendix II

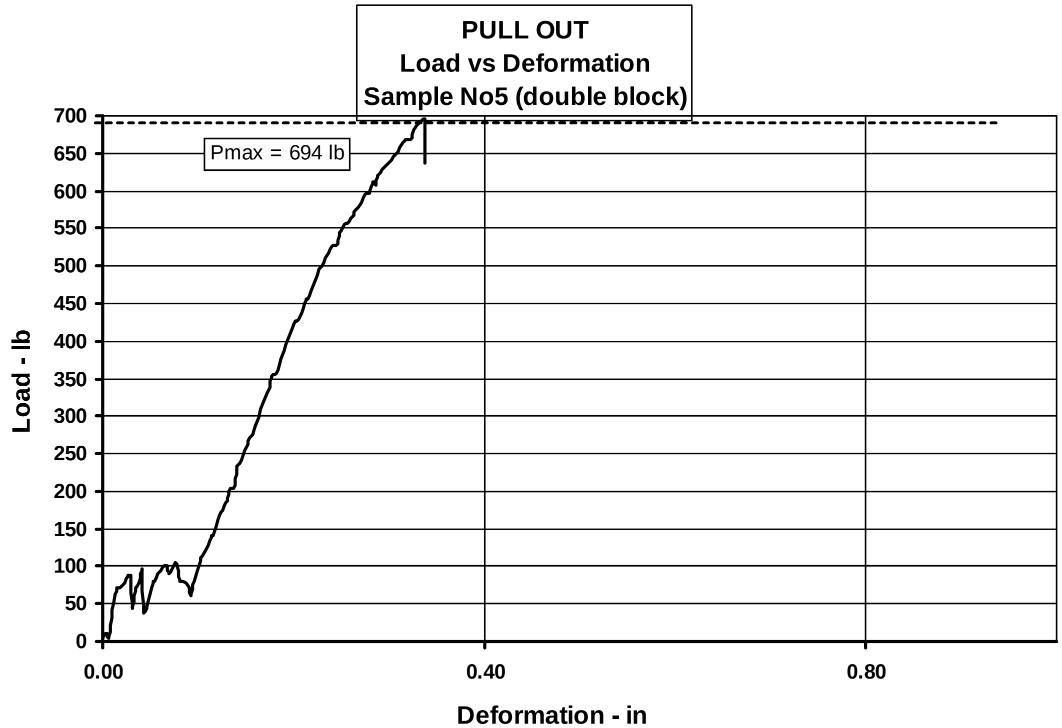
Pull Out Test


PULL OUT
Load vs Deformation
Sample No1 (single block)
Load - lb
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Pmax = 60.4 lb
0.00
0.40
0.80
Deformation - in


PULL OUT
Load vs Deformation
Sample No2 (single block)
Load - lb
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Pmax = 47 lb
0.00
0.40
0.80
Deformation - in


PULL OUT
Load vs Deformation
Sample No3 (double block)
Pmax = 285.3 lb
Load - lb
Deformation - in
0.00
0.40
0.80
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700


PULL OUT
Load vs Deformation
Sample No4 (double block)
Pmax = 130.1 lb
Load - lb
Deformation - in
0.00
0.40
0.80
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700



PULL OUT
Load vs Deformation
Sample No5 (double block)
Pmax = 694 lb
Load - lb
Deformation - in
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
0.00
0.40
0.80

Appendix III

Creep Test

MATERIAL: **Papercrete**
SAMPLE : **No4**
Area (in²): **26.25**
Load (lb)= **307.5** **(Constant)**

Time Days	Deform. Read (in)	Actual Deform. (in)	Strain in/in	Stress psi
0	0.000	0.0000	0.000	11.71
2	0.170	0.0255	0.003	11.71
5	0.310	0.0465	0.005	11.71
6	0.337	0.0506	0.006	11.71
7	0.367	0.0551	0.006	11.71
8	0.410	0.0615	0.007	11.71
9	0.400	0.0600	0.007	11.71
12	0.465	0.0698	0.008	11.71
13	0.465	0.0698	0.008	11.71
14	0.465	0.0698	0.008	11.71
15	0.482	0.0723	0.008	11.71
16	0.500	0.0750	0.009	11.71
19	0.516	0.0774	0.009	11.71