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# Laboratory Evaluation of Organic Soil Mixing

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by

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**Abstract**

Organic soils present a difficult challenge for roadway designers and construction due to the high compressibility of the soil structure, the often associated high water table, and the high moisture content. For other soft or loose soils (inorganic soils), stabilization via cement or similar binders (a method called soil mixing) has proven to be an effective solution. To this end, the Federal Highway Administration has published a comprehensive design manual for these techniques. Organic soils, however, are not addressed therein to a level of confidence for design, as organic soils do not follow the trends of inorganic soils. This has been attributed to the high porosity, high water content, and high levels of humic acids common to organic soils.

This thesis presents the findings from a literature search, laboratory bench tests, large scale laboratory tests, and concludes with recommendations for design involving soil mixing applications in highly organic soils.

Laboratory tests (bench tests) were performed to assess the effect of cementitious binder type, binder content, mixing method, organic content, and curing time on strength gain. This phase involved over 500 test where in all cases, specimens with organic content higher than approximately 10% required disproportionally more cement for the same strength gain when compared to inorganic or low organic content samples.

Using the findings of the bench tests, a 1/10$^{th}$ scale test bed was built in which soil containing approximately 44% organics was placed and conditioned with rain water. The dimensions of the bed accommodated three side-by-side tests wherein dry and wet soil mixing were performed each on one third of the bed. The remaining third of the bed was left untreated.

Load tests were then performed on the three portions of the bed where the load for a simulated roadway was placed. These loads were left in place for several weeks and monitored for movement. Results showed improvement for the treated portions relative to the untreatment with virtually identical response coming from both dry and wet methods (both used identical amounts of cement per volume).

The findings of this thesis suggest that the adverse effects of organic soils can be combatted where more cement content is required to bring the water / cement ratio down to acceptable levels and even more cement is required to offset the acidity. While this has been a recurring observation of past researchers, a cement factor threshold was defined by experimental data below which no strength gain was achieved. This threshold was then defined as a cement factor offset above which the measured strengths matched well with other soil types. As a result, a recommended approach for designing soil mixing applications in organic soils was developed.

# Chapter 1: Introduction

Florida is well known for its sunny beaches and year round moderate temperatures that attract tourists from around the world. The annual rainfall, climate and relatively flat land make Florida well-suited to produce wetlands, promote plant life and foster the associated organic decay. As the Everglades and Alligator Alley are home to lush plant life and recreational areas, these wetlands are almost as well known as the beaches. These areas contain over two million acres of organic deposits often termed “muck” and when the organic content exceeds 75% it is classified as “peat” (Stinnette, 1997). However, organic deposits are not isolated to wildlife preserves; rather, they are commonly encountered throughout the state in existing or proposed new roadway alignments. It is an undesirable subgrade material for construction of highways due to its high compressibility and low strength.

Historically there have been many approaches to handling soft compressible soils in proposed roadway alignments that include organic deposits. From these experiences the FDOT *Soils and Foundations Handbook* lists several options in Section 8.4.1.3:

1. *Reduce fill height. This is seldom practical except in planning phase.*
2. *Provide waiting period to allow for the majority of consolidation to occur.*
3. *Increase surcharge height.*
4. *Use a lightweight fill.*
5. *Install wick drains within the compressible material to be surcharged.*
6. *Excavate soft compressible material and backfill with granular soil.*
7. *Ground modification such as stone columns, dynamic compaction, etc.*

8. *Deep soil mixing.*

9. *Combinations of some of the above.*

This thesis focuses on ground modification in the form of soil mixing that incorporates cementitious binders introduced in one of two ways: (1) wet mixing methods where the cement is injected and mixed into the insitu soil in the form of a premixed grout slurry or (2) dry soil mixing where the cement is introduced as a dry powder. Figures 1.1 and 1.2 show both wet and dry soil mixing equipment being used, respectively. The study included both small and large scale laboratory testing and concluded with recommendations for design.

Figure 1.1 Double auger wet soil mixing system evidenced by pond of fluid grout formed in treatment area.


Figure 1.2 Dry soil mixing showing clouds of powdered cement injected below ground.

The thesis is organized into four ensuing chapters. Chapter 2 reviews and explains previous laboratory studies dealing with soil mixing in general and recognizes the uncertainty associated with organic soils.

Chapter 3 deals with laboratory testing where an exhaustive test matrix explored the effects of binder type, binder content, organic content, water to cement ratio, time of maturation and mixing method (i.e. dry or wet as discussed above).

Chapter 4 presents the findings of long-term performance of large scale outdoor testing that incorporated soil mixes derived from lab scale test results. Therein the results of both dry and wet mixing methods are presented in comparison to an untreated control sample of the same soil.

Chapter 5 provides a summary of the thesis’ findings and recommendations for the use of soil mixing in organic soils.

# Chapter 2: Literature Review

There are numerous proprietary methods of soil mixing wherein a binder such as lime, cement, or slag is mixed with the insitu material to improve its strength characteristics. The types of equipment range from full length multi-auger systems to huge blenders with vertically or horizontally oriented paddles.

Soil mixing can be categorized as dry or wet soil mixing depending on whether the binder is added to the soil as a dry powder or as a pre-wetted slurry. The decision between the application of the wet or dry methods is based on a threshold moisture content of the soil. When the moisture content is greater than 60%, enough natural moisture exists to use dry methods, and for insitu soils with moisture contents below 40%, wet methods are used. Dual applicability exists between moisture contents of 40 and 60%.

This thesis focuses on methods to strengthen / mix soil in place. This chapter discusses these methods in general, laboratory scale case studies and recommendations from the FHWA Design Manual for Deep Soil Mixing as well as the Swedish Deep Stabilization Research Centre.

## 2.1 Wet Soil Mixing

Wet soil mixing is any method that injects fluid grout into a soil matrix accompanied by some means of homogenizing the matrix. The injection may occur under modest fluid pressure of 200-400psi or very high pressures (e.g.10,000-20,000 psi). Lower pressure systems use equipment similar to drilled shaft rigs where a large diameter multi-paddle tool slowly spins and advances into the soil while injecting grout slurry (Figure 2.1). This process produces spoils up to 30 or 40%

of the final column volume which may be a problem if the soil is contaminated. High pressure wet soil mixing is more commonly called jet grouting and is not the focus of this thesis.

Figure 2.1 Wet soil mixing equipment (courtesy of Hayward Baker).

The resulting column strength is dependent on the cement content which is injected on a per linear foot basis to achieve the desired strength. The zone of improvement is limited to the diameter of the paddles and like all soil stabilization methods it is performed on a pattern that provides sufficient coverage to achieve the design strength of the entire treatment area. This method is most effective in soils with moisture content less than 60%.

### 2.2 Dry Soil Mixing

Dry soil mixing (DSM) is a technique relatively new to the US but it has been used for several decades abroad. It was first used in the US in 2006 on the Jewfish Creek Project along the US-1 corridor in south Florida (Garbin and Mann 2010). This method can use equipment similar to Figure 2.1 on the same type of pattern layout or it can be performed on shallow soil deposits using a horizontal axis, tilling-type tool head (Figure 2.2). The latter treatment produces complete coverage of side by side rectangular areas which can then be considered *mass stabilization*. This ground improvement/soil mixing method blends a dry binder into the soil (using either blade type) by means of high pressure air. Figure 2.2 shows a horizontal tilling tool.

DSM can be used to stabilize contaminated soils where spoil removal is problematic. But, like most soil mixing systems discussed, this requires highly specialized equipment.

Figure 2.2 Tilling type mixing tool for DSM mass stabilization (2 to 3 ft diameter and 5 ft wide).

DSM is ideal for weak soils where the undrained shear strength is less than 200 psf. It is well suited for organic soils as it requires the higher moisture content to fully activate the binder and can be performed on both shallow and deep deposits. The high moisture content of organic soil results in high w/c ratios unless large amounts of cement are used. Contractors purport that use of a combination of cement and slag tends to give better results.

At the onset of this study, there had been only 35 dry mixing projects in the US of which several have been in organic deposits in Florida.

## 2.3 FHWA Design Manual for Deep Soil Mixing

The Federal Highway Administration Design Manual for deep soil mixing (Bruce, et al, 2013) provides a comprehensive design and quality assurance guideline for deep soil mixing using both wet and dry methods. Therein, equipment types, mix methods, binder types, design procedures, site characterization, binder content, etc. are all discussed at length along with design examples and quality control protocols. This design manual also provides an overview of previous laboratory case studies in its literature review and culminates with a strength versus w/c (w/b, water to binder ratio) for the purposes of estimating the required binder (Figure 2.3).

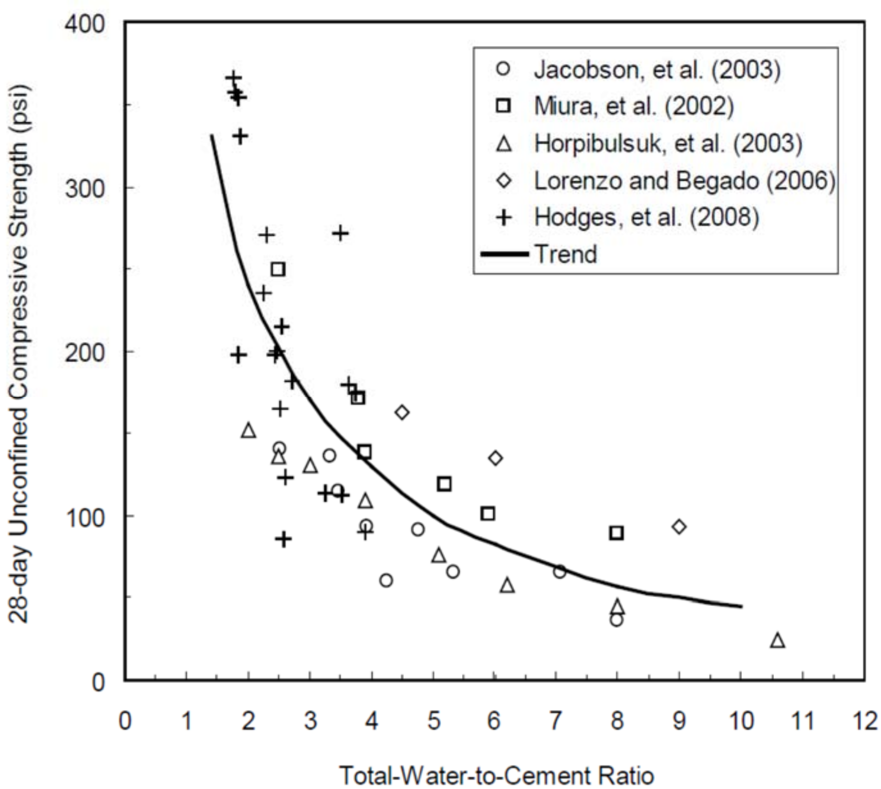


Figure 2.3 Strength vs. w/c ratio (Bruce et al., 2013, public domain).

It should be noted that the trend curve provided in Figure 2.3 does not represent all of Hodge's data. In order to show all of the available data, Figure 2.4 includes the higher strength samples that were not included in FHWA design manual. Figure 2.5 shows an adapted version of the FHWA design curve. The updated trend curve includes the influence of Hodge's data that is beyond the scope of the axis provided (Figure 2.5). While these curves are similar, there are discrepancies at both ends of the curves. The modified FHWA design curve reflects slightly lower strengths than the published curve. Considering that organic soil mixes may have high w/c ratios, ratios, the trend used in this study will be the modified FHWA design curve as it includes all available data.

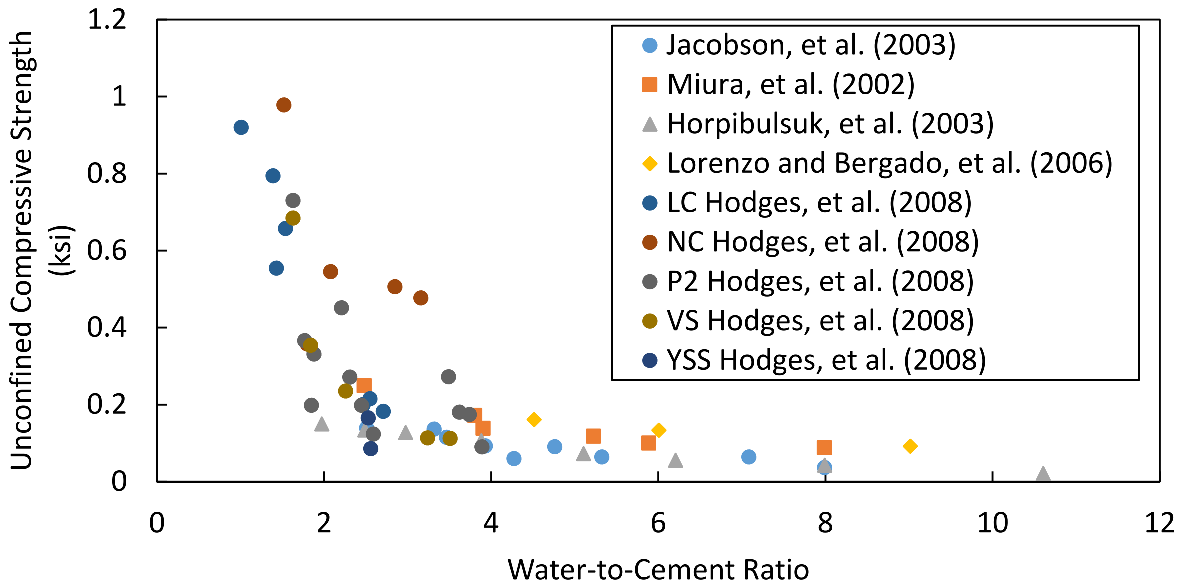


Figure 2.4 Strength vs. w/c ratio including all of Hodges data (Costello, 2015).

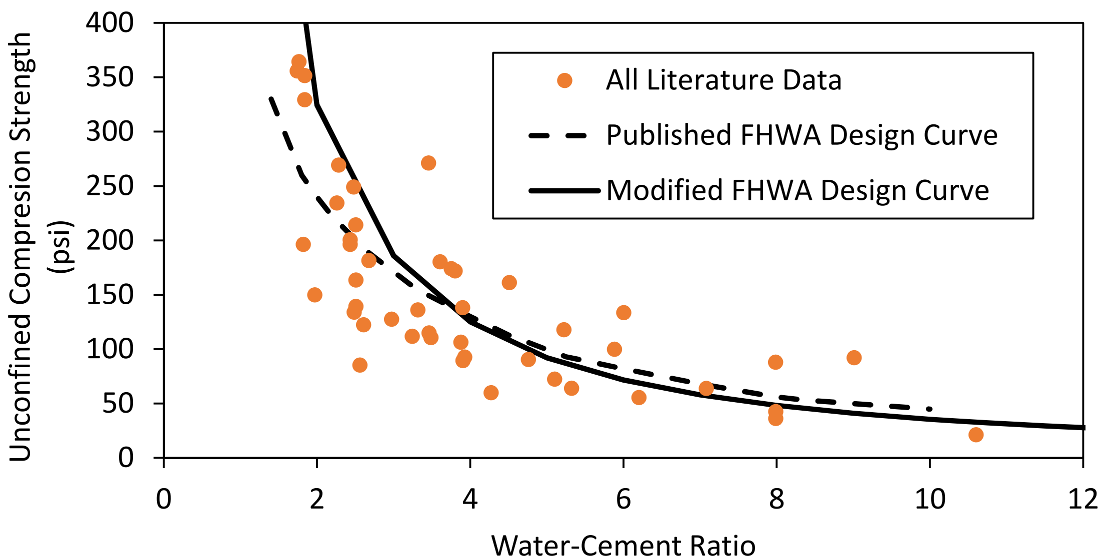


Figure 2.5 Strength vs. w/c ratio (Costello, 2015).

With the exception of some of Jacobson's data, these curves are defined for inorganic soils. Jacobson reported three samples that had organic content as high at 15% (Jacobson, Filz, & Mitchell, 2003). This was by far the highest organic content presented above. In fact, the manual acknowledges that organic soils do not adhere to any predictive methodologies and extra care and review should be exercised when dealing with organic soil. The manual also suggest that significant uncertainty arises when organic contents are above 10%. The cause is taken to be related to the acetic nature of organics. However, no recommendations are provided to address this.

Given the design curve in Figure 2.5, the manual states that a starting cement content or w/c ratio can be estimated where decreasing w/c ratios tend to increase the strength. The manual recognizes that there is a significant amount of scatter in the data; this is why the amount of binder required, according to theses graphs, is considered "a starting point." Additionally, the manual also recognizes that laboratory test results, which produced these figures, often vary from field results. The strength of field-mixed samples was shown to be as low as 20% of laboratory specimens making field verification an important part of quality control / assurance. This percentage is independent of soil type.

### 2.4 Swedish Deep Stabilization Research Centre

The Swedish Deep Stabilization Research Centre and the US National Deep Mixing programs collaborated in translating a Swedish Geotechnical Institute publication (1999) which was published in 2002 (Axelsson et al., 2002). The mission of both organizations was the dissemination of international experience where the Swedish experiences with dry soil mixing were far beyond that of the rest of the world. Organic soils were a focus of this effort.

This study identified organic soils, called *mud and peat*, as problematic. Due to its acetic nature, the low pH of organic soils negatively impacts the binder's reaction. The study also suggested that enough binder must be present in the system to neutralize the acids before strength increased. However, the study addresses a case study from Finland that recognized the acid content of organics soils as being only one of many factors. Nevertheless, results from the Finland study claimed that the binder content needed to exceed a "threshold" before the soil achieved any strength gain.

In addition to binder amount, binder type was addressed as well. The study claimed that pure cement binders out performed binders with pozzolans (slag) in organic soils. This was based on the lack of clay particles in organic soils needed for a pozzolanic reaction to occur.

While the FHWA manual is thorough in all areas except organic soils, this study pointed out possible explanations for the effects of organic soils on cement stabilization performance: (1) the concept of a required binder threshold that is required to offset the acidity of organic soils below which no improvement is achieved and (2) the possibility that pure cement works better for organic sands and perhaps that slag/cement mixes are better suited for organic clays. These concepts were scrutinized and entertained during this research project.

The study concluded that the strength of treated organic soils cannot be confidently predicted at this time.

# Chapter 3: Small Scale Laboratory Testing

In an effort to better understand the effects of cement stabilization in organic soil, extensive laboratory tests were performed. This chapter studies the use of different binder types, binder contents, organic content, and curing time on the mixed soil strength. The two binders studied were cement and slag. Contractors interviewed during this study were of the impression that slag performed more favorably in organic soils thinking that they were more tolerant to the lower pH conditions. While this contradicts the previous excerpts from the Swedish study, it presented another variable to consider. In addition to binder variations, the effects of organic content were investigated. This was done by adding sand as an inorganic component to the 66% organic soil collected. A more detailed explanation of this is presented in the Varying Organic Content section.

With several variables involved in organic soil mixing, the testing matrix became enormous. Knowing this, the goal of this master's thesis was to create a number of mix designs that would give some insight to how the several variables involved relate to strength. The study consisted 56 different mix designs in total. These mix designs are occasionally referred to as batches within this thesis. Each mix design produced nine testing cylinders; this accounts for a total of 504 cylinders. The nine cylinders in each batch made it possible to test three at a time at three different curing durations. In general, curing durations were 14, 28, and 61 days long. These cylinders varied in cement, slag, water, and organic content as well as cure time. Information about all batches and their results are provided in the Appendix. The cement used was Portland Type I/II. The ground granulated blast furnace slag (simply referred to as "slag" in this thesis) was obtained from Argos, a local concrete supplier in Tampa. In reality, even the type of cement and slag could be further subdivided but was not. Figure 3.1 shows the overall mixing matrix. It should be noted that Figure 3.1 does not include time and therefore only represents 1/3 of the test conducted.

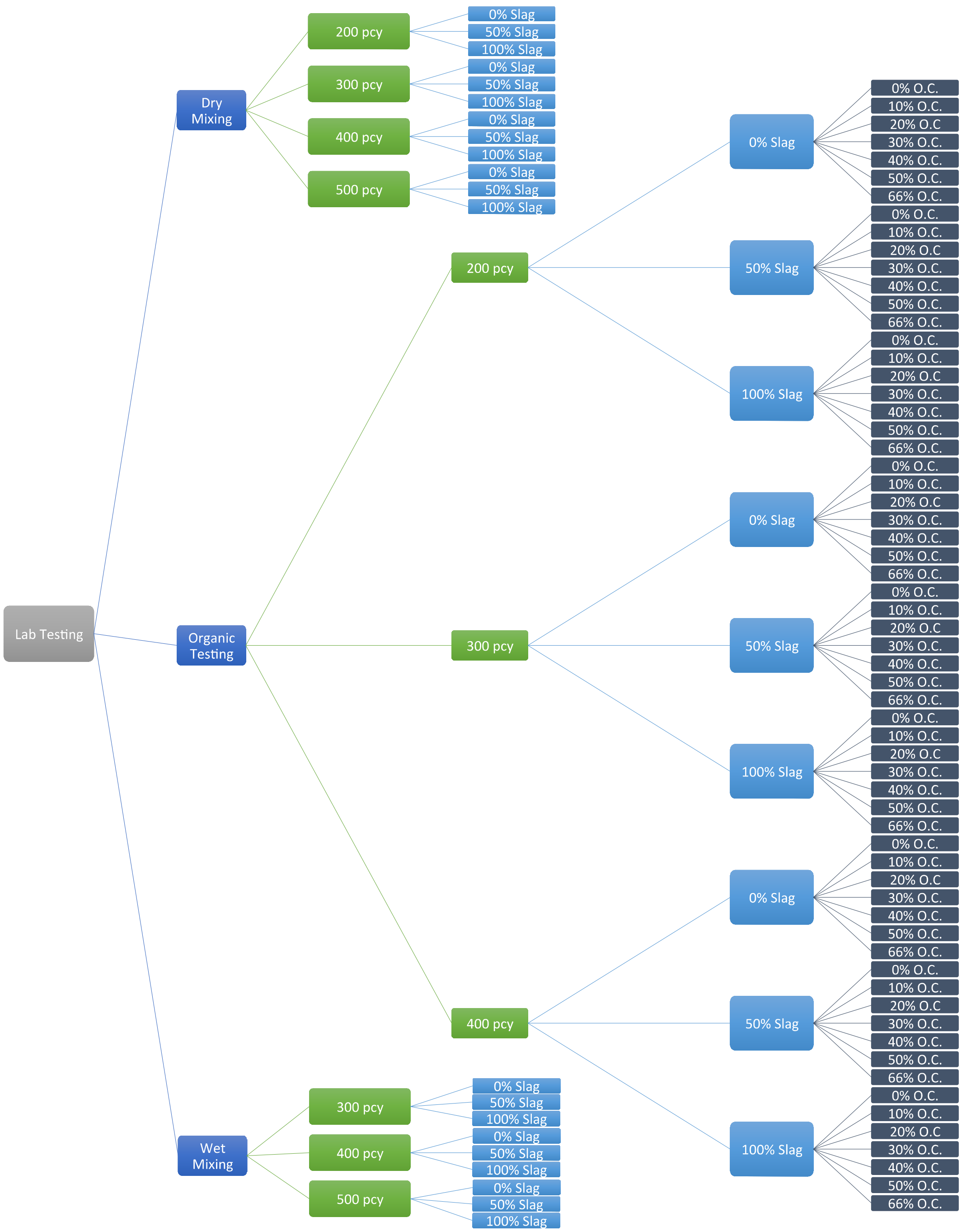


Figure 3.1 Overall mixing matrix.

### 3.1 Cement and Slag in Organic Soils

The first item of interest was the effects of blended binders. In these experiments, the organic content was not adjusted. The adjusted variables were cement and slag content. As stated in the literature review chapter of this thesis, replacing a portion of cement with slag may have some level of strength increases. The purpose of these tests was to investigate how slag replacement affects strength in highly organic soils. The soils used in this section had organic contents ranging from 42-66%, the highest used in this study.

Eleven different mix designs were used in this investigation. These eleven mixes can be broken into essentially three groups. The first group used only cement as the binder, the second group used a combination of cement and slag as the binder, and the third group used only slag as the binder. In the second group, slag accounted for 50% of the binder by mass; this is denoted as 50% slag replacement. The mixes varied in binder amount from 200 to 500pcy. It should be noted that 100pcy mixes were attempted earlier in this study; however, they proved to have zero strength. Therefore this was noted, but no further 100pcy batches were created. Figure 3.2 displays the series of tests as a branch off the overall test matrix.

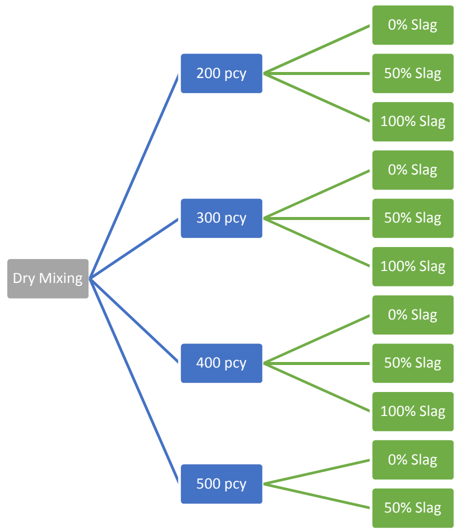


Figure 3.2 Test matrix for dry mixing.

It should be noted that a 100% slag replacement mix design is missing from Figure 3.2. This is due to the fact that the 100% slag replacement mixes were created before the 500pcy mix was added to the matrix, but they proved to have no strength and could not be removed from the cylinder mold. Therefore only 0% and 50% slag replacement batches were prepared for the 500pcy dry mixing section.

### 3.2 Varying Organic Content

In addition to the effects of blended binders, the effect of organic content on strength was evaluated. Data from 45 different mix designs were used in this series of tests. This included 39 additional mix designs created specifically for this investigation. These mix designs primarily varied in organic content, but they also varied in cement and slag content. This series made up a majority of the test matrix, and a branch of test matrix is provided in Figure 3.3 below for reference. While Figure 3.3 represents the 300pcy branch, it should be known that there also exist similar branches for 200, 400 and 500pcy.

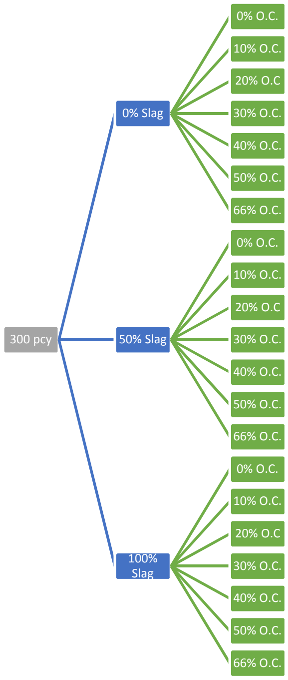


Figure 3.3 Example test matrix for 300pcy binder content showing further subsets based on organic content, % O.C.

Referring to Figure 3.3, 0% O.C. mix designs used only sand, and no organic soil. The 66% O.C. was used as the upper limit due to the fact that it was the highest organic content available. The increments of 10, 20, 30 40, and 50% O.C. in-between the upper and lower limits were target values. The actual organic content of each mix was measured and documented.

To adjust the organic content of the soil, various amounts of sand were used to lower the percentage of organic material. When sand was added to the system, it was oven dried, 0% M.C. It was recognized that adding dry sand would lower the moisture content of the mix, and therefore change two variables (% O.C. and M.C.) instead of the one that is being tested for (% O.C.). To combat this effect, enough water was added to the system to make the moisture content of the sand and additional water alone to be 30%. This value was chosen because 30% M.C. is close to fully saturated for loose sands (Das 2008). While this still lowered the M.C. of the mix, the amount that it is lowered was the result of the saturation limit being lowered, not the effect of dry material entering the system. This was expected to give more meaningful results.

**3.3 Wet Mixing**

The main difference between wet mixing and previously described dry mixing is that the binder is pre-mixed, or hydrated, with water before being mixed with the soil. The water present within organic soils is typically more acidic due to chemically being affected by the organic soil. Mixing the binder with potable water, with a pH of 7, may then be less prone to adverse effects. However, wet mixing involves adding additional water to system that already has a high amount of water. This results in very high w/c ratios, which yield weaker strengths.

Six mix designs were created for this series of tests. It was decided to use binder contents of 300, 400, and 500pcy as opposed to 200, 300, 400, and 500pcy used in dry mixing. The

200pcy mixes were dropped in the wet mixing investigation due to their dry mixing counterpart producing very little strengths. Figure 3.4 provides the wet mixing section of the test matrix.

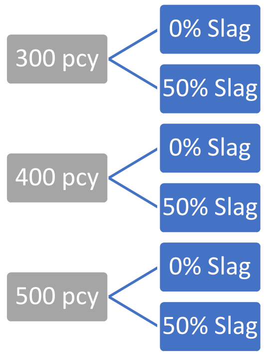


Figure 3.4 Test matrix for wet mixing showing binder variations.

### 3.4 Mixing Procedures

While the mixing procedure was relatively rudimentary, it is helpful to have a standalone section in this chapter dealing with each mixing procedure. In this Master's thesis, there were three mixing procedures: Dry Mixing, Varying Organic Content Mixing, and Wet Mixing. While they were similar, they were each distinct. Therefore for completeness and clarity, all three procedures are provided. Figures 3.5 and 3.6 show the mixer used and the prepared samples, respectively.


Figure 3.5 Small scale laboratory mixer.

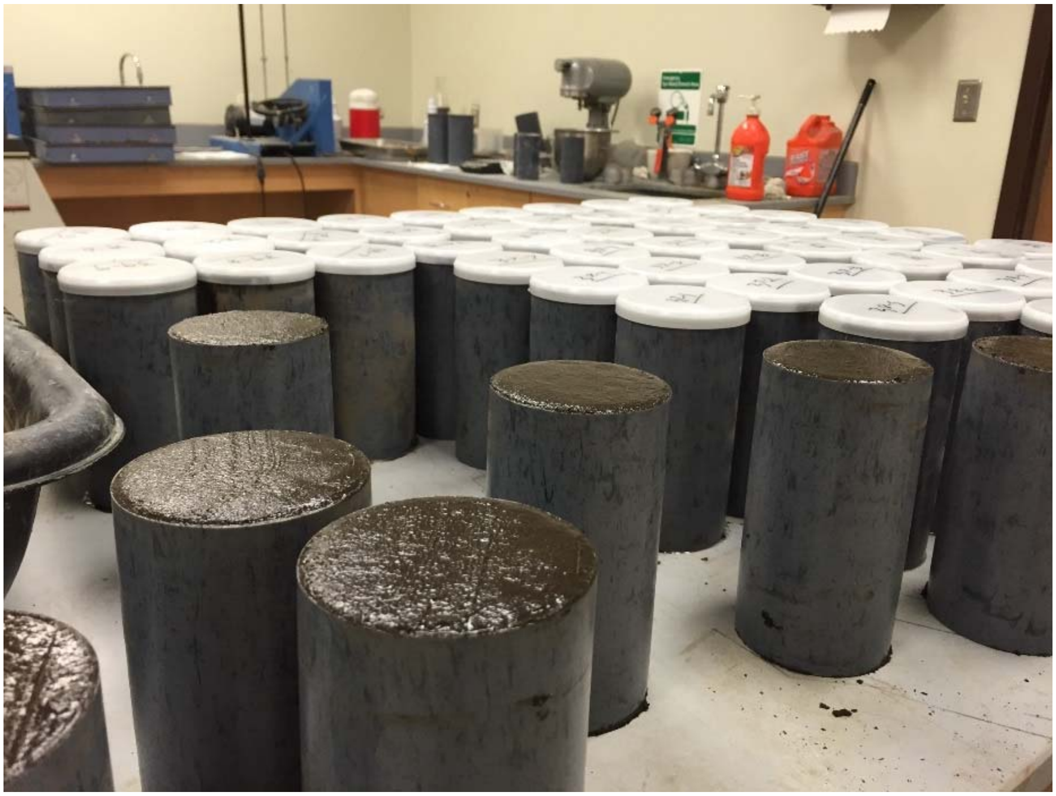

Figure 3.6 Prepared 3 x 6 in. cylinders.

### 3.4.1 Dry Mixing Procedure

The dry mixing procedure applies for the eleven mix designs used in the initial Cement and Slag in Highly Organic Soils section. This is also known as batches 1-9 and 55-56. Dry mixing means that a binder was added to the soil as a dry powder.

1. Calculate the amount of materials needed for nine 3 inch by 6 inch cylinders: soil, cement, and slag.
2. Mix the raw soil alone for approximately 4 minutes in the large mixer.
3. Measure pH with litmus paper.
4. Take small samples to calculate moisture content.
5. Add dry binder. This is either cement, slag, or both. Mix together for 4 minutes.
6. Measure pH with litmus paper.

7. Place mixed soil into nine 3 x 6 in. cylinders. This was done in three layers. As opposed to traditional tamping, the cylinders were moderately taped on the table. This was done to remove air voids while avoiding over compacting the soil.

### 3.4.2 Varying Organic Content Mixing Procedure

This procedure applies to the 39 additional mix designs that were used in the Varying Organic Content section. This accounts for batches 10-48.

1. Calculate the amount of materials needed for nine 3 inch by 6 inch cylinders: soil, cement, slag, water, and sand.
2. Mix the raw soil alone for approximately 4 minutes in the large mixer.
3. Measure pH with litmus paper.
4. Add calculated amounts of water and sand and mix for approximately 4 minutes.
5. Measure pH with litmus paper.
6. Take small samples to calculate moisture content. These samples may also be used to measure organic content.
7. Add dry binder. This is either cement, slag, or both. Mix together for 4 minutes.
8. Measure pH with litmus paper.
9. Place mixed soil into nine 3 x 6 in. cylinders. This was done in three layers. As opposed to traditional tamping, the cylinders were moderately taped on the table. This was done to remove air voids while avoiding over compacting the soil.

### 3.4.3 Wet Mixing Procedure

This procedure applies to the six mix designs used in the wet mixing section. This accounts for batches 49-54.

1. Calculate the amount of materials needed for nine 3 inch by 6 inch cylinders: soil, cement, slag, and water.
2. Mix the raw soil alone for approximately 4 minutes in the large mixer.
3. Measure pH with litmus paper.
4. Take small samples to calculate moisture content.
5. In a separate container, mix the calculated amounts of binder and water with a high energy mixer for approximately 4 minutes, or until thoroughly mixed.
6. Introduce the mixed binder and water to the soil and mix together for 4 minutes.
7. Measure pH with litmus paper.
8. Place mixed soil into nine 3 x 6 in. cylinders. This was done in three layers. As opposed to traditional tamping, the cylinders were moderately taped on the table. This was done to remove air voids while avoiding over compacting the soil.

**3.5 Results**

To test the compressive strength of each cylinder, the Material Testing System (MTS) machine was used. A sample being tested is shown in Figure 3.7. Cylinders were tested at three different curing durations. The first two were typical 14 and 28 day curing times. The third curing duration, as opposed to 56 days, was 62, or in some cases 61, due to schedule conflicts. In cases were cylinders were deemed untestable due to low strengths, some cylinders were withheld from testing in order to test at a longer cure time.

Figure 3.7 Unconfined compression testing of 3 x 6 in. cylinders.

To account for changes in mass, specifically water losses, cylinders were weighed twice. They were weighed once directly after mixing and again right before testing. At largest, the drop in mass was 1.06%, and the average loss in mass was only 0.42%.

Overall test results may be seen in Figures 3.8, 3.9, and 3.10. In order to more closely examine the results, these figures only show results up to 100psi. These graphs plot all experimental data collected against a single variable. While this presentation of the data reveals no clearly significant trends, it highlights the extensiveness of the testing performed and demonstrates the need for a more sophisticated analysis. The rest of this section breaks down the data presented into more manageable categories. Analysis beyond that provided in this section will be presented in Chapter 5.

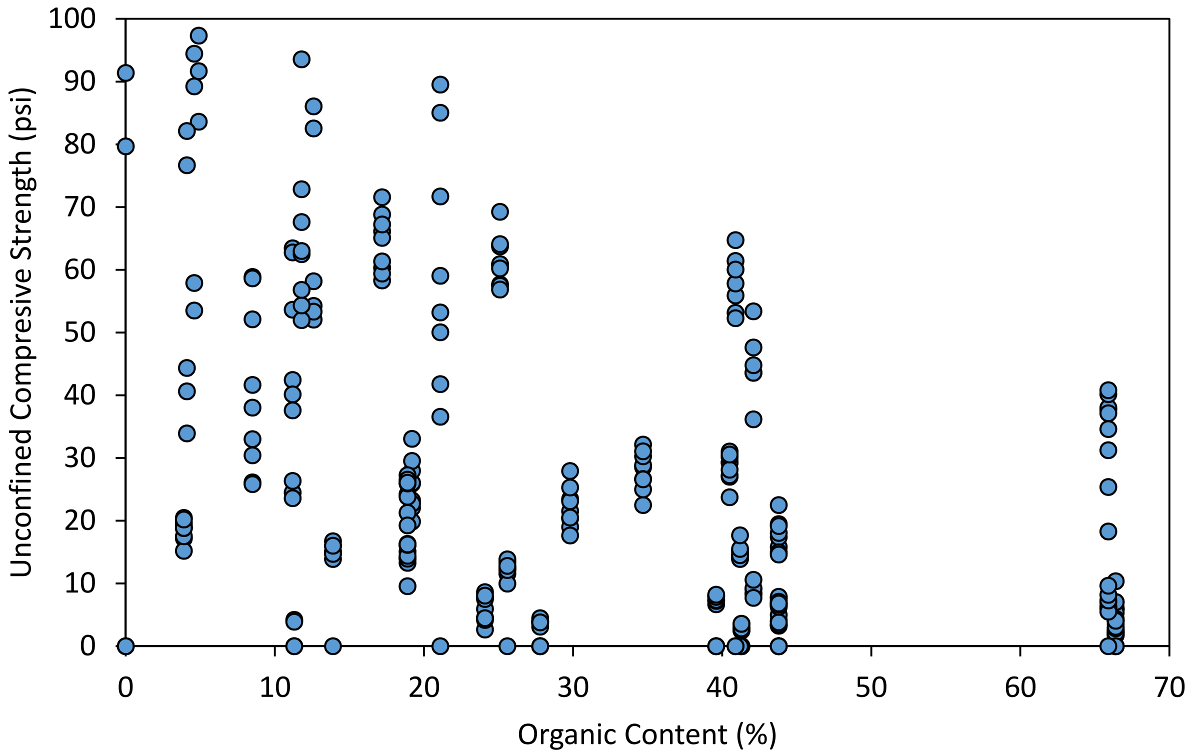


Figure 3.8 Strength vs organic content for all samples below 100psi.

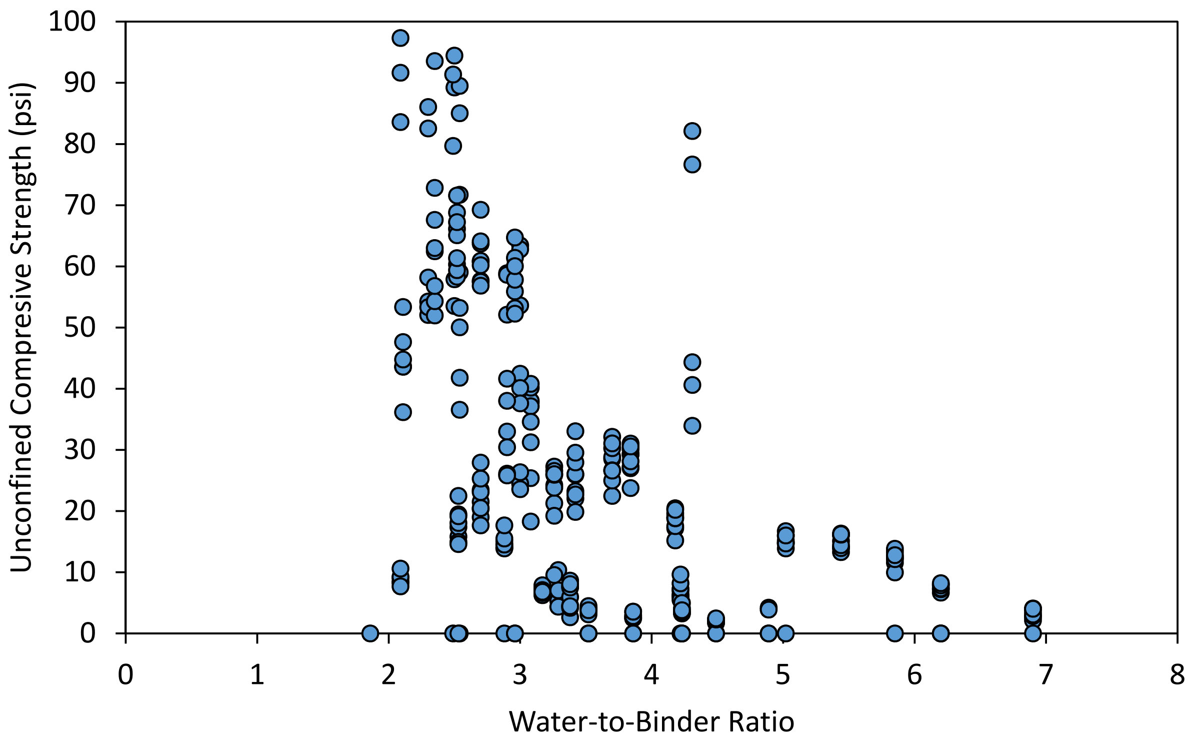


Figure 3.9 Strength vs water-to-binder ratio for all samples below 100psi.

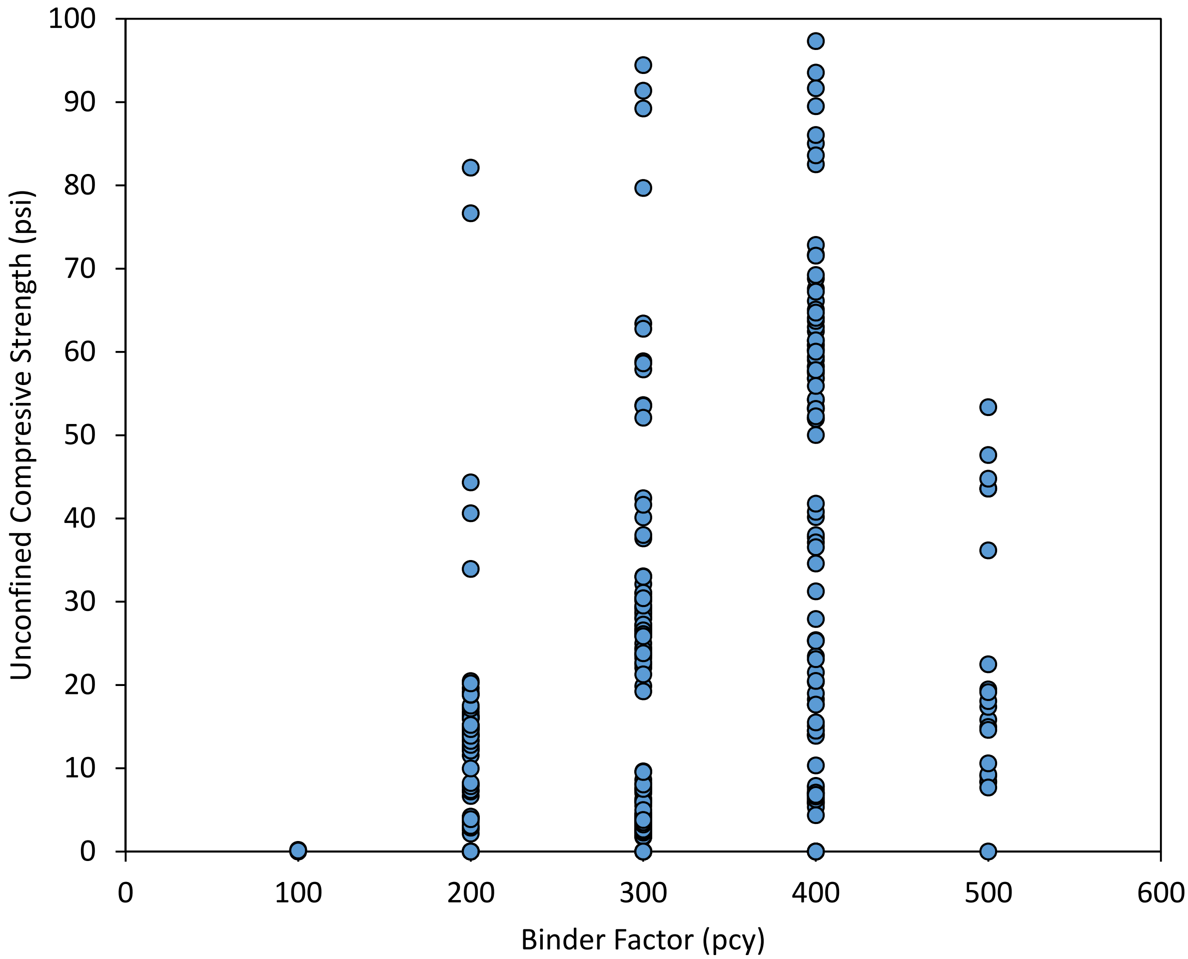


Figure 3.10 Strength vs cement factor for all samples below 100psi.

### 3.5.1 Cement vs Slag in Organic Soils

It was intended that the 0, 50, and 100% slag replacement mix designs would produce enough data to calculate an optimum slag replacement value at a given binder content. However, cylinders containing 100% slag replacement were extremely weak and considered untestable. In other words, they could not be taken out of the cylinder molds without falling apart.

While in contrast with literature, the data from the 0 and 50% slag replacement revealed that mixes with only cement as the binder clearly outperformed those with slag replacement. This trend may be seen in Figure 3.11. In this figure, each data point represents the average of three tests.

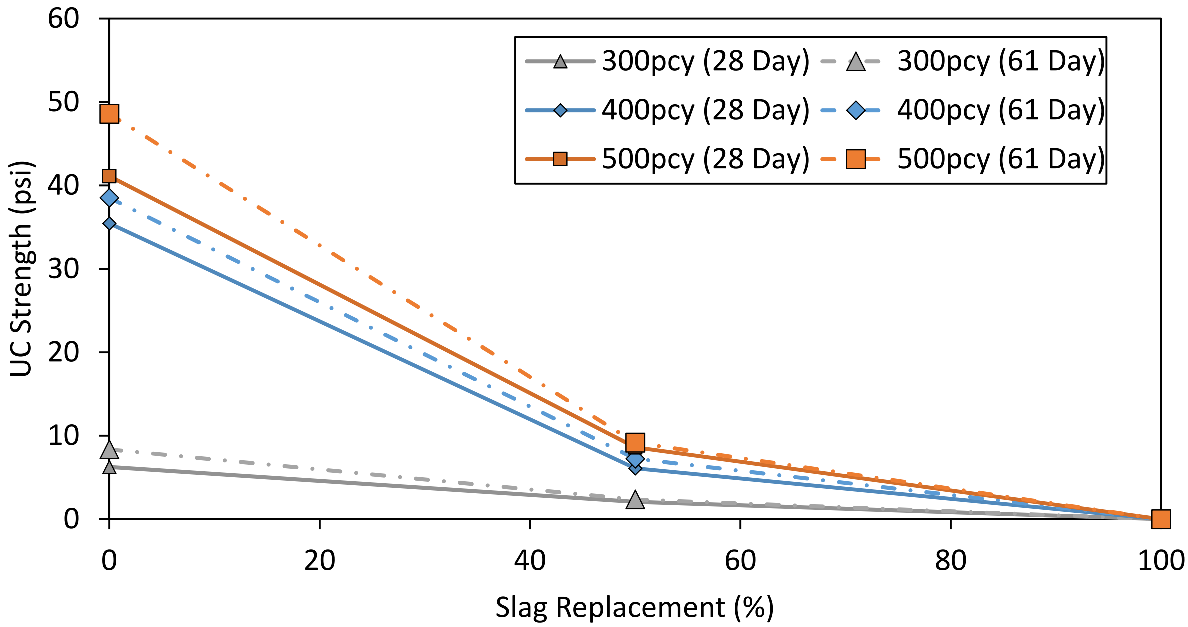


Figure 3.11 Slag replacement vs 28 day strength with O.C. = 44-66%.

This data may also be presented in terms of binder content vs strength. Figure 3.12 displays this using the raw data points, and Figure 3.13 uses the average of three raw data points.

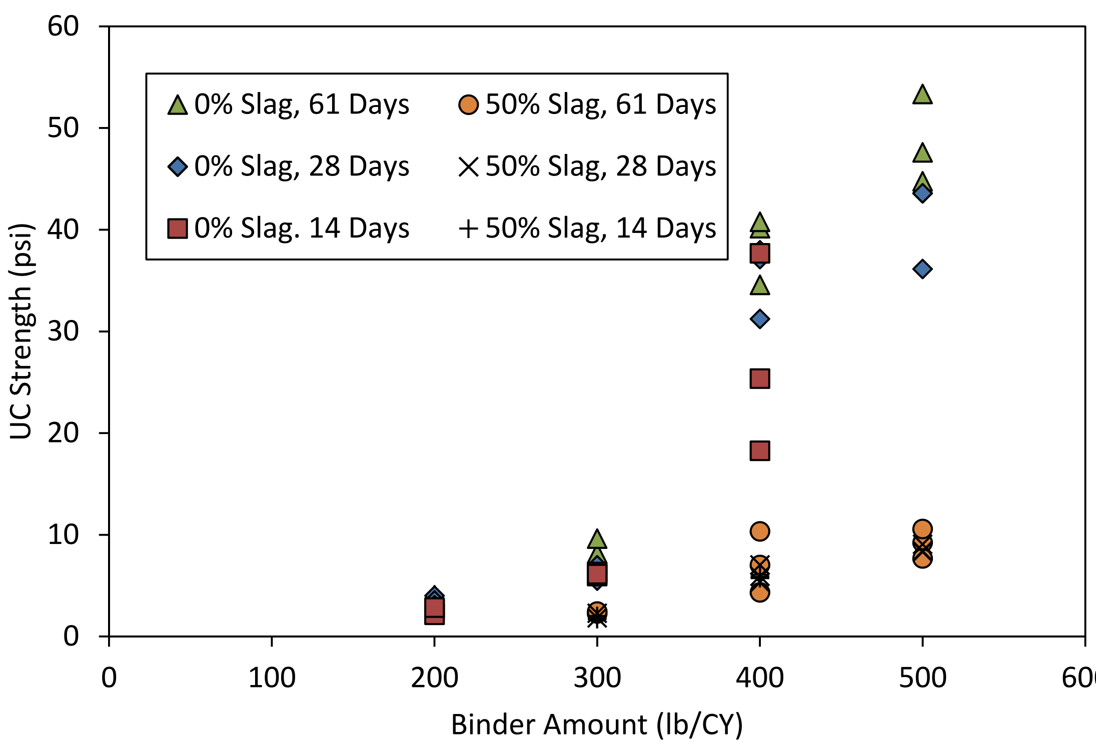


Figure 3.12 Binder amount & type vs strength in highly organic soil (raw data).

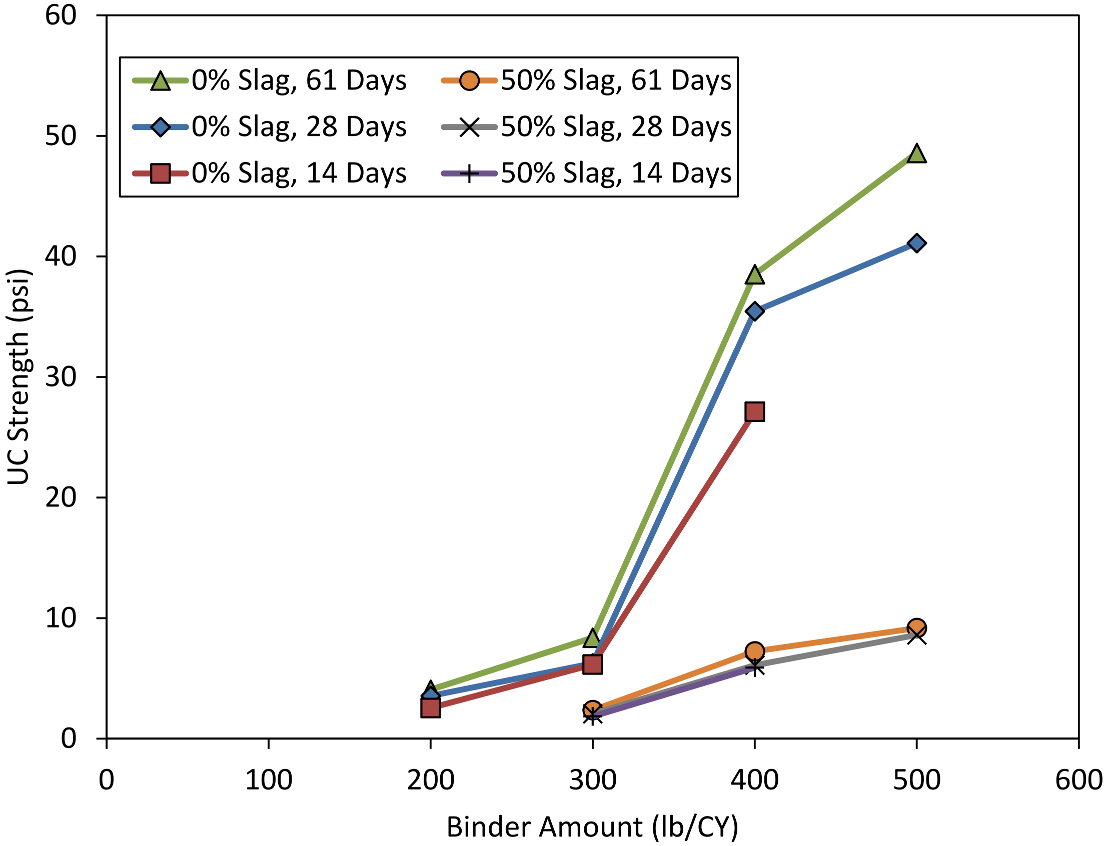


Figure 3.13 Binder amount & type vs strength in highly organic soil (average).

Many observations may be drawn from Figure 3.13. First of all, mixes with 50% slag replacement produced considerably lower strengths than their 0% counterpart. This begs the question, "how much of an effect does slag actually have on strength?" The data suggest that slag may contribute to strength in some degree, just not more than cement.

As an example, the 400pcy mix with 50% slag replacement contains 200pcy of cement. If the slag did not contribute to strength at all, it would be expected that the results of the 400pcy mix with 50% replacement would have similar results to that of the 200pcy mix with 0% slag replacement. However at 28 and 61 days of cure time, the presence of slag increased strength from 3.55psi to 6.10psi and from 4.06psi to 7.25psi, respectively. These are gains of 72% and

79%, respectively. These gains may be the product of some binding effect in the slag, or they may just purely be a product of less organic soil per unit of volume.

While adding slag to a mix in addition to a fixed amount cement increases strength, the strength was considerably higher when more cement was added instead or slag. As an example and referring to 0% slag replacement mixes, there is an 899% increase in unconfined compressive strength from 200pcy to 400pcy. Once again focusing on the 0% slag replacement mixes, qualitatively, there is very little gains in strength from 200pcy to 300pcy; however there is a considerable increase in strength from 300pcy to 400pcy. Then there is once again a smaller increase from 400pcy to 500pcy. This leaves Figure 3.13 with somewhat of an "S" shape. Considering the fact that the 500pcy samples had lower moisture contents than the 400pcy mixes, one might expect the 500pcy to be significantly stronger than the 400pcy mixes; however this is not the case. While there are gains in strength, they are not as significant as expected. This may be attributed to the cement not having proper access to enough water to fully hydrate. This information is presented quantitatively in Table 3.1 - 3.3. Table 3.2 and 3.3 contains the same data that is plotted in Figure 3.13.

Table 3.1 Increases in 28 day strength in dry mixing of highly organic soils.

| Amount of Cement | Increase in 28 Day Strength (psi) | Increase in Strength (%) |
|---|---|---|
| **200 → 300** | 2.71 | 76% |
| **300 → 400** | 29.20 | 467% |
| **400 → 500** | 5.65 | 16% |

Table 3.2 Binder amount vs strength in highly organic soil (0% slag).

| Slag Replacement | Batch | lb/CY | w/c | Moisture | % O.C. | 14 Strength (psi) | 28 Strength (psi) | 61 Strength (psi) |
|---|---|---|---|---|---|---|---|---|
| 0% | 4 | 200 | 6.90 | 362% | 66.4% | 2.55 | 3.55 | 4.06 |
| | 8 | 300 | 4.22 | 221% | 65.9% | 6.15 | 6.26 | 8.37 |
| | 9 | 400 | 3.08 | 216% | 65.9% | 27.12 | 35.46 | 38.52 |
| | 55 | 500 | 2.11 | 154% | 42.1% | N/A | 41.11 | 48.59 |

Table 3.3 Binder amount vs strength in highly organic soils (50% slag).

| Slag Replacement | Batch | lb/CY | w/c | Moisture | % O.C. | 14 Strength (psi) | 28 Strength (psi) | 61 Strength (psi) |
|---|---|---|---|---|---|---|---|---|
| 50% | 1 | 200 | 6.88 | 362% | 66.4% | N/A | N/A | N/A |
| | 2 | 300 | 4.49 | 362% | 66.4% | 1.85 | 2.07 | 2.37 |
| | 3 | 400 | 3.29 | 362% | 66.4% | 5.90 | 6.10 | 7.25 |
| | 57 | 500 | 2.09 | 154% | 42.1% | N/A | 8.61 | 9.18 |

It should be noted that in Table 3.2 and 3.3, or anywhere else within this chapter, the w/c ratio provided is considered the w/c of the entire system. In other words, it is the ratio of all of the water present in the system divided by all of the binder present within the system. This includes all of the water present in the soil before introducing any binder.

### 3.5.2 Varying Organic Content

Testing compressive strengths in soils with various organic contents proved to produce some of the most significant findings of this thesis. As expected, strength increased as organic content decreased. Fourteen day compressive strength data taken at various organic contents are shown in Figure 3.14. Similarly, the 28 day and 61-62 day compressive strength data are shown in Figure 3.15 and 3.16, respectively. In order to more easily observe any trends, Figures 3.17, 3.18, and 3.19 present the same data but exclude the 0% O.C. data points; this provides a zoomed in version of their counterpart graph. This data is also provided in a tabular form in Table 3.4. Every data point shown in Figures 3.14-3.19 and listed in Table 3.4 represents the average of 2 or 3 data points.

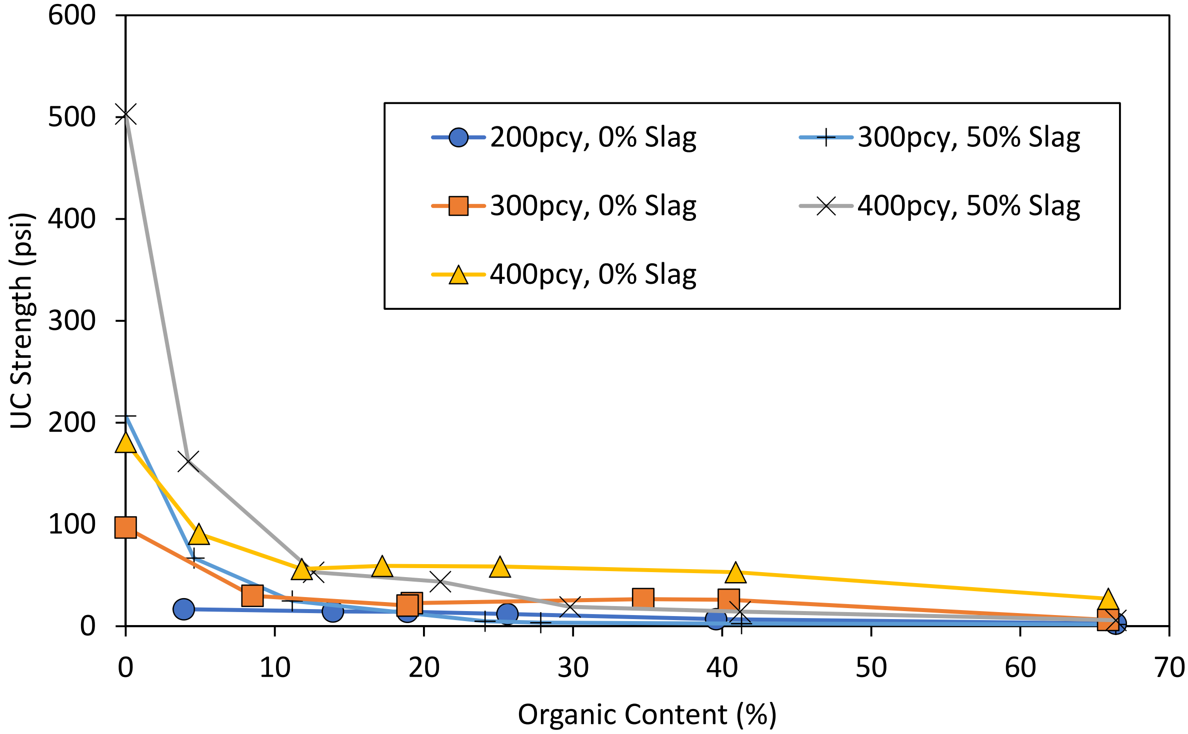


Figure 3.14 Organic content vs 14 day strength.

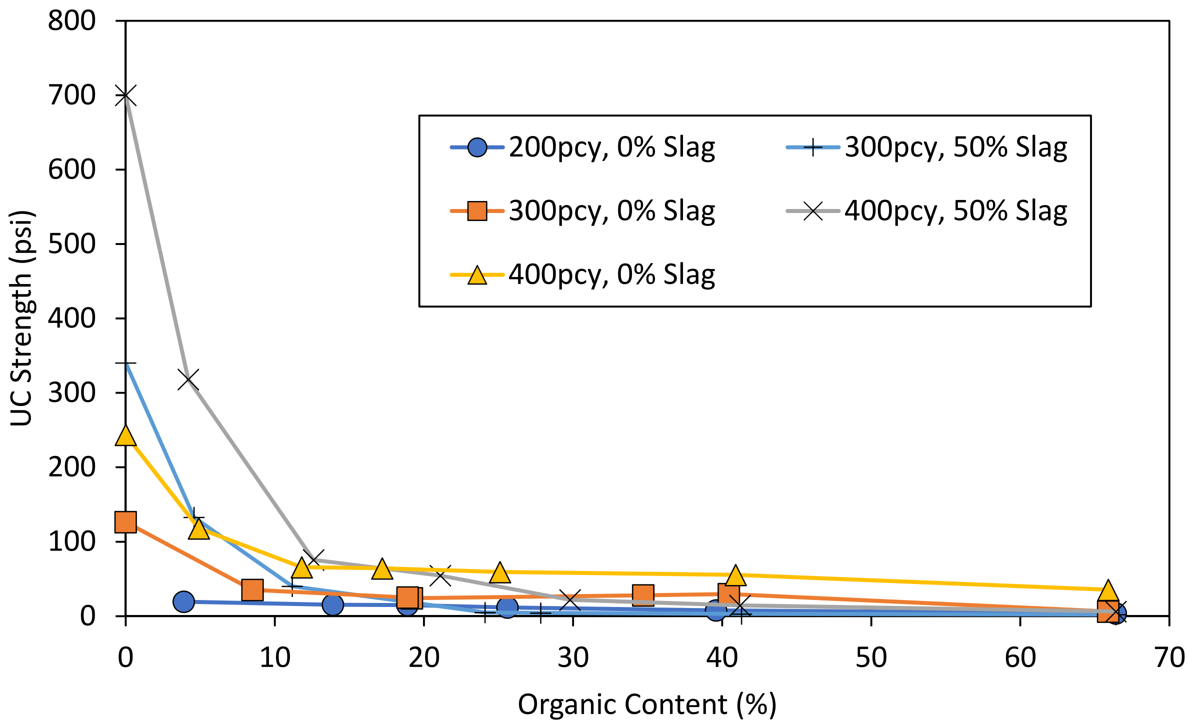


Figure 3.15 Organic content vs 28 day strength.

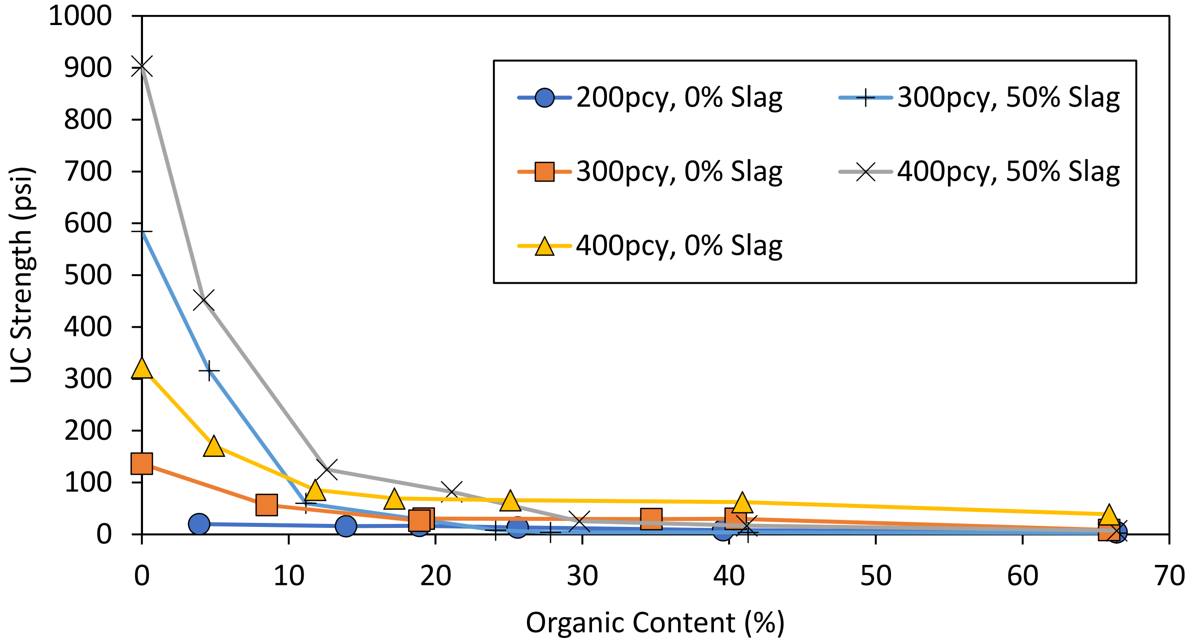


Figure 3.16 Organic content vs 61-62 day strength.

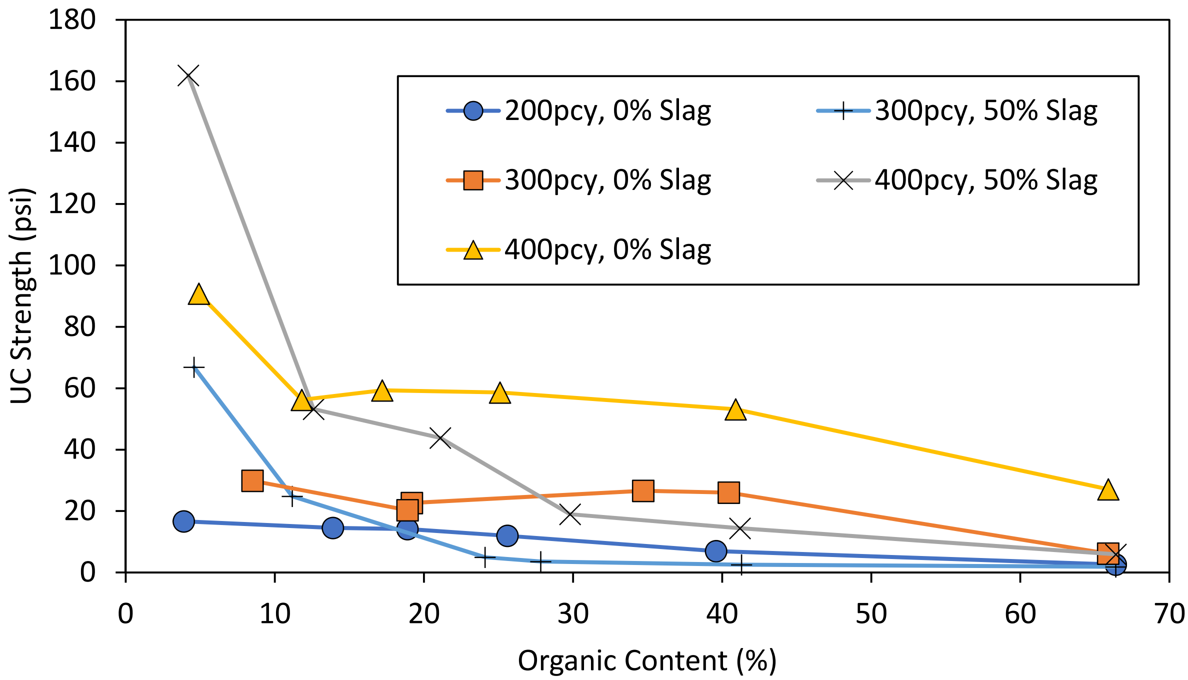


Figure 3.17 Organic content vs 14 day strength (zoom).

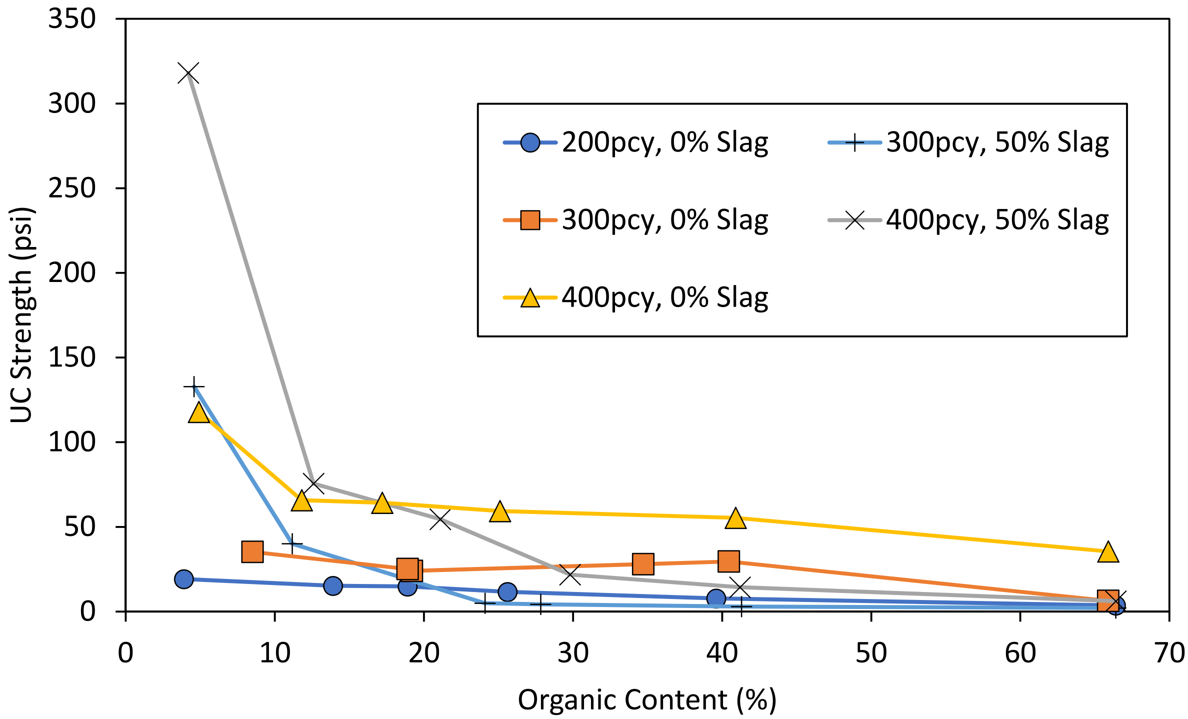


Figure 3.18 Organic content vs 28 day strength (zoom).

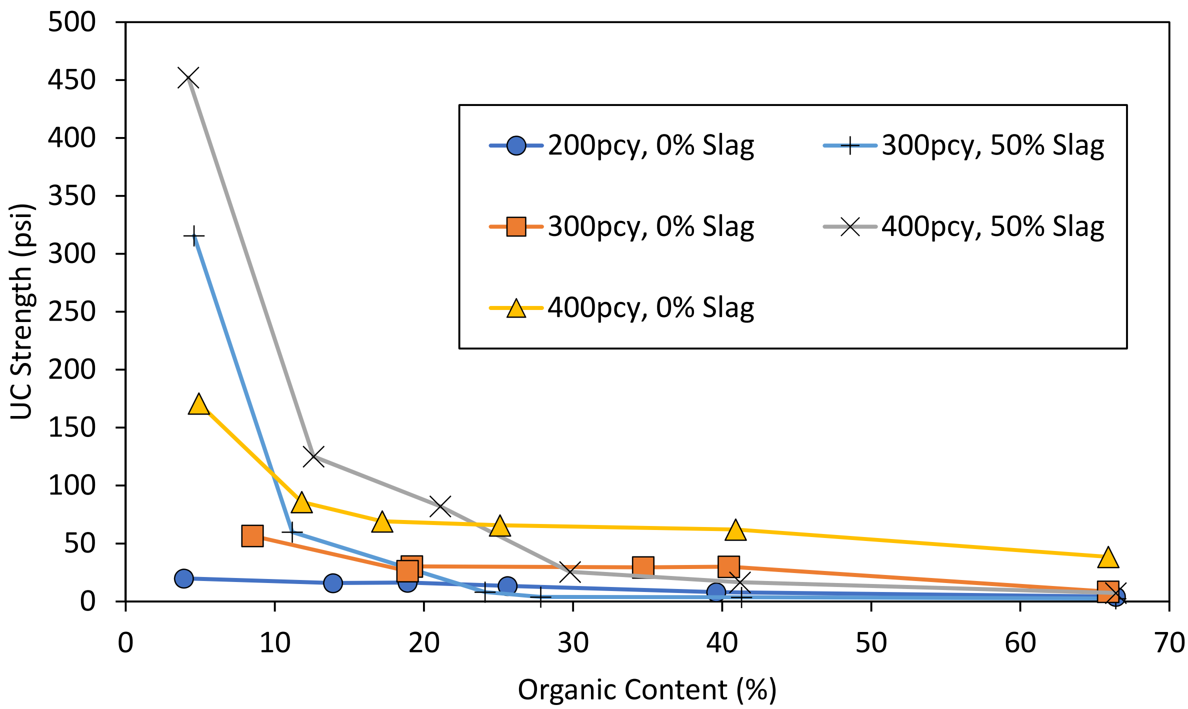


Figure 3.19 Organic content vs 61-62 day strength (zoom).

Table 3.4 Batch information and strengths at various organic contents.

| Batch | O.C. | Binder Content | Slag Replace | w/c | 14 Day Strength (psi) | 28 Day Strength (psi) | 61-62 Day Strength (psi) |
|---|---|---|---|---|---|---|---|
| **2** | 66.4% | 300 | 50% | 4.49 | 1.85 | 2.07 | 2.37 |
| **10** | 41.3% | | | 3.86 | 2.53 | 2.90 | 3.57 |
| **11** | 27.8% | | | 3.52 | 3.57 | 4.26 | 3.8 |
| **12** | 24.1% | | | 3.38 | 4.96 | 4.86 | 8.06 |
| **13** | 11.2% | | | 3.00 | 24.80 | 40.06 | 59.94 |
| **14** | 4.6% | | | 2.50 | 66.88 | 132.80 | 315.56 |
| **48** | 0.0% | | | 2.50 | 206.51 | 340.28 | 584.24 |
| **8** | 65.9% | 300 | 0% | 4.22 | 6.15 | 6.26 | 8.37 |
| **15** | 40.5% | | | 3.84 | 25.99 | 29.57 | 29.9 |
| **16** | 34.7% | | | 3.70 | 26.61 | 27.93 | 29.32 |
| **17** | 19.2% | | | 3.42 | 22.62 | 23.99 | 30.19 |
| **18** | 18.9% | | | 3.26 | 20.26 | 25.10 | 26.18 |
| **19** | 8.5% | | | 2.90 | 29.85 | 35.17 | 56.53 |
| **46** | 0.0% | | | 2.49 | 96.96 | 126.42 | 136.31 |
| **3** | 66.4% | 400 | 50% | 3.29 | 5.90 | 6.10 | 7.25 |
| **25** | 41.2% | | | 2.88 | 14.40 | 14.32 | 16.59 |
| **26** | 29.8% | | | 2.70 | 19.00 | 21.82 | 25.44 |
| **27** | 21.1% | | | 2.54 | 43.84 | 54.53 | 82.08 |
| **28** | 12.6% | | | 2.30 | 53.21 | 75.59 | 125.02 |
| **29** | 4.2% | | | 1.97 | 161.89 | 318.12 | 452.23 |
| **47** | 0.0% | | | 1.86 | 503.18 | 699.98 | 903.41 |
| **9** | 65.9% | 400 | 0% | 3.08 | 27.12 | 35.46 | 38.52 |
| **34** | 40.9% | | | 2.96 | 53.15 | 55.33 | 62.05 |
| **33** | 25.1% | | | 2.70 | 58.63 | 59.31 | 65.68 |
| **32** | 17.2% | | | 2.52 | 59.33 | 64.18 | 69.2 |
| **31** | 11.8% | | | 2.35 | 56.25 | 65.75 | 85.87 |
| **30** | 4.9% | | | 2.09 | 90.86 | 117.89 | 170.97 |
| **45** | 0.0% | | | 1.83 | 181.06 | 243.64 | 322.2 |
| **4** | 66.4% | 200 | 0% | 6.90 | 2.55 | 3.55 | 4.06 |
| **35** | 39.6% | | | 6.20 | 6.95 | 7.71 | 8.03 |
| **36** | 25.6% | | | 5.85 | 11.94 | 11.55 | 13.33 |
| **37** | 18.9% | | | 5.44 | 14.15 | 14.82 | 16.23 |
| **38** | 13.9% | | | 5.02 | 14.52 | 15.20 | 15.81 |
| **39** | 3.9% | | | 4.18 | 16.64 | 19.19 | 19.84 |

At this point, two observations may be made. The first observation is a point exist where slag replacement is beneficial. As discovered in section 3.5.1., mixes with 0% slag replacement out-performed the 50% slag replacement mixes in soils with organic contents greater than 42%. In fact Figure 3.18 suggests that in 400pcy at 28 days, slag replacement only increases strength if the organic content is less than 18%. However when cure time was increased to 61 days, 50% slag replacement out performed 0% slag replacement if the organic content was less than 25%. This point is shown where the lines for 0% slag replacement and 50% slag replacement for a given binder content intersect. Therefore as cure time increased, the benefits of slag replacement applied to a higher range of organics. This is shown in Table 3.5 and Figure 3.20. It could be concluded that at any given cure time, slag replacement was most beneficial in soils with lower organic contents, and binders made of only cement were more beneficial in soils with higher organic contents.

Table 3.5 When slag replacement is beneficial in organic soils.

| **Cure Time (Days)** | **Point Were Slag Replacement was Beneficial in 300pcy Mixes** | **Point Were Slag Replacement was Beneficial in 400pcy Mixes** |
|---|---|---|
| **14** | < 11% O.C. | < 12% O.C. |
| **28** | < 16% O.C. | < 18% O.C. |
| **61-62** | < 19% O.C. | < 25% O.C. |

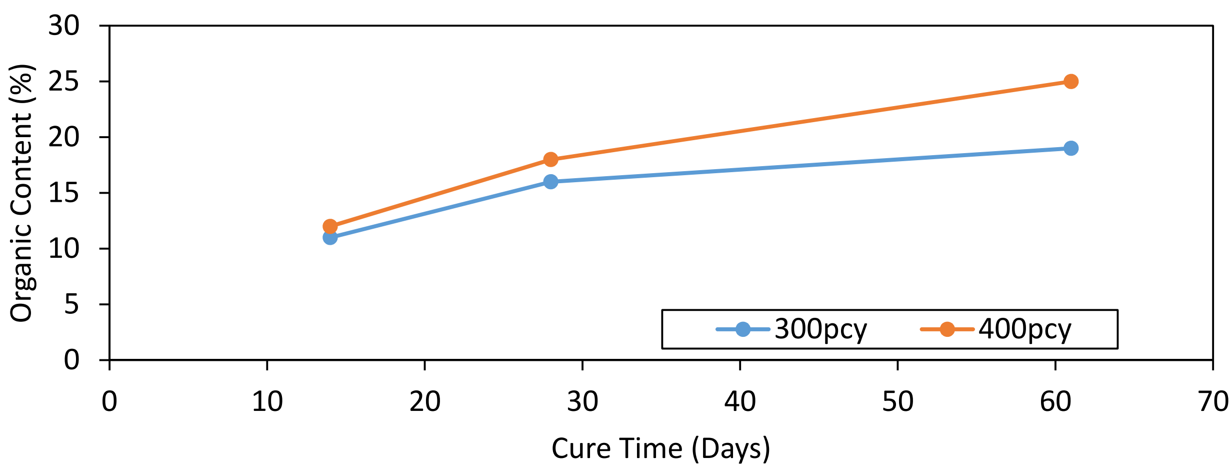


Figure 3.20 When slag replacement is beneficial in organic soils.

The strength vs time plot is shown for this series of tests in Figure 3.21. In this figure, the point where a 50% slag replacement line intersects with a 0% slag replacement line of similar O.C. reveals at what cure time slag replacement is beneficial. If the slag is helpful, it occurs later.

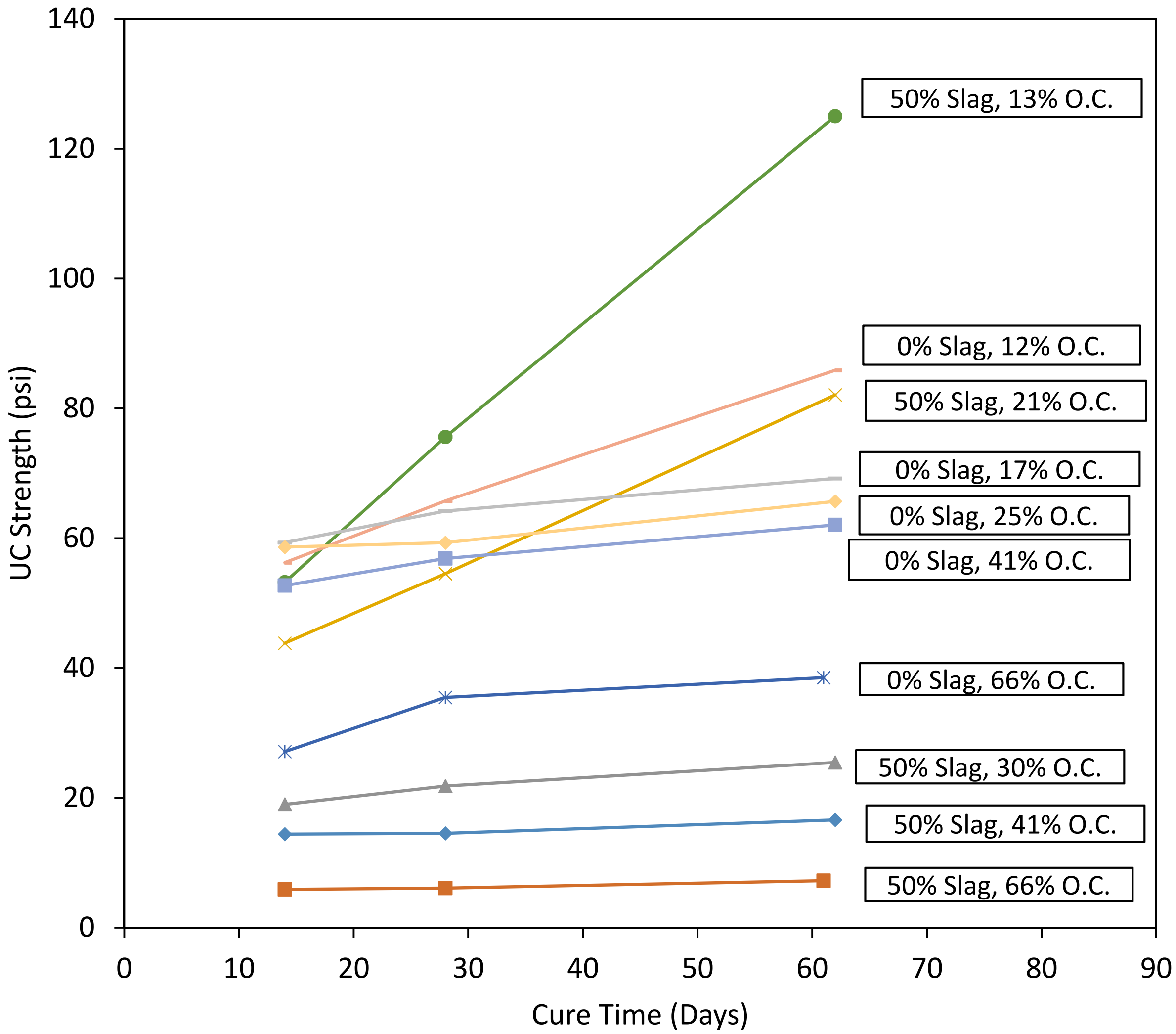


Figure 3.21 Strength vs time in 400pcy mixes.

As seen in Figure 3.21, longer cure times are needed for slag replacement to be beneficial at higher organic contents. However at organic contents over 25%, 50% slag replacement batches never had higher strengths than the 0% replacement batches. It should be noted that this is based on the longest cure time of 62 days. Additional testing at longer cure times may reveal cure times where slag replacement will be beneficial for higher organic contents.

The second observation made was that organic content is irrelevant for a particular range. This trend only appears for mixes without slag. Considering Figures 3.17, 3.18, and 3.19, there is a range where strength appears to be somewhat independent of organic content. This is seen in sections of the graphs where strength vs O.C. curves become relatively horizontal. At 61-62 days of cure time, this range is shown between 19 and 41% O.C. Strengths only change by 7.15 psi, or 11.5%, within this range for 400pcy mixes and by 0.87 psi, or 2.97%, for 300pcy mixes. Even though w/c ratios within this range vary by approximately 0.5, the data suggest this variation has little impact on strength.

### 3.5.3 Wet Mixing

Out of the six wet mixes created, only the 0% slag replacement set was deemed testable. Figure 3.22 shows the results obtained from wet mixing. Notable information about this data may be found in Table 3.6. Figure 3.23 compares these results to their dry mixing counterpart. The markers in Figure 3.22 represent each cylinder test and the lines represent an average; in Figure 3.23, both markers and lines refer to averages of two or three data points.

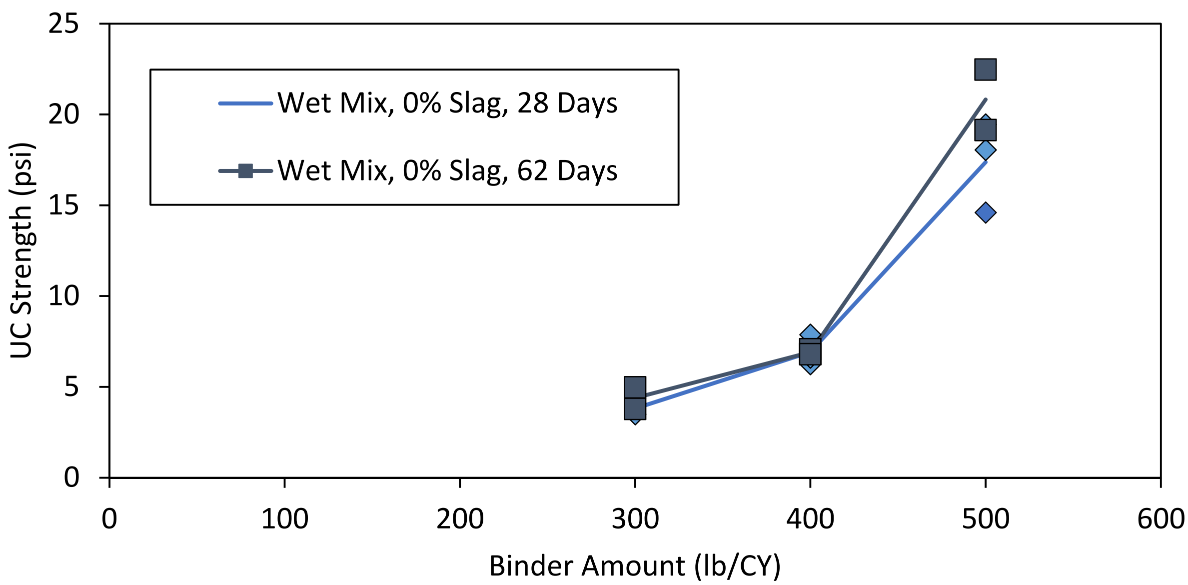


Figure 3.22 Wet mixing test results.

Table 3.6 Wet mixing results and information.

| Slag Replacement | Batch | lb/CY | w/c | Moisture | % O.C. | 28 Strength (psi) | 61 Strength (psi) |
|---|---|---|---|---|---|---|---|
| 0% | 49 | 300 | 4.23 | 154% | 43.8% | 3.81 | 4.39 |
| | 50 | 400 | 3.17 | 154% | 43.8% | 6.92 | 6.91 |
| | 51 | 500 | 2.53 | 154% | 43.8% | 17.37 | 20.82 |

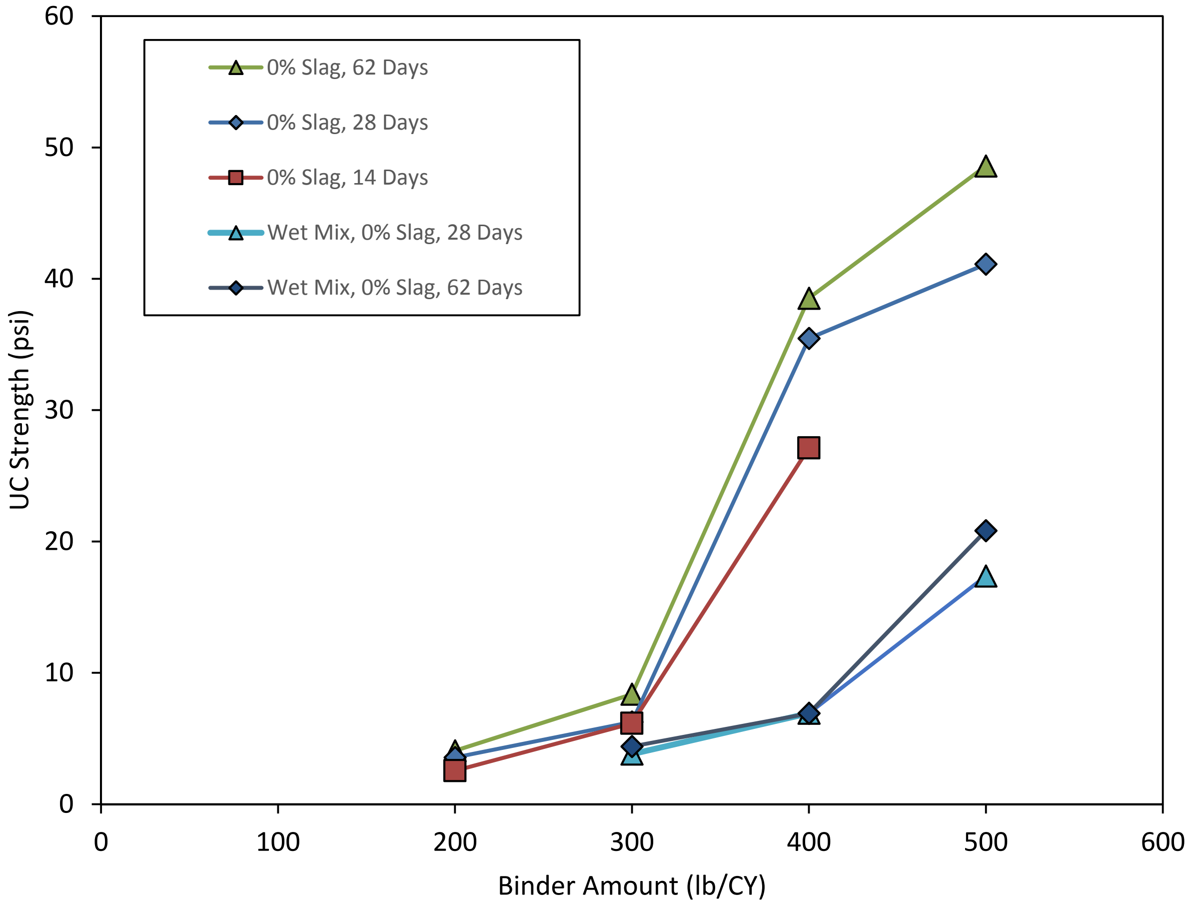


Figure 3.23 Dry mixing and wet mixing test results.

No clear explanation is available as to the poorer performance of the wet mixes relative to the dry mix counterparts. This is not supported by literature findings.

# Chapter 4: Large Scale Laboratory Testing

In order to confirm the findings in Chapter 3, 1/10th scale testing was performed using simulated field conditions where both wet and dry mixing methods were employed. Both of these methods were then compared to an untreated control of the same organic soil composition. Using a test bed divided into three sections, these tests were performed side-by-side: the outer two portions of the test bed were treated and the middle represented the control soil. After treatment, all three portions were individually loaded with water tanks. The loading took place gradually over time. Both load and displacement were monitored throughout the testing.

Wet and dry mixes were both designed to simulate a roadway subjected to 5ft of fill. This is equivalent to a design load of approximately 600psf. To closely investigate potential differences between wet and dry mixes, the same binder content was used in both treatments.

This chapter presents all of the events involved in large scale laboratory testing in chronological order. This includes the fabrication of the test bed, soil preparation, wet mixing, dry mixing, loading of the system, and the test results.

## 4.1 Fabrication of Test Bed

The test bed was designed to be 12ft long, 4ft wide, and 3ft tall and to be a structurally sound confining bed that resisted any deformations of the walls due to lateral soil pressures. The test bed was fabricated using sheet metal for the floor and walls of the bed. Additionally, I-sections were used as base supports and C-channel sections were used as wall reinforcement. This added significant stiffness to the bed. The 12ft length of the bed allowed the bed to be partitioned into three 4ft x 4ft sections; these sections featured a wet mix design, a dry mix design, and an untreated control. Figure 4.1 shows the fabrication of the bed, and Figure 4.2 shows the partitions. Figure 4.3 shows the finished bed.

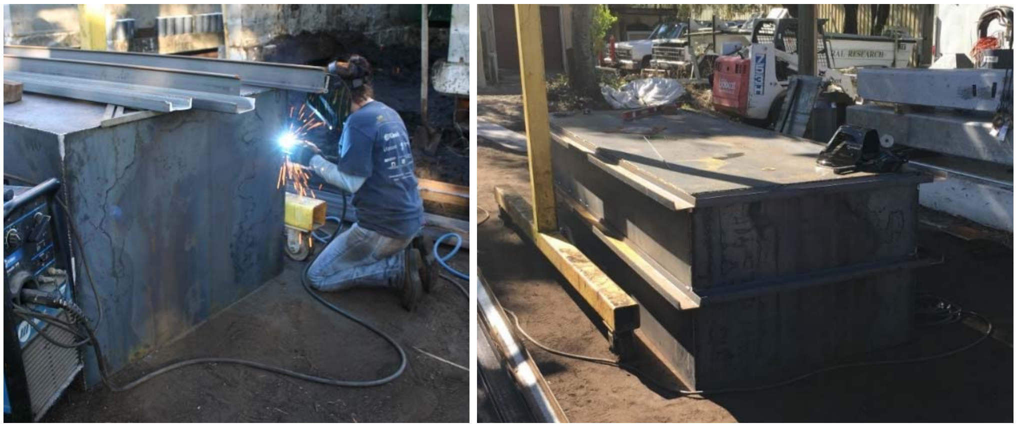

Figure 4.1 Welding of the bed (left) and the bed upside-down during fabrication (right).

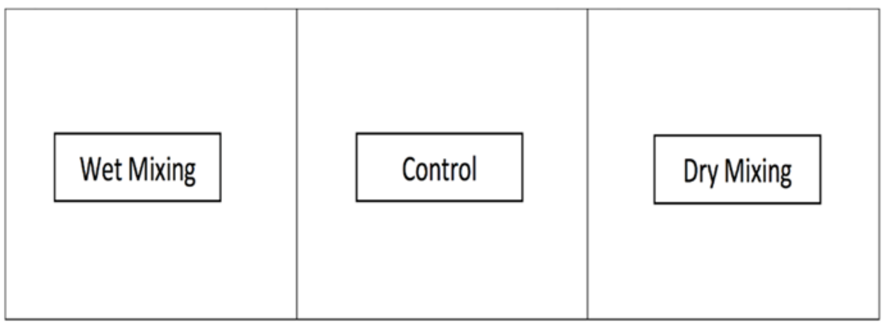


Figure 4.2 Partitions of the steel testing bed.

Figure 4.3 Testing bed with tent.

### 4.2 Organic Soil Placement and Properties

After the bed was fabricated, organic soil was delivered from SR33. This soil was evenly placed in the bed until the bet was 2ft deep. Once in the bed, the moisture content was 167% and the organic content was 40%. Figure 4.4 shows the excavation of the soil, it being delivered to the laboratory, and being placed in the bed.

Figure 4.4 Excavation and delivery of organic soil to bed.

### 4.3 Applying Small Scale Test Results to Large Scale Testing

When applying small scale laboratory data to the field, it is important to account for the increased volume due to mixing. In the laboratory, mix designs were created using a unit volume design. This was then scaled down to the appropriate volume. Within the unit volume, the amount of binder (cement) was fixed for each mix design. Enough soil was then added to fill the unit volume. Therefore a cement factor of 300pcy was exactly 300pcy ($CF_{in\text{-}place}$) in the mix because the volume was fixed. This is not as simple outside of the laboratory.

When cement or grout is added to a system in the field, the volume of the system increases. Therefore the equation that one might use to determine the amount of cement needed is no longer valid. This equation is shown below.

$$C = CF * V_s \qquad \text{(Eqn. 4.1)}$$

where,

- C = Cement needed (lbs)
- $V_s$ = Volume of soil to be treated ($ft^3$)

Realistically, the cement factor should be multiplied by the total volume of the system after treatment. The following equation (Eqn. 4.2) was derived and accounts for the final volume of the system.

$$C = \frac{V_s * CF}{1 - \frac{CF}{62.4}\left(\frac{1}{3.15} + w/c\right)} \qquad \text{(Eqn. 4.2)}$$

where,

- C = Cement needed (lbs)
- $V_s$ = Volume of soil to be treated ($ft^3$)
- CF = Cement factor ($lb/ft^3$)
- w/c = Grout water to cement ratio (lb/lb)

This equation can be used for both wet and dry mix applications. If dry mixing is used, the w/c may be taken as 0. The example below compares the results of both equations and demonstrates the error of the one mentioned first.

Given:

- $CF = 12$ lb/ft$^3$
- $V_s = 100$ (ft$^3$)
- $w/c = 0.8$

Table 4.1 Cement needed example.

| | | |
|---|---|---|
| **Equation** | $C = CF * V_s$ (Eqn. 4.1) | $C = \frac{V_s * CF}{1 - \frac{CF}{62.4}\left(\frac{1}{3.15} + w/c\right)}$ (Eqn 4.2) |
| **Cement Needed** | $C = 12 * 100 = 1200\ lbs$ | $C = \frac{100 * 12}{1 - \frac{12}{62.4}\left(\frac{1}{3.15} + 0.8\right)} = 1528.5\ lbs$ |
| **Volume Added** | $V_{Grout} = \frac{1200}{62.4 * 3.15} + \frac{1200 * 0.8}{62.4}$<br>$V_{Grout} = 21.5\ ft^3$ | $V_{Grout} = \frac{1528.5}{62.4 * 3.15} + \frac{1528.5 * 0.8}{62.4}$<br>$V = 27.37\ ft^3$ |
| **System Volume** | $V = V_s + V_{Grout} = 121.5\ ft^3$ | $V = V_s + V_{Grout} = 127.37\ ft^3$ |
| **Check** | $CF = \frac{Cement}{Total\ Volume} = \frac{1200}{121.5} = 9.88\frac{lb}{ft^3}$ | $CF = \frac{Cement}{Total\ Volume} = \frac{1528.5}{127.37} = 12\frac{lb}{ft^3}$ |

As shown above, it is important to account for the increased volume of the system.

### 4.4 Wet Mixing Concept and Equipment Testing

In wet soil mixing, it is typical to create columns of mixed soil rather than treating the entire volume. This is known as area replacement. This method was found to be practical for large scale laboratory testing. This section explains the mix design to be used, the concept for the mixer, and the testing of the concept.

#### 4.4.1 Mix Design

Using an area replacement ratio of 20%, a system strength of 600psf (5ft embankment) would require a column strength of 3000psf or 20.83psi. The highest strength tested with wet mixing obtained was 17.37psi using 500pcy of cement with O.C. = 40%. Both the binder content and w/c ratio data was extrapolated to find the necessary binder content. As the soil to be mixed was similar to the lab soil, lab data was directly applicable to selecting binder content. Figure 4.5 shows the extrapolated data.

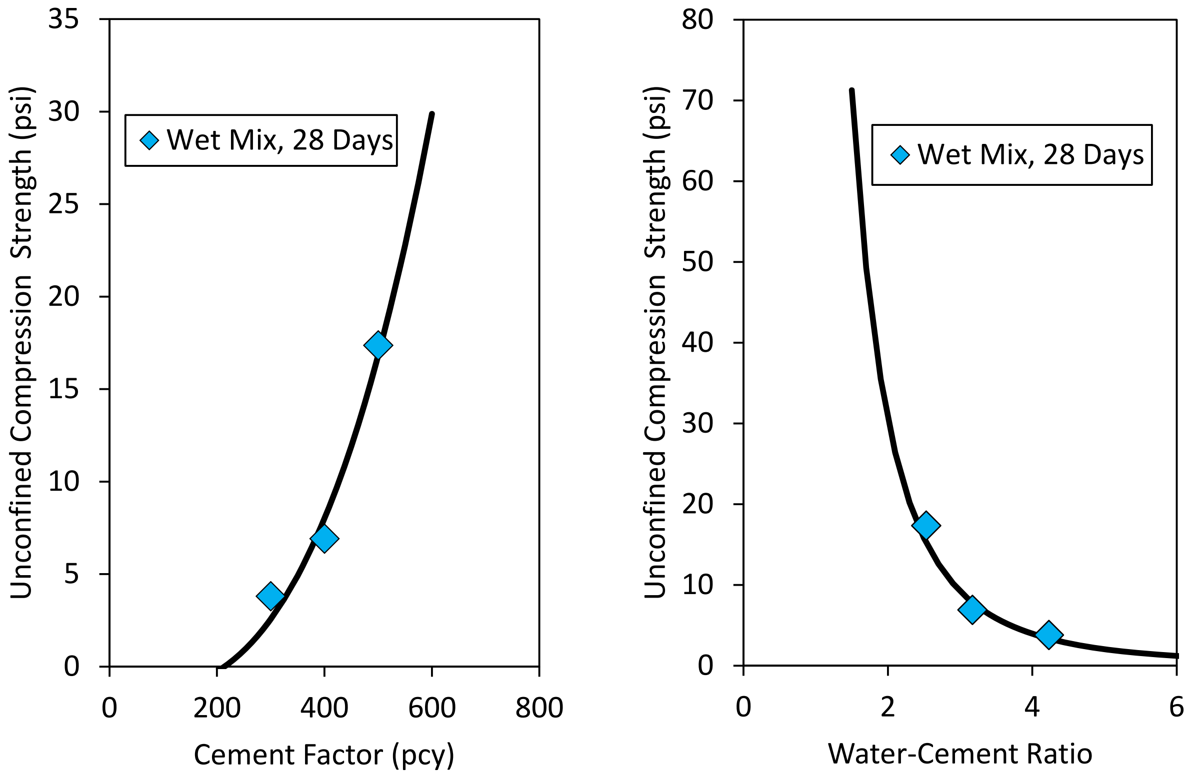


Figure 4.5 Extrapolated wet mixing data for a grout w/c ratio of 0.8.

Using Figure 4.5, the cement factor curve suggested 535pcy of cement was needed. However, using an assumed moisture content of 200%, the w/c ratio relationship predicted a cement factor of 590pcy would be needed. This translates into about 13lbs of 0.8 w/c grout per 4.25in diameter, 24in deep column.

### 4.4.2 Mixer Concept and Final Design

In order to simulate field mixing practices, a mixing machine was designed to follow the conceptual diagram in Figure 4.6. The machine concept involved an auger with a hollow core, through which the 0.8 w/c grout could be pumped while being spun/mixed with an engine attachment. Before drilling, a fixed volume of grout was mixed externally and placed in the pressure pot that was connected via grout hoses to the auger swivel head. As the drilling occurred, pressurized air would force the grout to flow out of the pressure pot, through the hoses, into the hollow core of the auger and discharged into the untreated soil as it spun. Both the engine and the pressure pot were suspended from crane hoists that were capable of translating in three dimensions to accommodate vertical and spatial positioning.

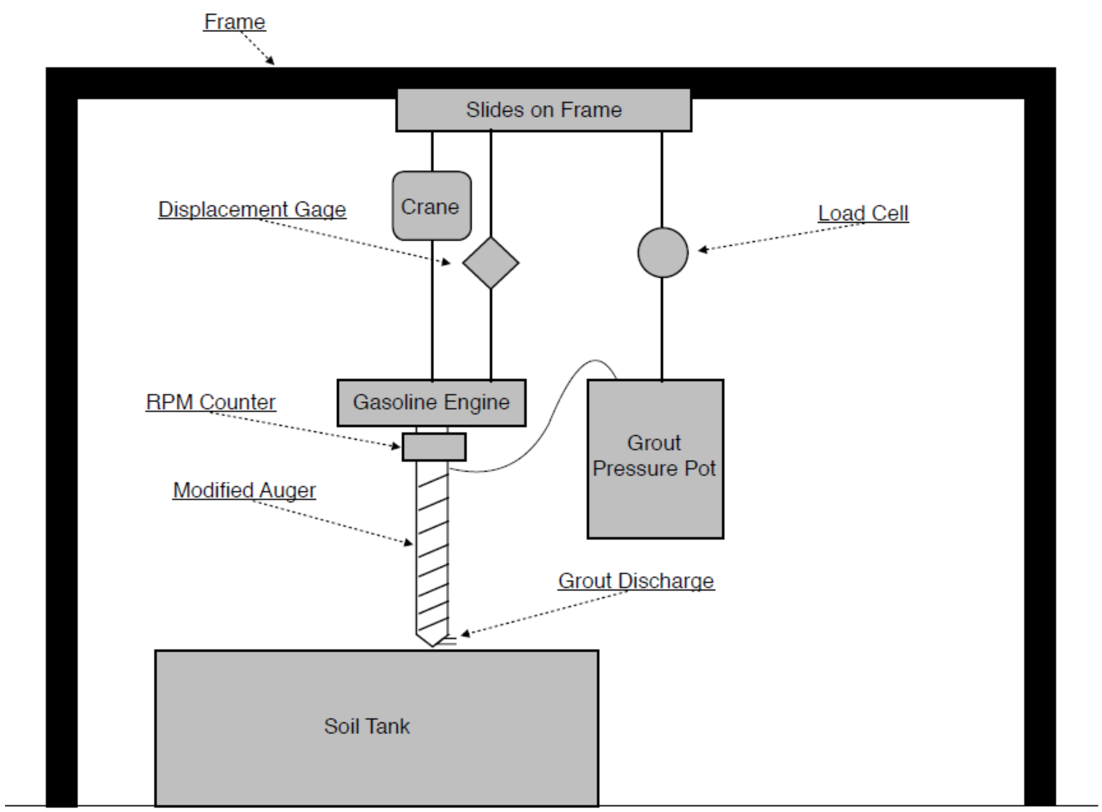


Figure 4.6 Wet mixing machine concept.

The mixing machine equipment consisted of a 2.75ft long, 4in diameter auger with a hollow core, attached to a 5hp two man hole digger, henceforth called the mixer. The auger was modified such that every ¼ turn of the auger flights were removed and a ¼ in. diameter hole was drilled near base to allow for grout discharge. By removing half of the flight area the soil would be mixed and not lifted/mined from the bed. Figure 4.7 shows the modified auger.

Figure 4.7 Modified auger.

The mixer was suspended from a manual chain hoist that hung from a geared trolley attached to the frame. The manual chain hoist allowed for vertical translation of the mixer while the geared trolley allowed for horizontal translation of the mixer. Attached to the geared trolley was a wheeled electric hoist, also situated on the frame that allowed for both the horizontal and vertical translation of the grout pressure pot.

The mixer was instrumented with a string line vertical displacement transducer and an actuating magnetic switch allowing for the monitoring of the vertical translation of the mixer and rotations of the auger (Figure 4.8). Similarly, the volume of grout pumped was monitored by suspending the grout pressure pot from a load cell. The load cell measured the weight of the pressure pot, and using the measured density of the grout, the load measurement was converted to grout volume. The final design also included a flowmeter as a backup for measuring the amount of grout pumped. The actual mixing machine can be seen in Figure 4.9.


Figure 4.8 Magnetic rotation counter.

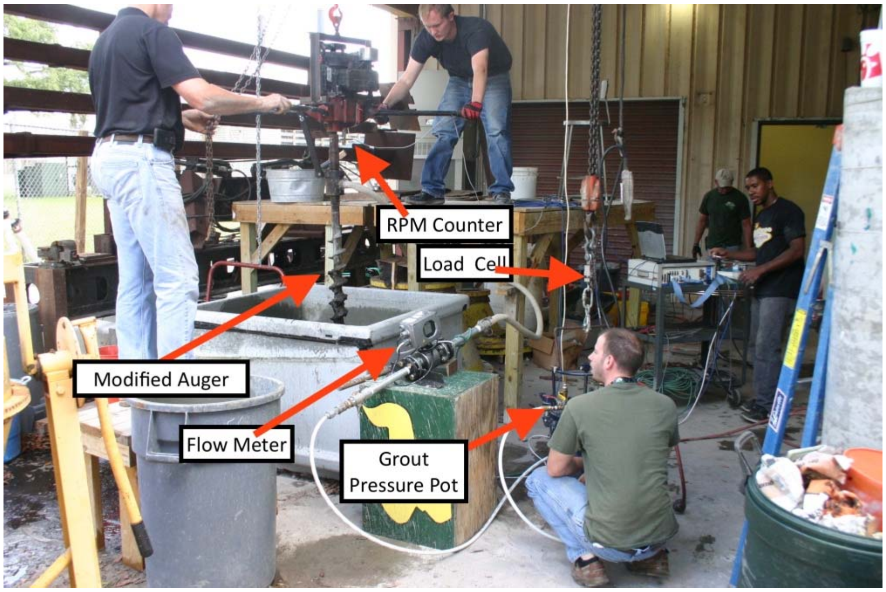

Figure 4.9 Wet mixing system.

### 4.4.3 Calibration of the Wet Mixing System

Before mixing, it was important to measure the relationship between grout pressure and flow rate. A calibration curve was obtained by measuring the weight loss of the pressure pot at various pressures. The weight loss was then converted into volume. A water - cement ratio of 0.8 was chosen for the grout. Figure 4.10 below shows the calibration test setup overview.

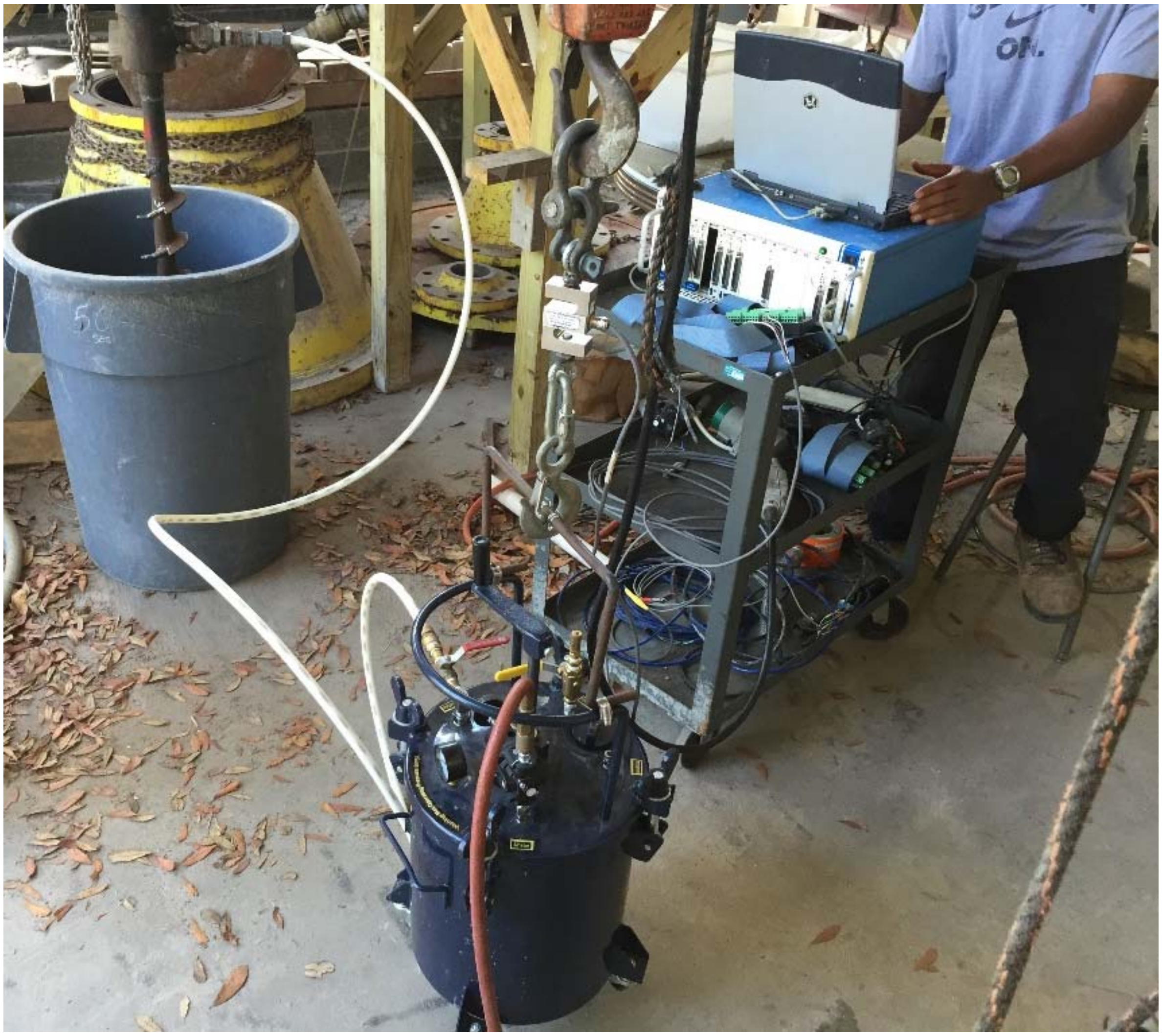


Figure 4.10 Grout calibration setup.

For calibration testing, the modified auger was placed in an open barrel (Figure 4.11). Note that care was taken to ensure that the bottom of the auger was never submerged in grout. This allows grout to flow through the system with no soil resistance. However it was expected that once the auger was in the soil, there would be some level of back pressure. Due to the loose nature of organic soils, it was also expected that this back pressure would be minimal. Therefore the results from this test should provide a reasonable prediction for grout flowrates and the required grout pot pressure. While a grout flow meter was also used, these calibrations confirmed the capability of the grout delivery system over a wide range of flow rates.

Figure 4.11 Modified auger in test barrel.

Flow rates were measured at five different grout pressures. The weight of the pressure pot was monitored electronically while the grout pressure was manually read. Figure 4.12 shows the analog pressure gauge.

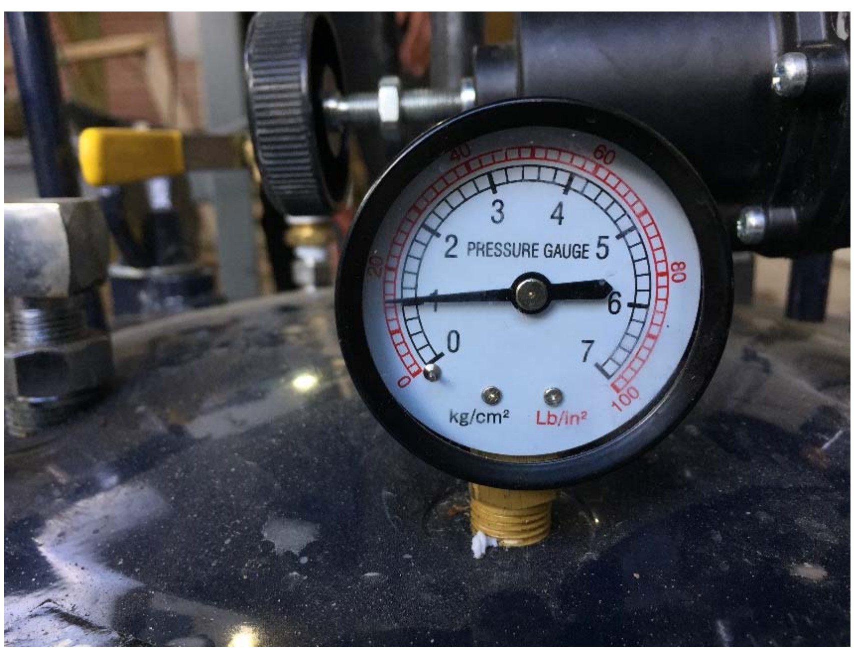


Figure 4.12 Analog pressure gauge (15 psi).

The data collected is presented in Figure 4.13. The slope of each line in Figure 4.13 represents the flowrate at each of the five grout pressures. The flowrate was then plotted as a function of grout pressure. This became the calibration curve. Figure 4.13 shows the calibration curve in terms of gallons per second, and potentially more helpful, Figure 4.15 is the same calibration curve but in terms of gallons per minute.

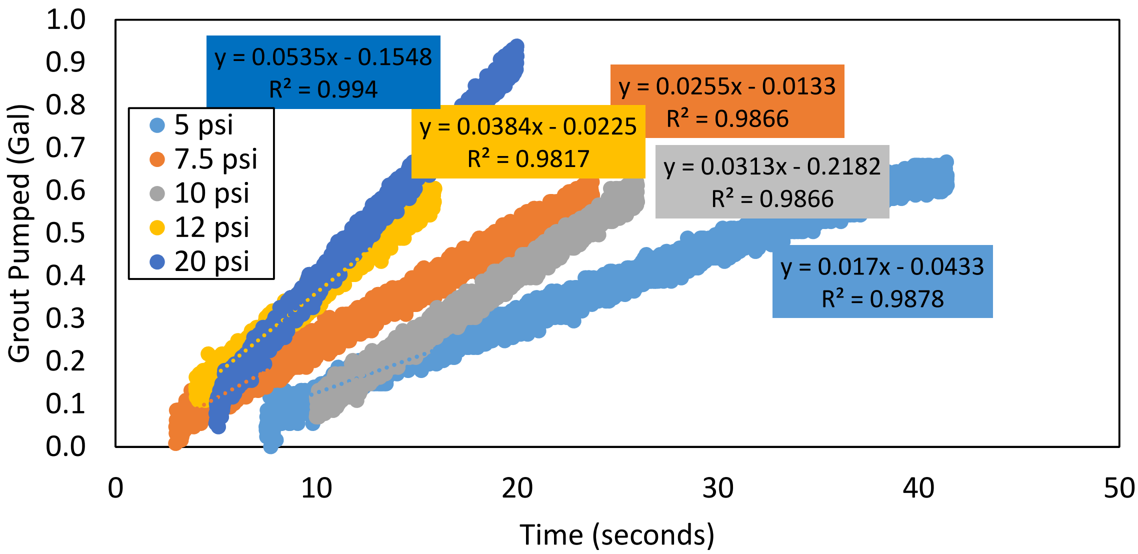


Figure 4.13 Grout volume pumped vs time.

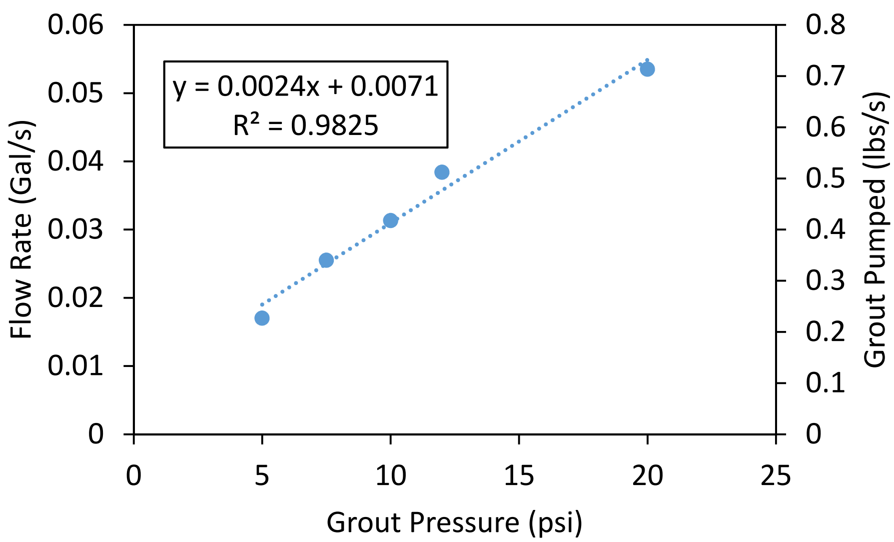


Figure 4.14 Calibration curve in gallons per second.

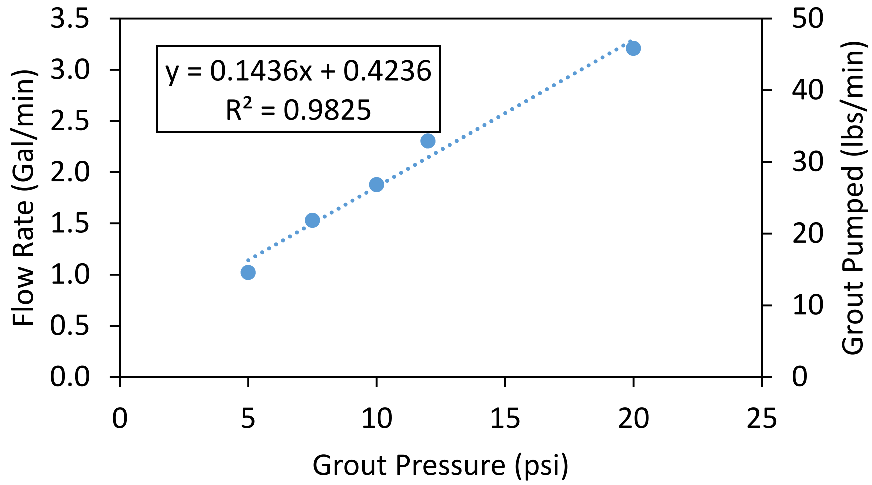


Figure 4.15 Calibration curve in gallons per minute.

These results proved to be linear as predicted. It should be noted that these calibration curves are only valid for grout pressures within the range tested as the linear trend line has a y intercept not equal to 0.

### 4.4.4 Preliminary Equipment Tests

Before being used on the large steel bed, the wet mixing system was tested on soil in a separate container filled with the same soil to the same depth (Figure 4.9). Figure 4.16 shows the mixing of a test column.

When running the system, grout was monitored in terms of weight. 16lbs of 0.8 w/c grout was chosen as the target amount of grout to place in a column. This consisted of 8.9lbs of cement and 7.1lbs of water per column. Additionally, a flow rate of 1gpm was used. 8.9lbs of cement in a final column volume of 0.36ft$^3$ generates a cement factor of 674pcy. This was 14% more than the 590pcy previous prescribed, but proved to be more achievable with the rates of penetration and extraction that could be performed.

Figure 4.16 Test column being wet mixed (left); close up (right).

After a test column was created, a threaded rod was placed in the middle of the column so that it could later be removed. Figure 4.17 shows the column being removed after 28 days. Figure 4.18 shows a closer view of the column before and after it was rinsed off.

Figure 4.17 Wet mixed column being removed from soil after 28 days.

Figure 4.18 Wet mixed column (left) and after washed (right).

Figures 4.17 and 4.18 demonstrated that this wet mixing system could create the cementitious columns that were needed and therefore was acceptable for the large scale laboratory mixing bed. The measured diameter of the column was 4.25in.

**4.5 Dry Mixing Concept and Equipment Testing**

To stay consistent with the column approach, the first dry mixing concept was to mix dry powder cement into the soil. However the dry powder cannot be pumped in the same manner that grout was for the wet mixing. Therefore dry powder was inserted into a PVC pipe. This pipe had a cap at the bottom that could be removed once the pipe was in the proper location. The pipe was designed to hold the same amount of cement per column as the wet mix, 8.9lbs. Once the cap was removed, the pipe was carefully removed. This left the dry powder cement vertically distributed within the target area. The modified auger used in wet mixing was then placed to the side of the cement column. It was then vertically raised and lowered to mix the cement with the soil. This process is shown conceptually in Figure 4.19. This method was tested several times in the smaller prototyping bed. Unfortunately each time a dry mixed column was created, it showed zero evidence of strength. Therefore a different approach was developed. Figure 4.20 shows this method being tested.

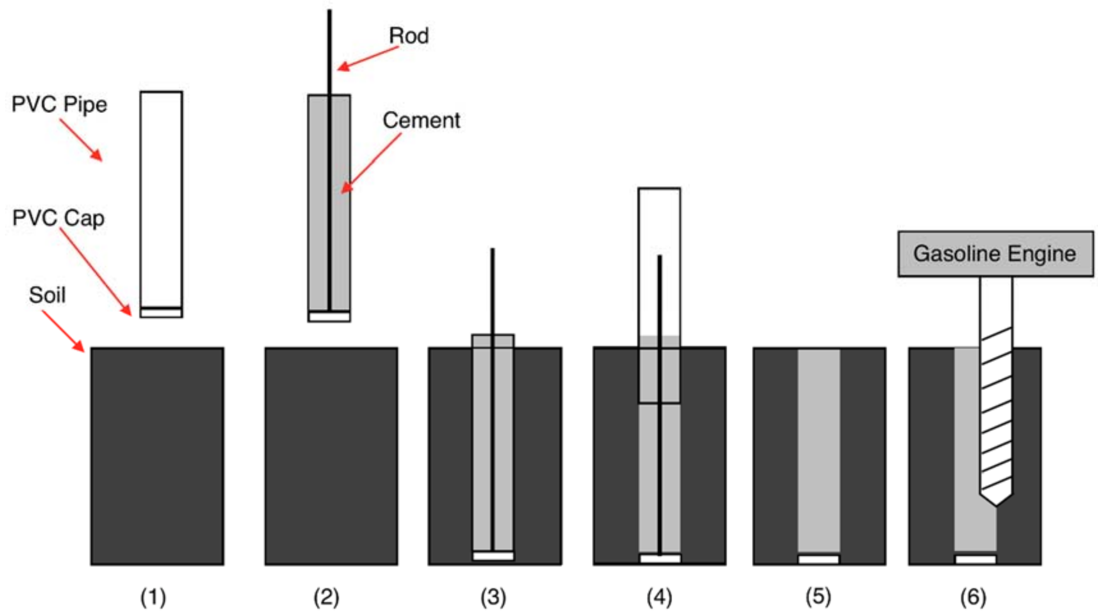


Figure 4.19 Stages of the dry mixing concept.

Figure 4.20 Testing of dry mixing concept.

Mass dry mixing was the second concept and was used in the large scale laboratory mixing bed. The amount of cement needed was simply placed on top of the soil in the form of a dry powder. This was then mixed using a tiller (see section 4.6)

## 4.6 Wet Mix Column Installation

Using an area replacement ratio of 20%, a hexagonal column pattern, and an effective column diameter of 4.25in, the center to center spacing of columns was 9in. The wet mixing partition of the steel bed used flag markers to designate column locations. Figure 4.21 shows the column layout and the numbering. Since the loading area (discussed in section 4.7) consisted of a 2ft diameter bearing plate, the two “rings” of columns shown in Figure 4.21 were chosen to provide an adequate loading area. This pattern consisted of 19 columns. The loaded areas would only be the center 7 columns while the more peripheral columns were intended to provide later confinement. The mix design called for 16lbs of grout in each column. Figure 4.22 provides a summary of the actual grout placed in each column. It should be noted that these amounts do not include the grout discharged on the surface of the soil. Figures 4.23 and 4.24 provide an overview of the mixing and a close up view, respectively.

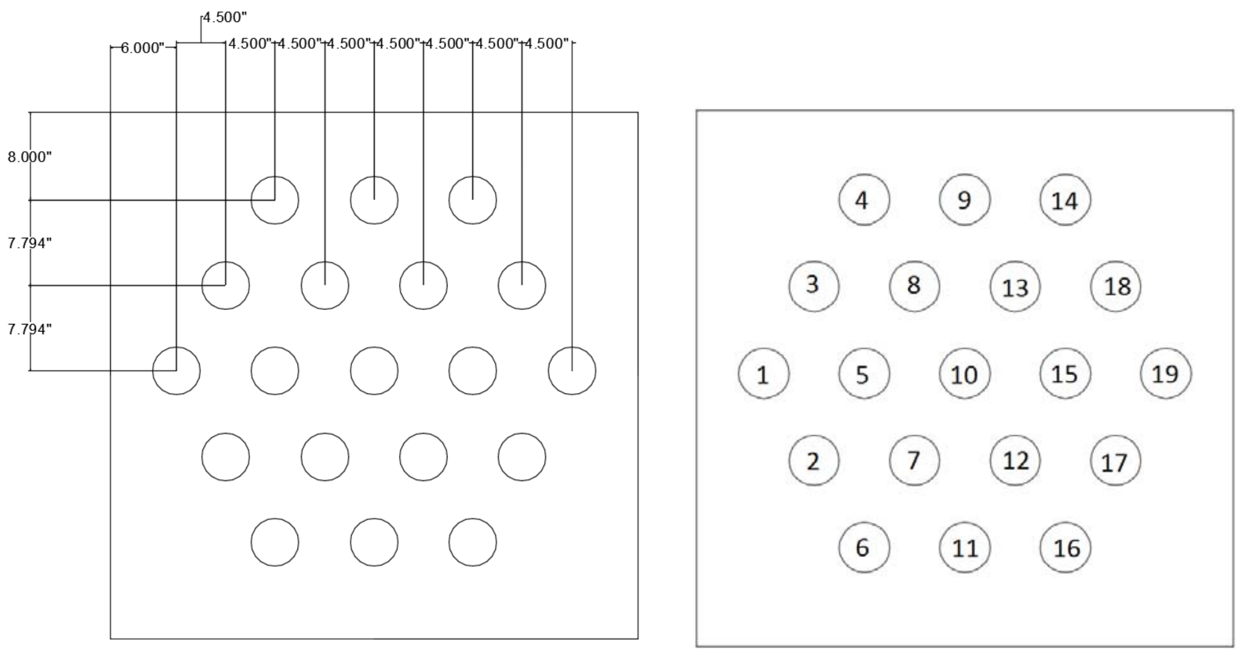


Figure 4.21 Hexagonal column pattern and numbering.

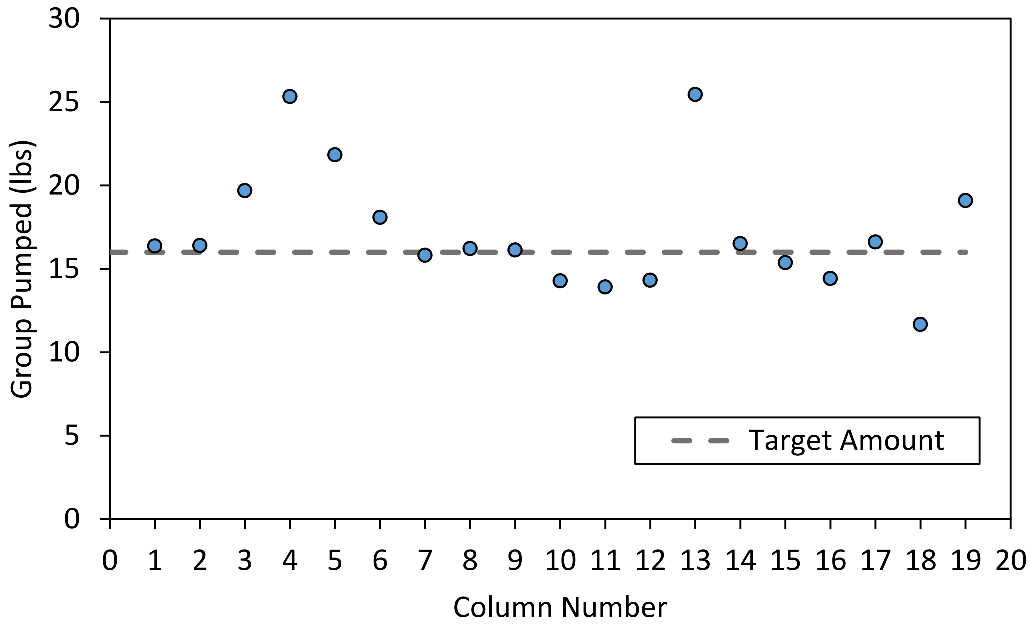


Figure 4.22 Grout injected into each column.

Figure 4.23 Wet mixing in steel bed overview.

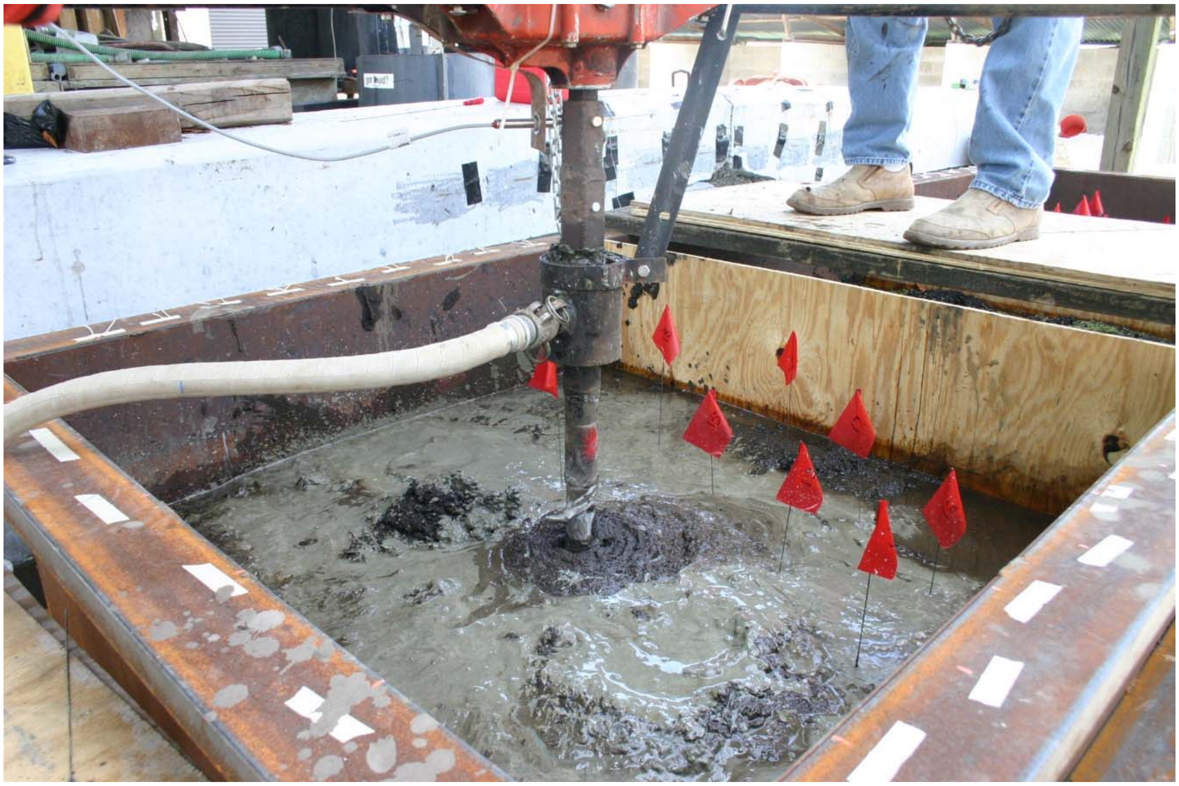

Figure 4.24 Close up of wet mixing.

**4.7 Dry Mixing**

The dry mixing method added dry powder cement directly on the surface of the soil. The soil was then mixed in place. In order to closely compare wet and dry mixing methods, the same global cement factor used in wet mixing was used for the dry. The wet mixing method used a total of 168.9lbs of cement for a total treatment volume of 19.6 ft$^3$. Note that this treatment volume is not the volume of the tank partition, but rather the volume of the soil affected by the treatment plus the volume of the grout added. See the calculation below.

$$Treatment\ Area = \frac{Area\ of\ Columns}{\%\ Replacement} = \frac{19 * 12.57\ in^2}{20\%} = 1193.8\ in^2$$

$$Treatment\ Volume = Treatment\ Area * Soil\ Depth + Volume\ of\ Grout$$

$$Treatment\ Volume = 1193.8\ in^2 * 24\ in^2 + 19\ Columns * \frac{275.1\ in^3}{Column} = 33877.6\ in^3$$

$$Treatment\ Volume = 19.6\ ft^3$$

This equated to a cement factor of 8.6pcf or 232.6 pcy. Since the entire dry mixing partition of the tank will be treated, Equation 4.2 was used to determine the amount of cement needed.

$$C = \frac{V_s * CF}{1 - \frac{CF}{62.4}\left(\frac{1}{3.15} + w/c\right)}$$

$$C = \frac{(4\,ft * 4\,ft * 2\,ft) * 8.6\,lb/ft^3}{1 - \frac{8.6\,lb/ft^3}{62.4}\left(\frac{1}{3.15} + 0\right)} = 288\,lbs$$

A tiller, shown in Figure 4.25, was used for pre-mixing the soil and mixing the cement with the soil. Pre-mixing was performed to break up the soil without adding any binder. This was not only to loosen the soil but also to test the mixing capabilities of the tiller.

Figure 4.25 Dry mixing tiller.

During the pre-mixing stage, the tiller had trouble mixing once below the surface. At all times the soil condition was maintained in a fully saturated state whereby captured rainwater was used to fill any water that was lost to evaporation (Figure 4.26). Additionally, two smaller mixing paddles, used vertically, assisted in breaking up the soil (Figure 4.27).

Figure 4.26 Rainwater added to maintain saturation condition.

Figure 4.27 Two mixing paddles breaking up soil.

Rainwater was used to simulate field conditions and to avoid any chemical issues that would arise from using tap water. Additionally, the two outer blades of the mixing tiller assembly were removed to increase the depth to which the tiller could operate. After modifications, the tiller performed far better under the surface of the soil. Once the entire dry mixing portion of the bed could be tilled, the top was leveled. This is shown in Figure 2.28.

Figure 4.28 Tiller in soil prior to cement introduction.

After leveling, moisture tins were taken and cement was introduced. The entire weight of cement was uniformly added to the surface of the soil, then was leveled to help consistency in mixing (Figure 4.29).

Figure 4.29 Introducing dry cement to soil.

The addition of dry powder cement reduced workability, which required more mixing time using both the tiller and mixing paddles. Figure 4.31 shows the progression of mixing with the picture on the right displaying the soil smoothed out at the end of treatment.

Figure 4.30 Dry mixing progression, part 1 of 2.

Figure 4.31 Dry mixing progression, part 2 of 2.

**4.8 Loading**

In order to observe the effects of long term loading, the loading system was designed to gradually load the soil over time. Loading took place after the treated soils gained sufficient strength Water filled tanks were chosen as the load source because it was simple to gradually change and monitor. The water was stored in 300 gallon, 3ft diameter plastic tanks. Beneath the water tanks were 2ft diameter steel bearing plates. The ratio between the diameter of the water tank and bearing plate allowed the soil to be subjected to greater pressure with less height of water, 140psf / ft of water. The three tanks are shown below in Figure 4.32.

Figure 4.32 Water tanks placed on top of soil.

A steel frame of angle sections was constructed on top of the bed to keep the water tanks vertically aligned. Vertical movement of the water tanks was permitted but translation or tipping was restricted. A second frame was used to mount instrumentation.

A small amount of bedding sand was placed directly on the soil with the bearing plate on top of the sand. The sand helped to seat the plate and more uniformly apply the load. Due to displacements that would occur once loading began, the water tanks were not set directly on the bearing plate, but rather supported 6in above the bearing plate using struts welded to the plates. An intermediate layer of plywood was used to minimize local stress from the struts directly below while supporting the water tanks. This is shown in Figures 4.33 and 4.34.

Figure 4.33 Bearing plate assembly on top of sand (wet mix in background with tank in place, control in middle, and dry mix in foreground).

Figure 4.34 Bearing plate assembly with plywood.

An additional frame spanned the entire tank on which string line transducers were mounted to continuously monitor displacements using a field data logger. Figure 4.35 shows a string line transducer connected to the top of a water tank.

Figure 4.35 String line transducer mounted above water tank.

Using weight to volume relationships of water, the diameter of the tanks, and the diameter of the bearing plate, the water height within the tank was converted to pressure. As seen in Figure 4.32, the marks on the side of the tank measure pressure applied to the soil. The water levels were checked daily to ensure that there were no changes in load. Due to the tanks being capped, the only changes in load occurred when the load was intentionally raised to the next loading step. Each loading step was 50psf. ASTM D1143 criteria for increasing to the next load step was used whereby the displacement per hour had to be less than 0.01in/hr.

Displacement data collected by the string line transducers was remotely sent to an office computer for analysis. In addition to the computer collected data, daily survey measurements were manually taken as backup.

### 4.9 Results

Overall the two treated tanks supported the design load of 600psf and as expected far outperformed the control soil. The schedule of loading is shown in Figure 4.36. During the beginning of the loading process, the soil displacement would be low enough to perform multiple steps in one day. Note that in Figure 4.36, day 1 represents the first day that load was applied. Figure 4.37 shows the displacements of the soil over time. Note that the wet mixed and control soils began loading on the same day and the dry mixed soil began loading a few days later. Figure 4.38 goes on to show applied pressure vs displacement.

In these figures, the string lines collected the data for both wet mixed and control soils. Issues with the string line attached to the dry mixed soil led to unreliable data. Therefore the survey data was used in its place. In the wet mix and control soils, the survey data closely matched the string line data (Figure 4.38).

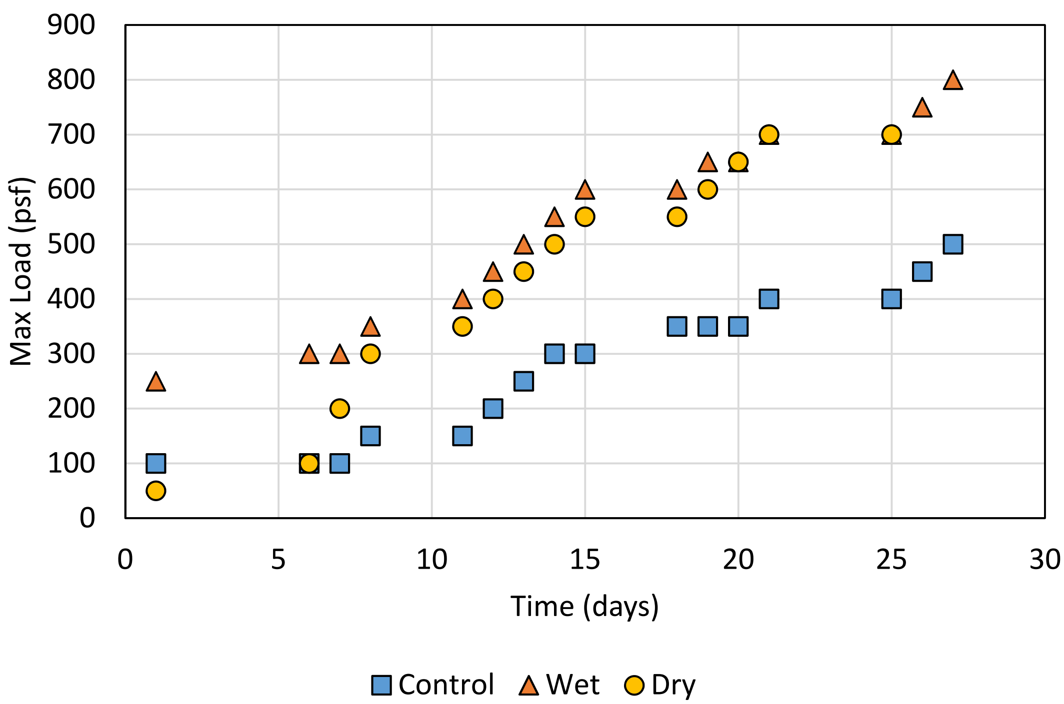


Figure 4.36 Schedule of loading.

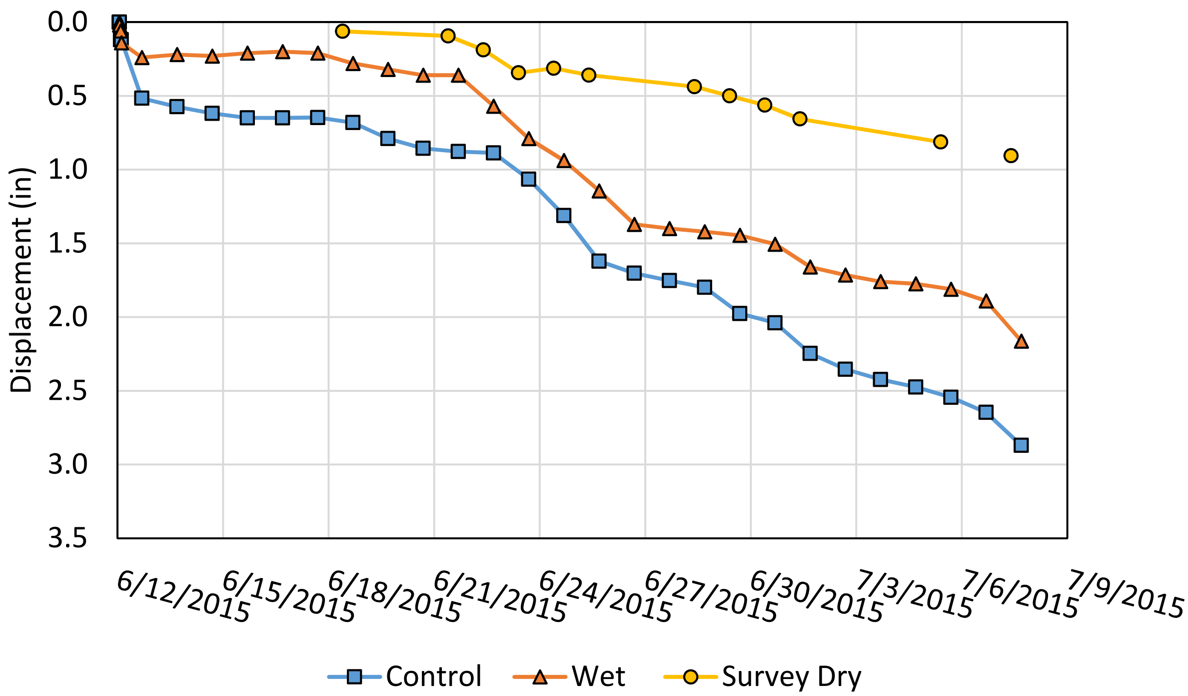


Figure 4.37 Displacement vs date.

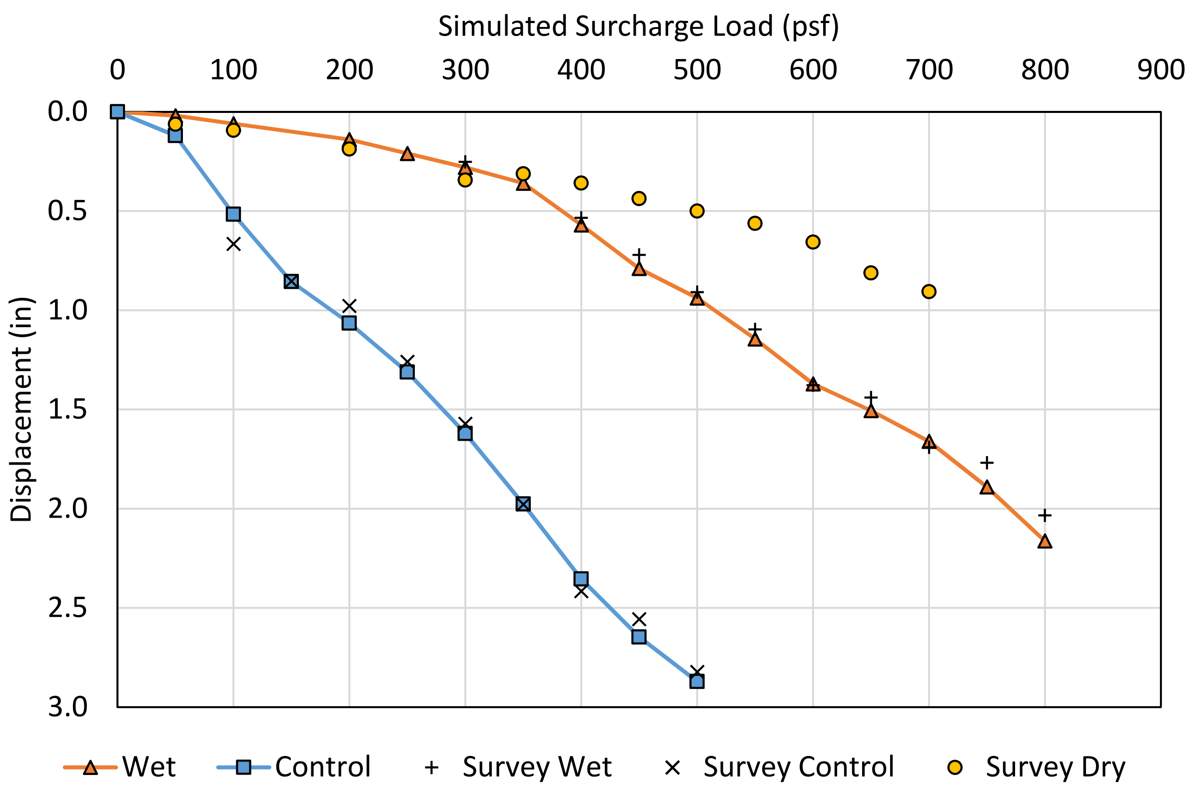


Figure 4.38 Pressure vs displacement.

# Chapter 5: Conclusions and Recommendations

Organic soils present a difficult challenge for roadway designers and construction due to the high compressibility of the soil structure, the often associated high water table, and high moisture content. For other soft or loose soils (inorganic soils), stabilization using cement or similar binders (a method called soil mixing) has proven to be an effective solution. To this end, the Federal Highway Administration has published a comprehensive design manual for these techniques. Organic soils, however, are not addressed therein to a level of confidence for design, as organic soils do not follow the trends presented for inorganic soils. This has been attributed to the high porosity, high water content, and high levels of humic acids common to organic soils.

Worldwide, the effect of organics on the strength of stabilized soils has been a recurring discussion but with vague recommendations. The FHWA manual suggests that soils with *organic contents greater than about 10 percent may produce significant interference with cementation.* It further states that *organic soils tend to require more binder than inorganic soils*.

Similarly cautionary language can be found from the Swedish Deep Stabilization Research Centre where it is simply stated that *the stabilization outcome of a binder cannot at present be definitely predicted merely by determining the organic content and humus content of the soil.* However, these recommendations provided a glimmer of insight noting that *in soils with high organic contents, such as mud and peat, the quantity of binder needs to exceed a "threshold." As long as the quantity of binder is below the threshold the soil will remain unstabilized.* This statement was supported by the findings of this thesis from which a proposed design approach was developed.

In the process of developing the proposed design recommendations, several tasks were undertaken including a thorough literature search, laboratory bench tests, large scale laboratory tests, and concluded with recommendations for designing for soil mixing applications in highly organic soils.

## 5.1 Laboratory Bench Tests

Laboratory tests (bench tests) were performed to assess the effect of cementitious binder type, binder content, mixing method, organic content and curing time on strength gain of stabilized organic soil. This phase involved 501 samples where in all cases, specimens with organic content higher than approximately 10% required disproportionally more cement for the same strength gain when compared to inorganic or lower organic content samples. Figure 5.1 shows the laboratory unconfined compression strengths as a function of w/c ratio along with literature values for inorganic soils. As most of the laboratory tests contained organic contents higher than 10%, most of these results do not agree with the more historically accepted trends. However, the laboratory organic specimens do follow a pattern of higher strength from lower w/c ratio mixes and vice versa.

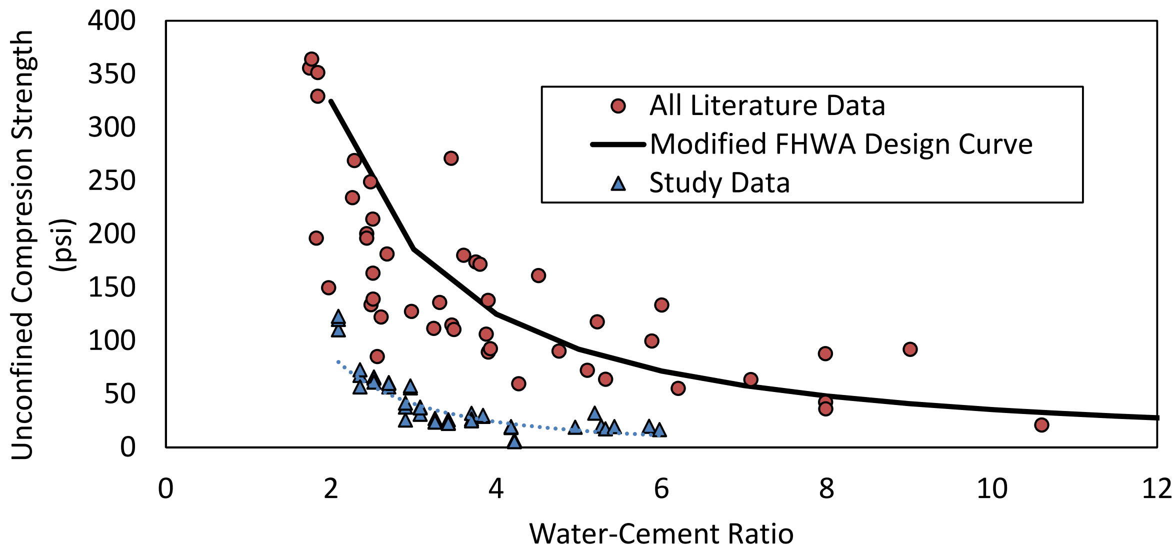


Figure 5.1 Results of laboratory unconfined compression tests along with literature values.

## 5.2 Large Scale Outdoor Laboratory Testing

Using the findings of the bench tests, a 1/10th scale test bed was built in which soil containing approximately 44% organics was placed and conditioned with rain water periodically to maintain a submerged or near submerged state. The dimensions of the bed accommodated three side-by-side tests wherein dry and wet soil mixing were performed each in one third of the bed. The remaining third of the bed was left untreated. Load tests were then performed on the three portions of the bed where the load for a simulated roadway was placed. These loads were left in place for several months and monitored for long-term movement.

Results of the simulated surcharge loading showed marked improvement for the soil mixed portions relative to no treatment with virtually identical response coming from dry or wet methods (both used identical amounts of cement per volume). The wet mix region was comprised of 20% replacement with columns of higher strength material (e.g. 20psi), and the dry mix region used an overall treatment strength (mass stabilization approach) where the required strength was closer to 4psi. Figures 5.2 and 5.3 show the load versus displacement response for the two simulated surcharges along with the untreated control. The control was not expected to ever withstand the design load (600psf). The maximum applied surcharge loads were 700, 600, and 400psf for the wet mix, dry mix, and control, respectively.

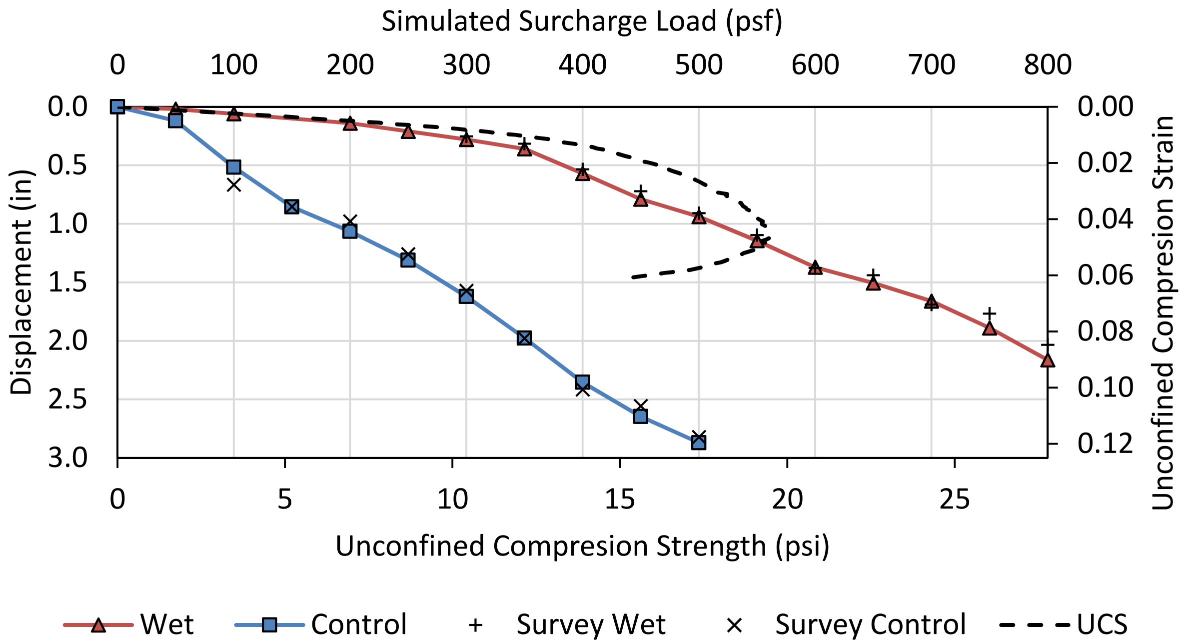


Figure 5.2 Simulated surcharge load response for the wet mix bed.

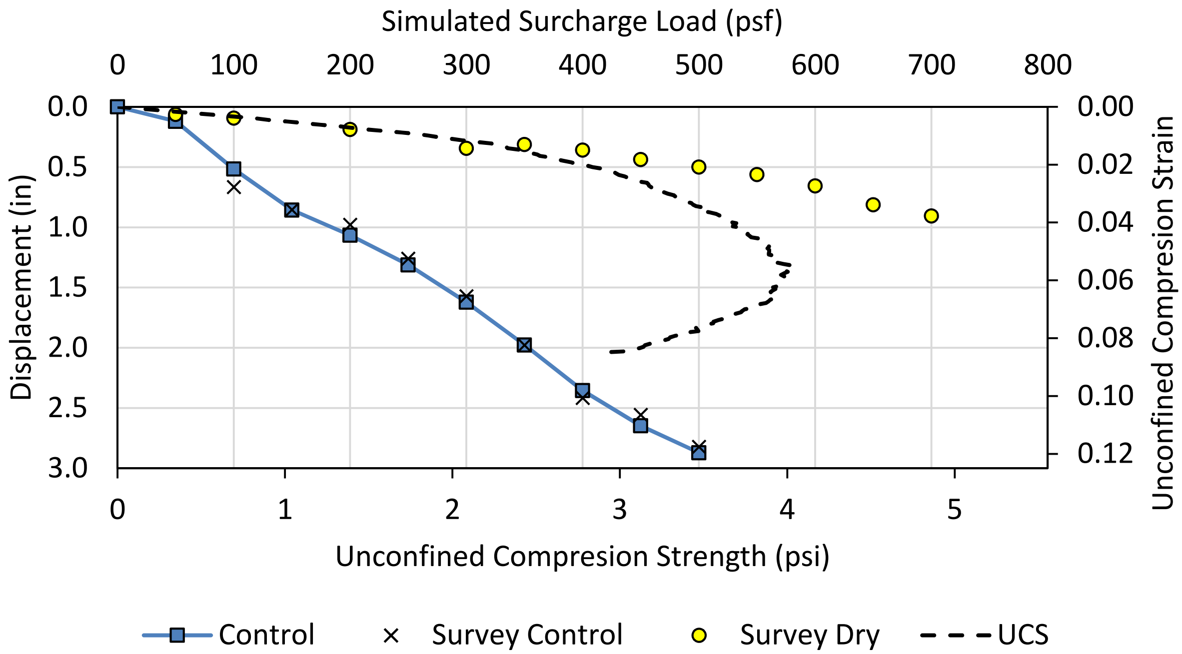


Figure 5.3 Simulated surcharge load response for the dry mix bed.

Also shown on these curves are the unconfined compression test results for laboratory samples superimposed over the two load response curves (Figures 5.2 and 5.3). Selection of the most appropriate lab test was based on the target strength of the column or mass stabilization (20 and 4psi, respectively). Further, the strain scales of the UC tests have been matched to the displacement associated with the same strain in the 24in deep soil bed. The stress-strain diagrams every for cylinder tested may be found in the Appendix.

Some variations exist, however, between the scenarios making the comparison slightly mismatched. For the wet mix, the highest cement content sample performed in the lab was 500pcy; the bed column mix was closer to 670pcy. At 750psf, the failure strength had not yet been defined. For the dry mix, the lab specimen used 200pcy at 66% organics while the test bed used 233pcy at 40% organics. Likewise, at 700psf no failure strength had been found. Despite the discrepancies between lab and surcharge test specimens, results were strikingly similar.

It should also be noted that the design of the soil mix in the surcharge bed was based on unconfined compression test results which are ultimate values and was not based on the non-linear stress strain response. As a result, both treatment regions showed some yielding prior to achieving the design surcharge loading.

While the stiffness of the dry and wet mixed regions had similar initial stiffness, the dry mixing continued to respond in a stiffer manner beyond the laboratory-predicted yield point. This was a side-effect of mass mixing instead of the originally planned isolated soil mixed columns. Whereas the wet mix surcharge plate load was solely supported by seven isolated columns, the dry mix plate load was resisted by a combination of compression of the material and distribution of stress via shear to the surrounding stabilized soil. The wet mix columns could not transfer load in the same fashion to the more peripheral columns. In essence, the wet mix load test was more representative of a continuously loaded field condition; the dry mix plate load provide a reasonable assessment of local punching stresses (wheel loads), but not global performance.

### 5.3 Recommendations for Designing Soil Mixed Organic Soils

Using the hypothesis presented by the Swedish Deep Stabilization Research Centre, a cement factor threshold was computed (Eqn 6.1) for all laboratory tests performed such that the resulting effective w/c ratio and strength aligned with the predicted modified FHWA design curve. Only a subtle variation was noted between the published curve (Figure 2.3) and that used for this adjustment exercise (Figure 2.5 and 5.1). Equation 5.1 was used to calculate the effective w/c ratio.

$$w/c_{effective} = w/c_{in\ place} \frac{CF_{in\ place}}{(CF_{in\ place} - CF_{threshold})} \qquad \text{Eqn 5.1}$$

The *CF* terms represent the cement factor (weight/volume,) *CF in place*, and that which does not contribute to meaningful soil improvement, *CF threshold*. The *CF threshold* may be thought of as “dead” cement. It takes up volume, but does not help with strength.

Cement factor threshold values were then selected for each batch so that the data aligned with the curve. Figure 5.4 shows the fitted data, and Figure 5.6 shows the selected cement factor threshold values used.

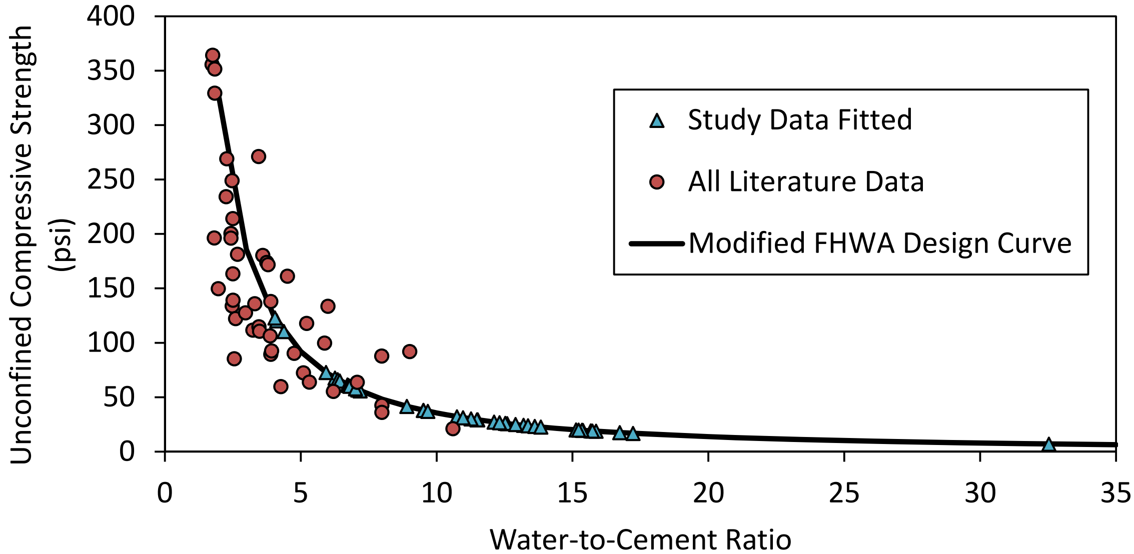


Figure 5.4 Study data fitted to modified FHWA design curve.

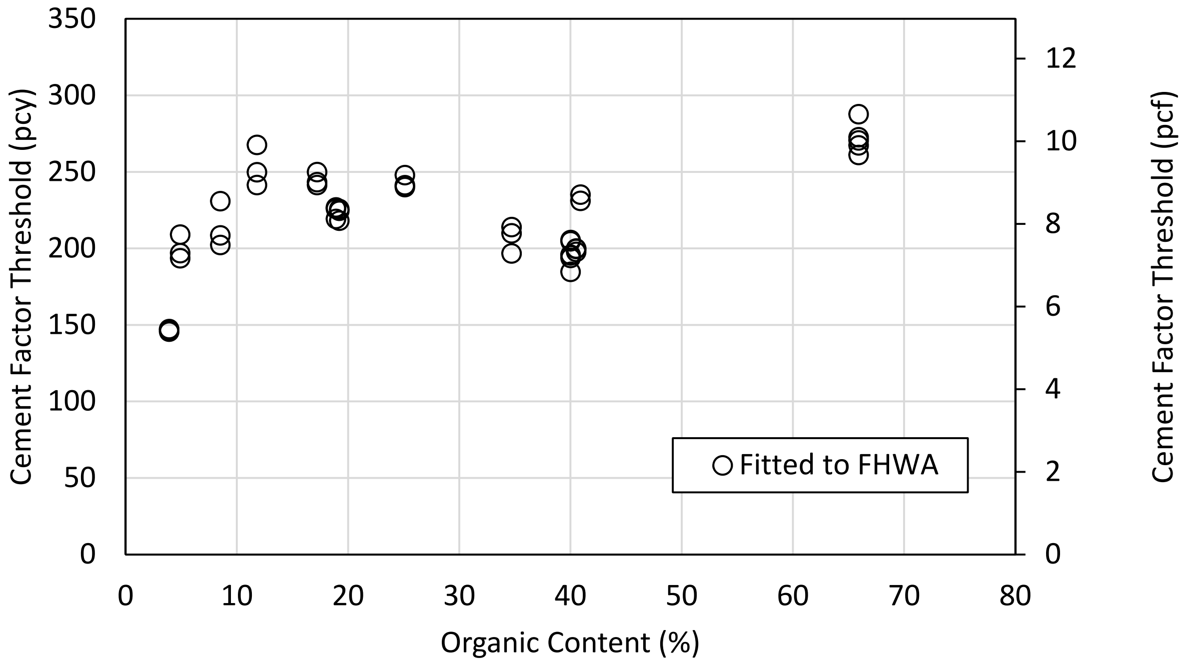


Figure 5.5 Cement factor threshold obtained by curve fitting.

In addition to the approach shown above, a second method computed the threshold values. The strength vs cement factor curves (Figure 3.13) in combination with the strength vs organic content curves (Figures 3.18) were also scrutinized to determine the cement factor below which no strength was achieved (for all organic contents). The first step was to plot organic content vs strength for various cement factors. This is shown in Figure 5.6.

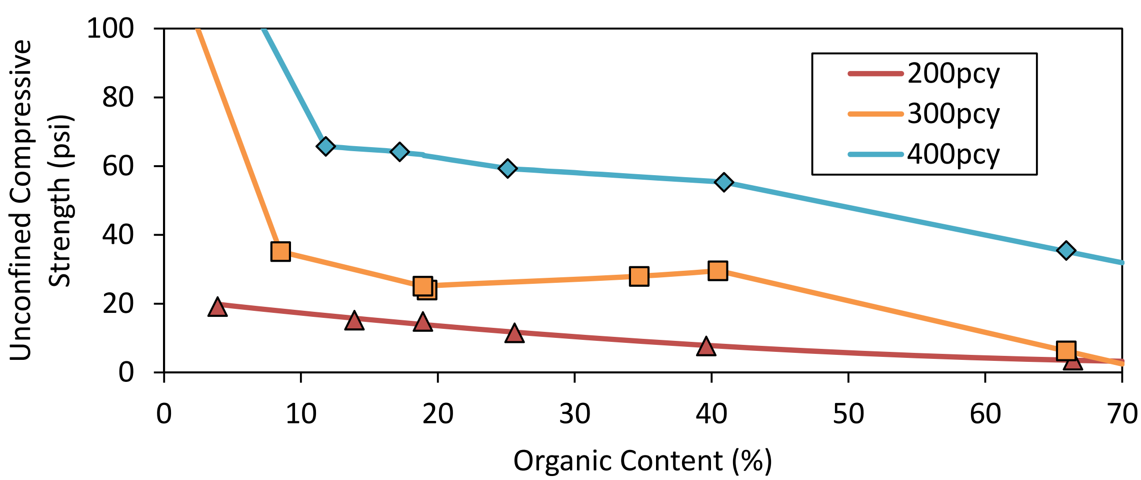


Figure 5.6 Strength vs organic content for various CF (28 days).

Since not all test were performed at the exact same organic contents, linear interpolation was used on Figure 5.6 to obtain a set of strength vs cement factor curves, each with constant organic content. These curves were then extrapolated to intercept the cement factor axis (x-axis), and therefore reveal the cement factor at zero strength, the cement factor threshold. Figure 5.7 shows the results of this exercise superimposed on all applicable test data (100% cement binder).

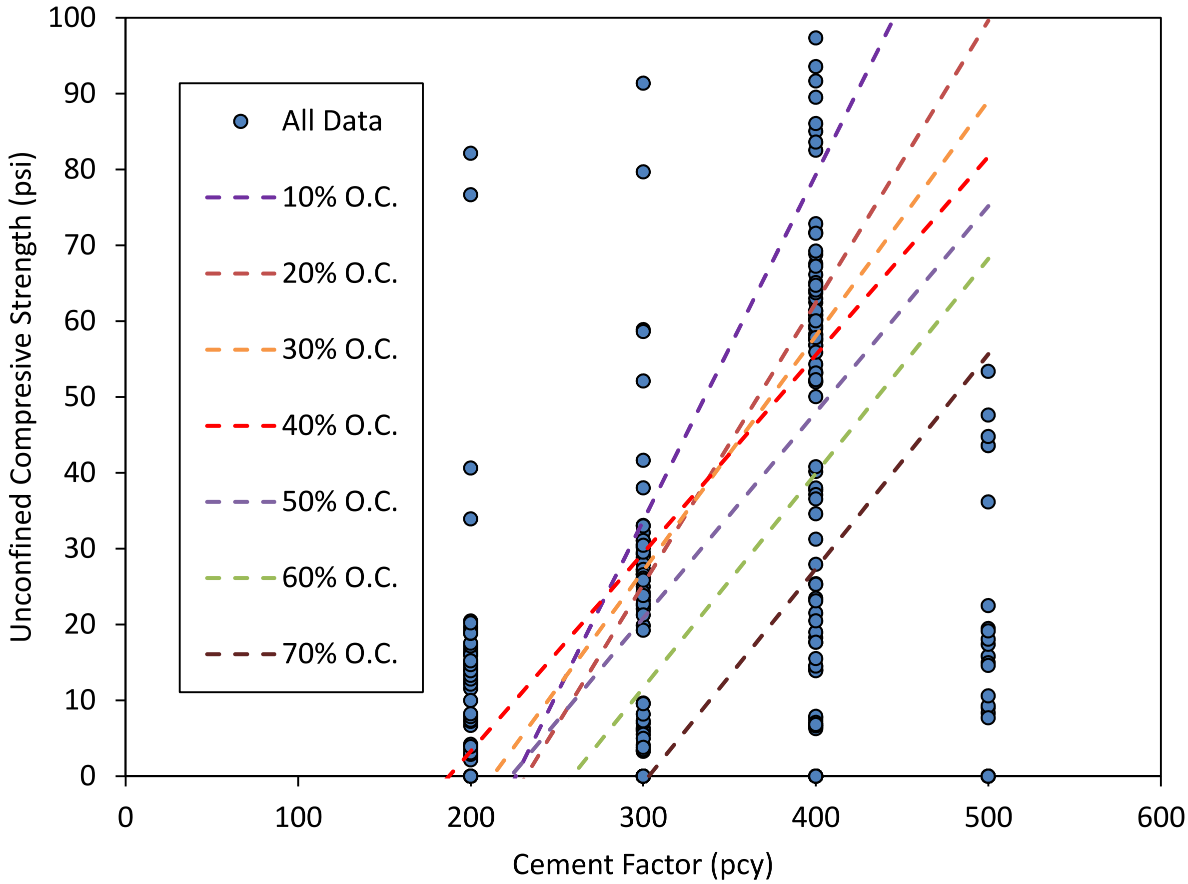


Figure 5.7 Strength vs cement factor for various organic contents.

Figure 5.8 represents the cement factor thresholds computed from both methods. As shown, the two approaches had similar results. Additionally, Figure 5.8 provides a recommended value for the threshold. The graph is presented as cement factor threshold versus organic content.

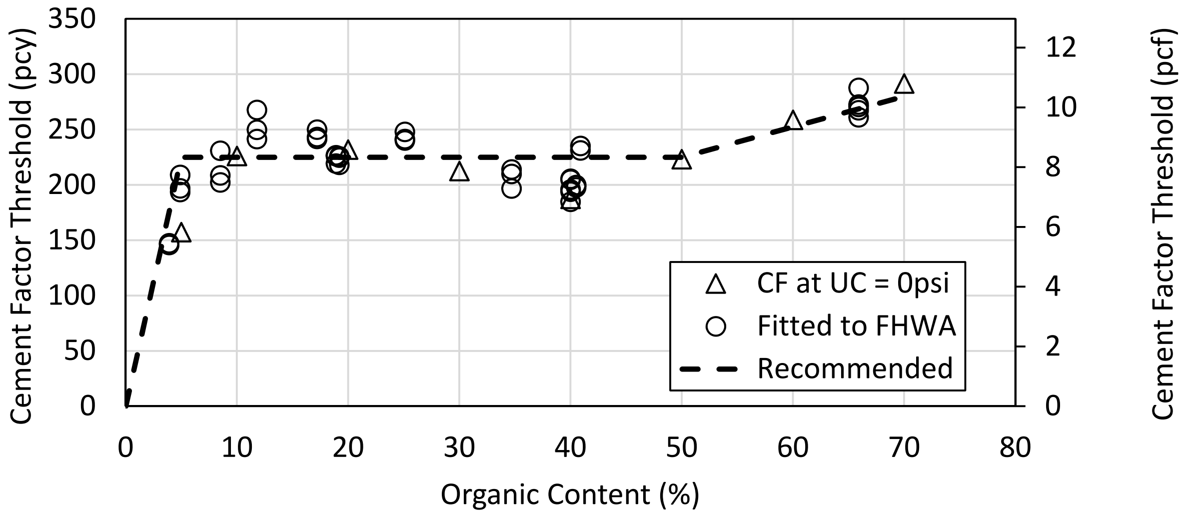


Figure 5.8 Cement factor threshold versus organic content.

As the shape of the data has a third order nature to it, the results are similar to the trend in Figure 3.15. In both cases, strength results varied little in the middle range of organic contents tested. However, there are notable increases and decreases in strength toward the end of the trends. Figure 5.9 shows the laboratory data adjusted using the recommended threshold values.

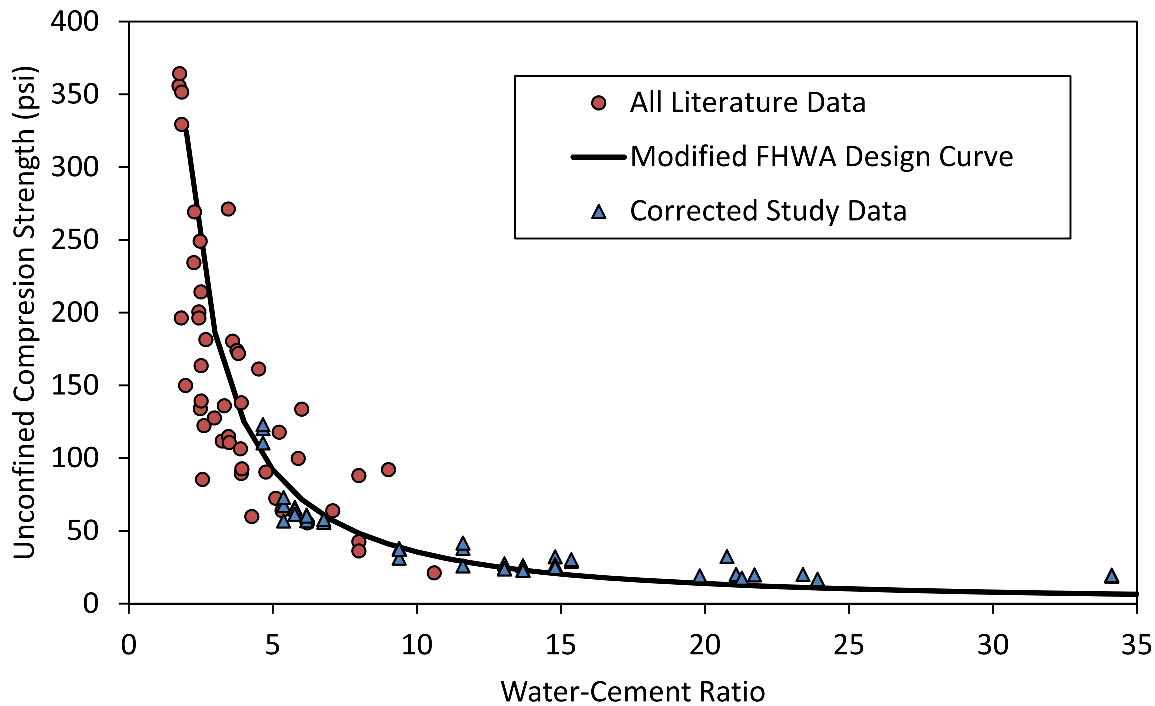


Figure 5.9 Strength versus w/c ratio corrected for cement factor threshold.

Using the threshold concept, the data collected during this thesis study now closely correlates to previous laboratory studies that used mostly inorganics.

Using this information, a design process was developed. It has two components. (1) Satisfy the water-to-cement ratio. This has a direct relationship to the total weight of water in the system and corresponds to the curve in Figure 5.9. (2) Account for additional cement needed to satisfy the cement factor threshold. Using this proposed design method (using Eqn 5.1 and Figure 5.9) an example design of dry mixing and wet mixing has been prepared for illustration:

Given:

- Organic soil (O.C. = 40%)
- Moisture Content (176%)
- Saturated unit weight (76pcf, )
- Dry Mixing

Compute the required cement factor to achieve a 50 psi required strength.

- Using FHWA design curve, 50 psi requires $(w/c)_{effective}$ ratio of 7.5.
- 1ft$^3$ of the soil contains 48.4lbs of water and 27.5lbs of solids to satisfy the 176% moisture content.
- The weight of effective cement from FHWA ($wt_{effective\ cem}$) would then be 48.4lbs / 7.5 = 6.45lbs. This increases the system volume to 1.033ft$^3$.
- The final volume is calculated by applying the cement factor threshold, $CF_{threshold}$, to Eqn. 4.2. In this case, the recommended value for $CF_{threshold}$ is 225pcy (8.33pcf). This expands the total volume to 1.079ft$^3$ and adds 8.99lbs of cement.

$$Total\ Volume = \frac{V_s}{1 - \frac{CF}{62.4}\left(\frac{1}{3.15} + \frac{w}{c}\right)} = \frac{1.033ft^3}{1 - \frac{8.33pcf}{62.4}\left(\frac{1}{3.15} + 0\right)} = 1.079ft^3$$

$$wt_{threshold\ cem} = Total\ Volume * CF = 1.079ft^3 * 8.33pcf = 8.99lbs$$

- Therefore the total amount of cement to be added per cubic foot of original soil is 6.45lbs + 8.99lbs = 15.44lbs.
- $CF_{in\ place}$ =15.44 / 1.079 = 14.32pcf (387pcy)
- The $(w/c)_{In\text{-}Place}$ is 48.4 / 15.44 = 3.13.
- To check, Eqn. 5.1 may be used to calculate the effective water to cement ratio. $(w/c)_{Effective}$ = 3.13 x [387 / (387 - 225)] = 7.5.

When applying this process to wet mixing, the procedure has an iterative component. This is due to both w/c ratio and cement factor requirements being co-dependent. In dry mixing, the w/c ratio is satisfied first and then the cement factor second. In wet mixing, the w/c ratio may be satisfied, but then becomes unsatisfied once more cement, and thus more water, is added. To combat this, the amount of water introduced by the threshold grout is assumed and checked. Convergence typically occurs within 2-3 iterations. A typical assumption is that the water introduced by the threshold grout is equal to the effective w/c.

For comparison purposes, the example from above is solved below using grout with a w/c ratio of 0.8 starting with the third step.

- Assume that grout water from the threshold cement is equal to $(w/c)_{effective}$ = 7.5.
- The uncorrected weight of required cement would then be (48.4lbs + 7.5lbs) / [7.5 – 0.8] = 8.34lbs. This cement comes with 6.67lbs of additional water, and thereby increases the total volume to 1.15ft$^3$.
- Using Eqn. 4.2 and a $CF_{threshold}$ of 225pcy (8.33pcf), the final volume of the system will be 1.35ft$^3$.

- At this point the assumption may be checked. The amount of cement in the system due to the cement factor threshold is 8.33pcy x 1.35ft$^3$ (total volume) = 11.26lbs. Therefore there is 11.26lbs x 0.8 = 9.01lbs of grout water from the threshold cement, so the assumption was too low. Therefore plug the new value into the original assumption. The value converges to 9.039lbs on the third iteration. The updated values are:
    - Uncorrected weight of cement = 8.57lbs.
    - Grout water = 6.86lbs.
    - Final volume = 1.36ft$^3$.
    - Additional threshold cement = 11.30lbs.
- The uncorrected cement factor is 8.57lbs / 1.36ft$^3$ = 6.32pcf (171pcy).
- The corrected cement factor is (8.57lbs + 11.30lbs) / 1.36ft$^3$ = 14.66pcf (396pcy).
- Therefore the total amount of cement to be added per cubic foot of soil is 8.57lbs + 11.30lbs = 19.87lbs. This is about 36lbs of 0.8 w/c grout for every cubic foot of soil to be treated.
- The $(w/c)_{In\text{-}Place}$ is (48.4lbs + 9.039lbs + 6.86lbs) / 19.87lbs = 3.24.
- To check, equation 5.1 may be used to calculate the effective water to cement ratio. $(w/c)_{Effective}$ = 3.24 x [396 / (396 - 225)] = 7.5.

While the above examples outline a process for design, it should be understood that soil mixing in general is not a perfect science. Therefore, the values generated using the procedures above should be considered starting points for design. After the overall cement factor is calculated, bench test would add greater confidence to the design.

### 5.4 Summary

This thesis suggest that the adverse effects of organic soils can be combatted where more cement content is required to offset the acidity before the more commonly used water / cement ratio design curve can be used. While past researchers have alluded to the concept of a cement factor threshold, this thesis identified such a value below which no significant strength gain was achieved. This threshold was then defined as a cement factor offset. Once this concept was applied, the measured strengths matched well with other soil types. As a result, a recommended approach for designing soil mixing applications in organic soils was developed.

As this is a new development in design for organic soils, some stipulations should be placed on the proposed method: (1) the method was developed for a given composition of organic soil which was only partially decomposed having both fibrous and amorphous attributes. A natural extension of the methodology should incorporate the assignment of a threshold on the basis of more variations in decomposition. (2) The organic soil and range of organic contents was largely a sandy organic material with little to no clay fraction. Verification of the method should address variations in the inorganic composition of the organic soil tested. However, as the FHWA design curve is a compilation of sand and clay, this is likely to be less significant. (3) Finally, the organic soil used in this thesis was not responsive to the use of slag replacement which other studies have shown to be better suited for organic soils. There exists the possibility that clayey organic soils or organic soils of varied decomposition may be more positively affected by slag / cement mixes than that used in this thesis.

Potential future work may include applying the design method provided here to previous field studies. A comparison could then be drawn between the cement needed (using the approach herein) and the cement actually used. It would be predicted that successful field studies use a highly conservative amount of cement. The findings that result from this exercise would increase the accuracy of cost estimates and build confidence in this design approach. Additionally, the approach used to derive the cement factor threshold could be performed for other types of cement. In this study Portland Type I/II was used due to it being the most common in soil mixing.

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# Appendix A: Lab Cylinder Information and Test Results

Table A.1 Laboratory soil mixing matrix.

| Batch | CF (pcy) | Slag (%) | Organic Content (%) | Moisture Content | w/c Ratio | Mixing Date | Break Date | Days Cured | Cylinder Number | Max Strength (psi) | Average Strength (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 200 | 50% | 66.4% | 361.7% | 6.88 | 9/23/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 2 | 300 | 50% | 66.4% | 361.7% | 4.49 | 9/25/2014 | 10/9/2014 | 14 | 1 | 2.03 | 1.85 |
| | | | | | | | | | 2 | 1.79 | |
| | | | | | | | | | 3 | 1.73 | |
| | | | | | | | 10/23/2014 | 28 | 4 | N/A | 2.07 |
| | | | | | | | | | 5 | 2.3 | |
| | | | | | | | | | 6 | 1.84 | |
| | | | | | | | 11/25/2014 | 61 | 7 | N/A | 2.37 |
| | | | | | | | | | 8 | 2.28 | |
| | | | | | | | | | 9 | 2.46 | |
| 3 | 400 | 50% | 66.4% | 361.7% | 3.29 | 9/25/2014 | 10/9/2014 | 14 | 1 | 5.75 | 5.9 |
| | | | | | | | | | 2 | 6.09 | |
| | | | | | | | | | 3 | 5.86 | |
| | | | | | | | 10/23/2014 | 28 | 4 | 7.04 | 6.1 |
| | | | | | | | | | 5 | 5.93 | |
| | | | | | | | | | 6 | 5.34 | |
| | | | | | | | 11/25/2014 | 61 | 7 | 4.36 | 7.25 |
| | | | | | | | | | 8 | 7.04 | |
| | | | | | | | | | 9 | 10.35 | |
| 4 | 200 | 0% | 66.4% | 361.7% | 6.90 | 9/25/2014 | 10/9/2014 | 14 | 1 | 2.63 | 2.55 |
| | | | | | | | | | 2 | 2.15 | |
| | | | | | | | | | 3 | 2.86 | |
| | | | | | | | 10/23/2014 | 28 | 4 | 4.02 | 3.55 |
| | | | | | | | | | 5 | 3.56 | |
| | | | | | | | | | 6 | 3.08 | |
| | | | | | | | 11/25/2014 | 61 | 7 | 4.07 | 4.06 |
| | | | | | | | | | 8 | N/A | |
| | | | | | | | | | 9 | 4.04 | |
| 5 | 200 | 100% | 66.4% | 189.3% | 6.10 | 10/7/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 6 | 300 | 100% | 66.4% | 211.6% | 4.12 | 10/7/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |

Table A.1 (continued).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 400 | 100% | 66.4% | 218.3% | 3.05 | 10/7/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 8 | 300 | 0% | 65.9% | 221.1% | 4.22 | 10/10/2014 | 10/24/2014 | 14 | 1 | 5.96 | 6.15 |
| | | | | | | | | | 2 | 6.35 | |
| | | | | | | | | | 3 | 6.15 | |
| | | | | | | | 11/7/2014 | 28 | 4 | 7.01 | 6.26 |
| | | | | | | | | | 5 | 5.50 | |
| | | | | | | | | | 6 | N/A | |
| | | | | | | | 12/10/2014 | 61 | 7 | 7.30 | 8.37 |
| | | | | | | | | | 8 | 8.18 | |
| | | | | | | | | | 9 | 9.64 | |
| 9 | 400 | 0% | 65.9% | 215.6% | 3.08 | 10/10/2014 | 10/24/2014 | 14 | 1 | 37.70 | 27.12 |
| | | | | | | | | | 2 | 25.38 | |
| | | | | | | | | | 3 | 18.28 | |
| | | | | | | | 11/7/2014 | 28 | 4 | 37.99 | 35.46 |
| | | | | | | | | | 5 | 31.25 | |
| | | | | | | | | | 6 | 37.13 | |
| | | | | | | | 12/10/2014 | 61 | 7 | 34.60 | 38.52 |
| | | | | | | | | | 8 | 40.16 | |
| | | | | | | | | | 9 | 40.8 | |
| 10 | 300 | 50% | 41.3% | 135.8% | 3.86 | 10/14/2014 | 10/28/2014 | 14 | 1 | 2.57 | 2.53 |
| | | | | | | | | | 2 | 2.46 | |
| | | | | | | | | | 3 | 2.57 | |
| | | | | | | | 11/11/2014 | 28 | 4 | N/A | 2.9 |
| | | | | | | | | | 5 | 2.97 | |
| | | | | | | | | | 6 | 2.82 | |
| | | | | | | | 12/15/2014 | 62 | 7 | 3.567 | 3.57 |
| | | | | | | | | | 8 | 3.567 | |
| | | | | | | | | | 9 | N/A | |
| 11 | 300 | 50% | 27.8% | 95.3% | 3.52 | 10/14/2014 | 10/28/2014 | 14 | 1 | 3.62 | 3.57 |
| | | | | | | | | | 2 | 3.12 | |
| | | | | | | | | | 3 | 3.96 | |
| | | | | | | | 11/11/2014 | 28 | 4 | 4.06 | 4.26 |
| | | | | | | | | | 5 | N/A | |
| | | | | | | | | | 6 | 4.46 | |
| | | | | | | | 12/15/2014 | 62 | 7 | 3.8 | 3.8 |
| | | | | | | | | | 8 | N/A | |
| | | | | | | | | | 9 | N/A | |
| 12 | 300 | 50% | 24.1% | 76.2% | 3.38 | 10/14/2014 | 10/28/2014 | 14 | 1 | 2.64 | 4.96 |
| | | | | | | | | | 2 | 4.55 | |
| | | | | | | | | | 3 | 7.68 | |
| | | | | | | | 11/11/2014 | 28 | 4 | 4.19 | 4.86 |
| | | | | | | | | | 5 | 5.95 | |
| | | | | | | | | | 6 | 4.45 | |
| | | | | | | | 12/15/2014 | 62 | 7 | 7.51 | 8.06 |
| | | | | | | | | | 8 | 8.63 | |
| | | | | | | | | | 9 | 8.05 | |
| 13 | 300 | 50% | 11.2% | 54.2% | 3.00 | 10/14/2014 | 10/28/2014 | 14 | 1 | 24.47 | 24.8 |
| | | | | | | | | | 2 | 26.35 | |
| | | | | | | | | | 3 | 23.58 | |
| | | | | | | | 11/11/2014 | 28 | 4 | 42.44 | 40.06 |
| | | | | | | | | | 5 | 40.13 | |
| | | | | | | | | | 6 | 37.6 | |
| | | | | | | | 12/15/2014 | 62 | 7 | 63.42 | 59.94 |
| | | | | | | | | | 8 | 53.62 | |
| | | | | | | | | | 9 | 62.77 | |

Table A.1 (continued).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 300 | 50% | 4.6% | 36.3% | 2.50 | 10/14/2014 | 10/28/2014 | 14 | 1 | 53.51 | 66.88 |
| | | | | | | | | | 2 | 89.24 | |
| | | | | | | | | | 3 | 57.89 | |
| | | | | | | | 11/11/2014 | 28 | 4 | 132.25 | 132.8 |
| | | | | | | | | | 5 | 94.45 | |
| | | | | | | | | | 6 | 171.7 | |
| | | | | | | | 12/15/2014 | 62 | 7 | 327.75 | 315.56 |
| | | | | | | | | | 8 | 241.4 | |
| | | | | | | | | | 9 | 377.52 | |
| 15 | 300 | 0% | 40.5% | 134.5% | 3.84 | 10/17/2014 | 10/31/2014 | 14 | 1 | 27 | 25.99 |
| | | | | | | | | | 2 | 23.75 | |
| | | | | | | | | | 3 | 27.23 | |
| | | | | | | | 11/14/2014 | 28 | 4 | 29.23 | 29.57 |
| | | | | | | | | | 5 | 29.35 | |
| | | | | | | | | | 6 | 30.12 | |
| | | | | | | | 12/18/2014 | 62 | 7 | 31.03 | 29.9 |
| | | | | | | | | | 8 | 28.12 | |
| | | | | | | | | | 9 | 30.56 | |
| 16 | 300 | 0% | 34.7% | 105.9% | 3.70 | 10/17/2014 | 10/31/2014 | 14 | 1 | 28.53 | 26.61 |
| | | | | | | | | | 2 | 22.48 | |
| | | | | | | | | | 3 | 28.83 | |
| | | | | | | | 11/14/2014 | 28 | 4 | 32.13 | 27.93 |
| | | | | | | | | | 5 | 26.66 | |
| | | | | | | | | | 6 | 25.00 | |
| | | | | | | | 12/18/2014 | 62 | 7 | 30.28 | 29.32 |
| | | | | | | | | | 8 | 26.61 | |
| | | | | | | | | | 9 | 31.07 | |
| 17 | 300 | 0% | 19.2% | 78.5% | 3.42 | 10/17/2014 | 10/31/2014 | 14 | 1 | 22.06 | 22.62 |
| | | | | | | | | | 2 | 19.87 | |
| | | | | | | | | | 3 | 25.92 | |
| | | | | | | | 11/14/2014 | 28 | 4 | 26.03 | 23.99 |
| | | | | | | | | | 5 | 23.23 | |
| | | | | | | | | | 6 | 22.72 | |
| | | | | | | | 12/18/2014 | 62 | 7 | 33.06 | 30.19 |
| | | | | | | | | | 8 | 27.96 | |
| | | | | | | | | | 9 | 29.54 | |
| 18 | 300 | 0% | 18.9% | 62.9% | 3.26 | 10/17/2014 | 10/31/2014 | 14 | 1 | 9.55 | 20.26 |
| | | | | | | | | | 2 | 21.27 | |
| | | | | | | | | | 3 | 19.24 | |
| | | | | | | | 11/14/2014 | 28 | 4 | 27.26 | 25.1 |
| | | | | | | | | | 5 | 24.23 | |
| | | | | | | | | | 6 | 23.82 | |
| | | | | | | | 12/18/2014 | 62 | 7 | 25.94 | 26.18 |
| | | | | | | | | | 8 | 26.55 | |
| | | | | | | | | | 9 | 26.05 | |
| 19 | 300 | 0% | 8.5% | 45.5% | 2.90 | 10/17/2014 | 10/31/2014 | 14 | 1 | 33 | 29.85 |
| | | | | | | | | | 2 | 30.43 | |
| | | | | | | | | | 3 | 26.12 | |
| | | | | | | | 11/14/2014 | 28 | 4 | 38.02 | 35.17 |
| | | | | | | | | | 5 | 41.64 | |
| | | | | | | | | | 6 | 25.84 | |
| | | | | | | | 18-Dec | 62 | 7 | 52.1 | 56.53 |
| | | | | | | | | | 8 | 58.87 | |
| | | | | | | | | | 9 | 58.63 | |
| 20 | 300 | 100% | 43.8% | 138.5% | 3.80 | | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |

Table A.1 (continued).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 300 | 100% | 40.0% | 102.4% | 3.56 | | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 22 | 300 | 100% | 30.0% | 83.5% | 3.47 | | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 23 | 300 | 100% | 20.0% | 65.6% | 3.29 | | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 24 | 300 | 100% | 6.3% | 43.4% | 2.76 | | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 25 | 400 | 50% | 41.2% | 148.3% | 2.88 | 11/5/2014 | 11/19/2014 | 14 | 1 | 15.1 | 14.4 |
| | | | | | | | | | 2 | 14.08 | |
| | | | | | | | | | 3 | 14.03 | |
| | | | | | | | 12/3/2014 | 28 | 4 | 13.89 | 14.53 |
| | | | | | | | | | 5 | 14.54 | |
| | | | | | | | | | 6 | 14.52 | |
| | | | | | | | 1/6/2015 | 62 | 7 | N/A | 16.59 |
| | | | | | | | | | 8 | 15.51 | |
| | | | | | | | | | 9 | 17.66 | |
| 26 | 400 | 50% | 29.8% | 108.6% | 2.70 | 11/5/2014 | 11/19/2014 | 14 | 1 | 20.36 | 19 |
| | | | | | | | | | 2 | 18.99 | |
| | | | | | | | | | 3 | 17.65 | |
| | | | | | | | 12/3/2014 | 28 | 4 | 23.45 | 21.82 |
| | | | | | | | | | 5 | 21.51 | |
| | | | | | | | | | 6 | 20.49 | |
| | | | | | | | 6-Jan | 62 | 7 | 23.11 | 25.44 |
| | | | | | | | | | 8 | 25.3 | |
| | | | | | | | | | 9 | 27.92 | |
| 27 | 400 | 50% | 21.1% | 82.4% | 2.54 | 11/5/2014 | 11/19/2014 | 14 | 1 | 41.78 | 43.84 |
| | | | | | | | | | 2 | 36.56 | |
| | | | | | | | | | 3 | 53.19 | |
| | | | | | | | 12/3/2014 | 28 | 4 | 50.03 | 54.53 |
| | | | | | | | | | 5 | N/A* | |
| | | | | | | | | | 6 | 59.03 | |
| | | | | | | | 1/6/2015 | 62 | 7 | 85.03 | 82.08 |
| | | | | | | | | | 8 | 71.7 | |
| | | | | | | | | | 9 | 89.51 | |

Table A.1 (continued).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | 400 | 50% | 12.6% | 60.1% | 2.30 | 11/5/2014 | 11/19/2014 | 14 | 1 | 54.25 | 53.21 |
| | | | | | | | | | 2 | 52.06 | |
| | | | | | | | | | 3 | 53.33 | |
| | | | | | | | 12/3/2014 | 28 | 4 | 58.18 | 75.59 |
| | | | | | | | | | 5 | 86.05 | |
| | | | | | | | | | 6 | 82.53 | |
| | | | | | | | 1/6/2015 | 62 | 7 | 118.13 | 125.02 |
| | | | | | | | | | 8 | 144.59 | |
| | | | | | | | | | 9 | 112.35 | |
| 29 | 400 | 50% | 4.2% | 41.4% | 1.97 | 11/5/2014 | 11/19/2014 | 14 | 1 | 182.95 | 161.89 |
| | | | | | | | | | 2 | 129.62 | |
| | | | | | | | | | 3 | 173.09 | |
| | | | | | | | 12/3/2014 | 28 | 4 | 300.95 | 318.12 |
| | | | | | | | | | 5 | 348.02 | |
| | | | | | | | | | 6 | 305.38 | |
| | | | | | | | 1/6/2015 | 62 | 7 | 452.65 | 452.23 |
| | | | | | | | | | 8 | 420.8 | |
| | | | | | | | | | 9 | 483.23 | |
| 30 | 400 | 0% | 4.9% | 44.4% | 2.09 | 11/6/2014 | 11/20/2014 | 14 | 1 | 97.33 | 90.86 |
| | | | | | | | | | 2 | 91.66 | |
| | | | | | | | | | 3 | 83.6 | |
| | | | | | | | 12/4/2014 | 28 | 4 | 110.48 | 117.89 |
| | | | | | | | | | 5 | 120.24 | |
| | | | | | | | | | 6 | 122.95 | |
| | | | | | | | 1/7/2015 | 62 | 7 | 178.2 | 170.97 |
| | | | | | | | | | 8 | 159.24 | |
| | | | | | | | | | 9 | 175.48 | |
| 31 | 400 | 0% | 11.8% | 61.4% | 2.35 | 11/6/2014 | 11/20/2014 | 14 | 1 | 62.47 | 56.25 |
| | | | | | | | | | 2 | 51.97 | |
| | | | | | | | | | 3 | 54.31 | |
| | | | | | | | 12/4/2014 | 28 | 4 | 67.60 | 65.75 |
| | | | | | | | | | 5 | 72.84 | |
| | | | | | | | | | 6 | 56.8 | |
| | | | | | | | 1/7/2015 | 62 | 7 | 93.55 | 85.87 |
| | | | | | | | | | 8 | 63 | |
| | | | | | | | | | 9 | 101.07 | |
| 32 | 400 | 0% | 17.2% | 80.3% | 2.52 | 11/6/2014 | 11/20/2014 | 14 | 1 | 58.3 | 59.33 |
| | | | | | | | | | 2 | 60.31 | |
| | | | | | | | | | 3 | 59.39 | |
| | | | | | | | 12/4/2014 | 28 | 4 | 66.13 | 64.18 |
| | | | | | | | | | 5 | 65.08 | |
| | | | | | | | | | 6 | 61.34 | |
| | | | | | | | 1/7/2015 | 62 | 7 | 68.81 | 69.2 |
| | | | | | | | | | 8 | 67.23 | |
| | | | | | | | | | 9 | 71.57 | |
| 33 | 400 | 0% | 25.1% | 106.9% | 2.70 | 11/6/2014 | 11/20/2014 | 14 | 1 | 57.66 | 58.63 |
| | | | | | | | | | 2 | 57.47 | |
| | | | | | | | | | 3 | 60.77 | |
| | | | | | | | 12/4/2014 | 28 | 4 | 60.9 | 59.31 |
| | | | | | | | | | 5 | 56.84 | |
| | | | | | | | | | 6 | 60.2 | |
| | | | | | | | 1/7/2015 | 62 | 7 | 69.24 | 65.68 |
| | | | | | | | | | 8 | 63.72 | |
| | | | | | | | | | 9 | 64.08 | |
| 34 | 400 | 0% | 40.9% | 156.9% | 2.96 | 11/17/2014 | 12/1/2014 | 14 | 1 | 53.15 | 52.71 |
| | | | | | | | | | 2 | N/A | |
| | | | | | | | | | 3 | N/A | |
| | | | | | | | | | 4 | 52.27 | |
| | | | | | | | 12/15/2014 | 28 | 5 | 55.91 | 56.87 |
| | | | | | | | | | 6 | 57.82 | |
| | | | | | | | 1/18/2015 | 62 | 7 | 64.72 | 62.05 |
| | | | | | | | | | 8 | 61.4 | |
| | | | | | | | | | 9 | 60.04 | |

Table A.1 (continued).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 | 200 | 0% | 39.6% | 159.1% | 6.20 | 11/17/2014 | 12/1/2014 | 14 | 1 | N/A | 6.95 |
| | | | | | | | | | 2 | N/A | |
| | | | | | | | | | 3 | N/A | |
| | | | | | | | | | 4 | 6.68 | |
| | | | | | | | | | 5 | 7.21 | |
| | | | | | | | 12/15/2014 | 28 | 6 | 8.03 | 7.71 |
| | | | | | | | | | 7 | 7.38 | |
| | | | | | | | 1/18/2015 | 62 | 8 | 7.84 | 8.03 |
| | | | | | | | | | 9 | 8.22 | |
| 36 | 200 | 0% | 25.6% | 116.5% | 5.85 | 11/17/2014 | 12/1/2014 | 14 | 1 | N/A | 11.94 |
| | | | | | | | | | 2 | 12.31 | |
| | | | | | | | | | 3 | 11.56 | |
| | | | | | | | 12/15/2014 | 28 | 4 | 12.54 | 11.55 |
| | | | | | | | | | 5 | 9.97 | |
| | | | | | | | | | 6 | 12.13 | |
| | | | | | | | 1/18/2015 | 62 | 7 | 13.35 | 13.33 |
| | | | | | | | | | 8 | 13.84 | |
| | | | | | | | | | 9 | 12.8 | |
| 37 | 200 | 0% | 18.9% | 85.9% | 5.44 | 11/17/2014 | 12/1/2014 | 14 | 1 | 13.29 | 14.15 |
| | | | | | | | | | 2 | 15.10 | |
| | | | | | | | | | 3 | 14.06 | |
| | | | | | | | 12/15/2014 | 28 | 4 | 16.09 | 14.82 |
| | | | | | | | | | 5 | 13.95 | |
| | | | | | | | | | 6 | 14.41 | |
| | | | | | | | 1/18/2015 | 62 | 7 | 16.15 | 16.23 |
| | | | | | | | | | 8 | 16.32 | |
| | | | | | | | | | 9 | 16.21 | |
| 38 | 200 | 0% | 13.9% | 64.1% | 5.02 | 11/17/2014 | 12/1/2014 | 14 | 1 | 15.14 | 14.52 |
| | | | | | | | | | 2 | N/A | |
| | | | | | | | | | 3 | 13.9 | |
| | | | | | | | 12/15/2014 | 28 | 4 | 16 | 15.2 |
| | | | | | | | | | 5 | 14.83 | |
| | | | | | | | | | 6 | 14.78 | |
| | | | | | | | 1/18/2015 | 62 | 7 | 16.72 | 15.81 |
| | | | | | | | | | 8 | 14.71 | |
| | | | | | | | | | 9 | 16.01 | |
| 39 | 200 | 0% | 3.9% | 42.1% | 4.18 | 11/17/2014 | 12/1/2014 | 14 | 1 | 17.18 | 16.64 |
| | | | | | | | | | 2 | 15.21 | |
| | | | | | | | | | 3 | 17.53 | |
| | | | | | | | 12/15/2014 | 28 | 4 | 18.81 | 19.19 |
| | | | | | | | | | 5 | 19.63 | |
| | | | | | | | | | 6 | 19.13 | |
| | | | | | | | 1/18/2015 | 62 | 7 | 18.85 | 19.84 |
| | | | | | | | | | 8 | 20.46 | |
| | | | | | | | | | 9 | 20.2 | |
| 40 | 200 | 50% | 41.1% | 161.0% | 6.21 | 11/17/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 41 | 200 | 50% | 28.7% | 117.1% | 5.85 | 11/17/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |

Table A.1 (continued).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | 200 | 50% | 19.2% | 87.4% | 5.48 | 11/17/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 43 | 200 | 50% | 11.3% | 61.7% | 4.89 | 11/17/2014 | 1/18/2015 | 62 | 1 | N/A | 4.2 |
| | | | | | | | | | 2 | N/A | |
| | | | | | | | | | 3 | 4.2 | |
| | | | | | | | | | 4 | 3.89 | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 44 | 200 | 50% | 4.1% | 44.1% | 4.31 | 11/17/2014 | 12/15/2014 | 28 | 1 | 44.34 | 39.63 |
| | | | | | | | | | 2 | 40.62 | |
| | | | | | | | | | 3 | 33.93 | |
| | | | | | | | 1/18/2015 | 62 | 4 | 102.71 | 87.17 |
| | | | | | | | | | 5 | 76.66 | |
| | | | | | | | | | 6 | 82.13 | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 45 | 400 | 0% | 0.0% | 32.0% | 1.83 | 11/18/2014 | 12/2/2014 | 14 | 1 | 180.4 | 181.06 |
| | | | | | | | | | 2 | 134.66 | |
| | | | | | | | | | 3 | 228.12 | |
| | | | | | | | 12/16/2014 | 28 | 4 | 289.61 | 243.64 |
| | | | | | | | | | 5 | 227.9 | |
| | | | | | | | | | 6 | 213.41 | |
| | | | | | | | 1/19/2015 | 62 | 7 | 301.58 | 322.28 |
| | | | | | | | | | 8 | 313 | |
| | | | | | | | | | 9 | 352.26 | |
| 46 | 300 | 0% | 0.0% | 32.1% | 2.49 | 11/18/2014 | 12/2/2014 | 14 | 1 | 91.37 | 96.96 |
| | | | | | | | | | 2 | 119.82 | |
| | | | | | | | | | 3 | 79.68 | |
| | | | | | | | 12/16/2014 | 28 | 4 | N/A | 126.42 |
| | | | | | | | | | 5 | 141.6 | |
| | | | | | | | | | 6 | 111.23 | |
| | | | | | | | 1/19/2015 | 62 | 7 | 132.64 | 136.31 |
| | | | | | | | | | 8 | 172.01 | |
| | | | | | | | | | 9 | 104.28 | |
| 47 | 400 | 50% | 0.0% | 33.1% | 1.86 | 11/18/2014 | 12/2/2014 | 14 | 1 | N/A | 503.18 |
| | | | | | | | | | 2 | 518.26 | |
| | | | | | | | | | 3 | 488.09 | |
| | | | | | | | 12/16/2014 | 28 | 4 | 783.75 | 699.98 |
| | | | | | | | | | 5 | 716.6 | |
| | | | | | | | | | 6 | 599.58 | |
| | | | | | | | 1/19/2015 | 62 | 7 | 826.93 | 903.41 |
| | | | | | | | | | 8 | 1019.32 | |
| | | | | | | | | | 9 | 863.98 | |
| 48 | 300 | 50% | 0.0% | 32.5% | 2.50 | 11/18/2014 | 12/2/2014 | 14 | 1 | 181.84 | 206.51 |
| | | | | | | | | | 2 | 205.23 | |
| | | | | | | | | | 3 | 232.46 | |
| | | | | | | | 12/16/2014 | 28 | 4 | 422.72 | 340.28 |
| | | | | | | | | | 5 | 296.88 | |
| | | | | | | | | | 6 | 301.23 | |
| | | | | | | | 1/19/2015 | 62 | 7 | 617.39 | 584.24 |
| | | | | | | | | | 8 | 563.69 | |
| | | | | | | | | | 9 | 571.63 | |

Table A.1 (continued).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | 300 | 0% | 43.8% | 154.3% | 4.23 | 12/16/2014 | 1/7/2015 | 22 | 1 | 3.35 | 3.31 |
| | | | | | | | | | 2 | N/A | |
| | | | | | | | | | 3 | 3.26 | |
| | | | | | | | 1/13/2015 | 28 | 4 | 4.11 | 3.81 |
| | | | | | | | | | 5 | 3.5 | |
| | | | | | | | | | 6 | N/A | |
| | | | | | | | 2/16/2015 | 62 | 7 | 4.98 | 4.39 |
| | | | | | | | | | 8 | N/A | |
| | | | | | | | | | 9 | 3.79 | |
| 50 | 400 | 0% | 43.8% | 154.3% | 3.17 | 12/16/2014 | 1/7/2015 | 22 | 1 | 7.76 | 7.22 |
| | | | | | | | | | 2 | 7.43 | |
| | | | | | | | | | 3 | 6.47 | |
| | | | | | | | 1/13/2015 | 28 | 4 | 7.88 | 6.92 |
| | | | | | | | | | 5 | 6.26 | |
| | | | | | | | | | 6 | 6.62 | |
| | | | | | | | 2/16/2015 | 62 | 7 | 6.84 | 6.91 |
| | | | | | | | | | 8 | 7.08 | |
| | | | | | | | | | 9 | 6.81 | |
| 51 | 500 | 0% | 43.8% | 154.3% | 2.53 | 12/16/2014 | 1/7/2015 | 22 | 1 | 15.82 | 16.05 |
| | | | | | | | | | 2 | 17.38 | |
| | | | | | | | | | 3 | 14.96 | |
| | | | | | | | 1/13/2015 | 28 | 4 | 19.46 | 17.37 |
| | | | | | | | | | 5 | 18.06 | |
| | | | | | | | | | 6 | 14.6 | |
| | | | | | | | 2/16/2015 | 62 | 7 | 22.48 | 20.82 |
| | | | | | | | | | 8 | N/A | |
| | | | | | | | | | 9 | 19.15 | |
| 52 | 300 | 50% | 43.8% | 154.3% | 4.21 | 12/16/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 53 | 400 | 50% | 43.8% | 154.3% | 3.15 | 12/16/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 54 | 500 | 50% | 43.8% | 154.3% | 2.51 | 12/16/2014 | | | 1 | | |
| | | | | | | | | | 2 | | |
| | | | | | | | | | 3 | | |
| | | | | | | | | | 4 | | |
| | | | | | | | | | 5 | | |
| | | | | | | | | | 6 | | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |
| 55 | 500 | 0% | 42.1% | 154.1% | 2.11 | 12/18/2014 | 1/15/2015 | 28 | 1 | 43.59 | 41.11 |
| | | | | | | | | | 2 | 36.16 | |
| | | | | | | | | | 3 | 43.59 | |
| | | | | | | | 2/18/2015 | 62 | 4 | 53.37 | 48.59 |
| | | | | | | | | | 5 | 47.62 | |
| | | | | | | | | | 6 | 44.78 | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |

Table A.1 (continued).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 57 | 500 | 50% | 42.1% | 154.1% | 2.09 | 12/18/2014 | 1/15/2015 | 28 | 1 | 8.42 | 8.61 |
| | | | | | | | | | 2 | 9.07 | |
| | | | | | | | | | 3 | 8.33 | |
| | | | | | | | 2/18/2015 | 62 | 4 | 9.25 | 9.18 |
| | | | | | | | | | 5 | 10.59 | |
| | | | | | | | | | 6 | 7.69 | |
| | | | | | | | | | 7 | | |
| | | | | | | | | | 8 | | |
| | | | | | | | | | 9 | | |

Stress-strain data is shown in the following figures. The letter D or W refers to dry mixed or wet mixed, respectively. The first number represents the batch number, the number after the dash represents the cylinder number within that batch.

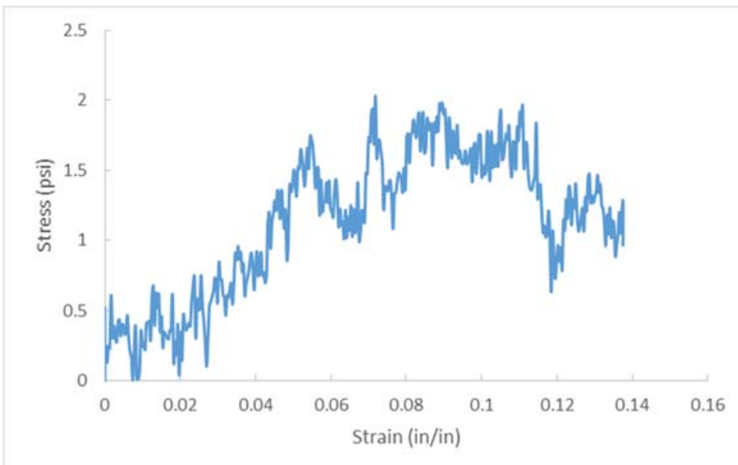


Figure A.1 D2-1, OC= 66.4%, CF= 300 pcf, T=14 days.

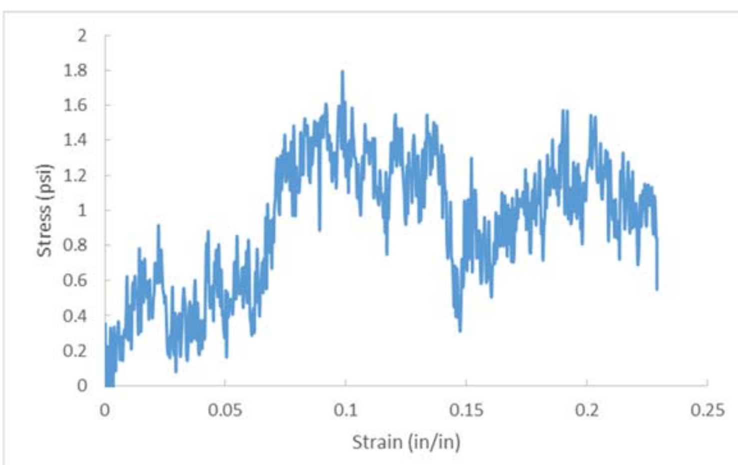


Figure A.2 D2-2, OC= 66.4%, CF= 300 pcf, T=14 days.

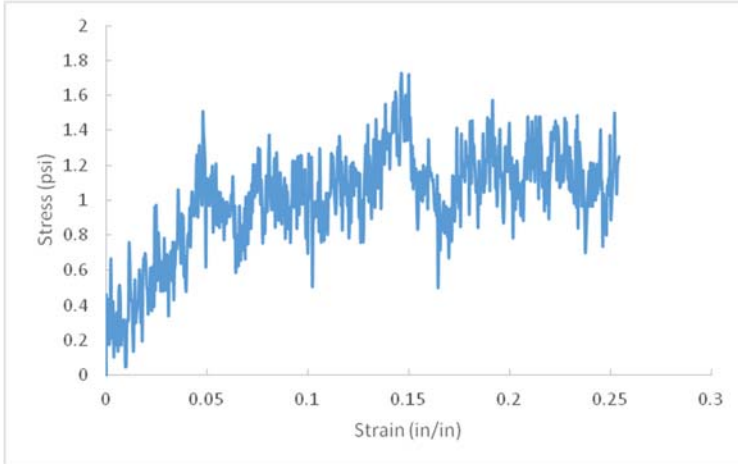

Figure A.3 D2-3, OC= 66.4%, CF= 300 pcf, T=14 days.

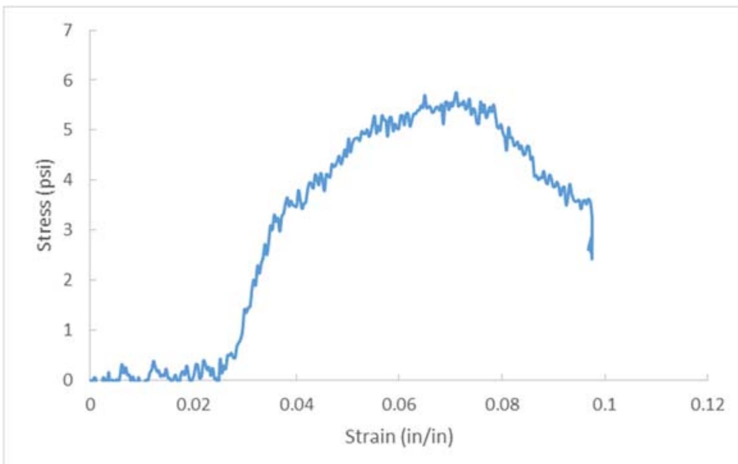

Figure A.4 D3-1, OC= 66.4%, CF= 400 pcf, T=14 days.

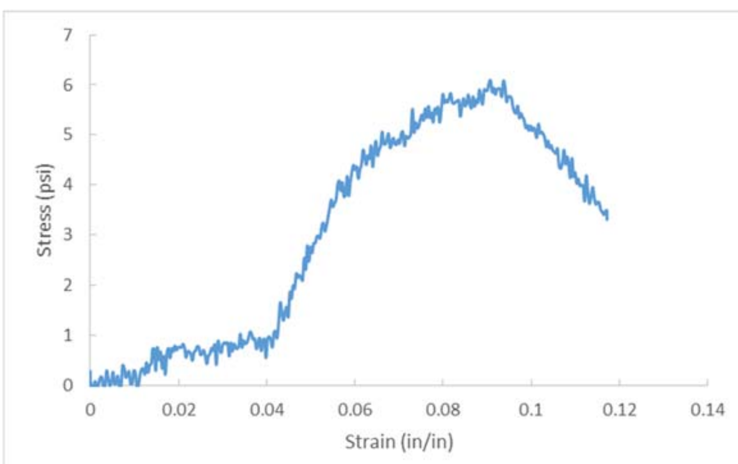

Figure A.5 D3-2, OC= 66.4%, CF= 400 pcf, T=14 days.

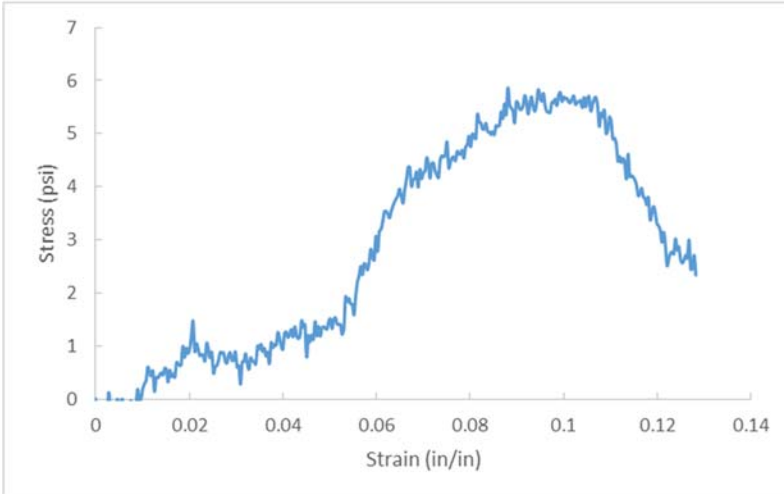

Figure A.6 D3-3, OC= 66.4%, CF= 400 pcf, T=14 days.

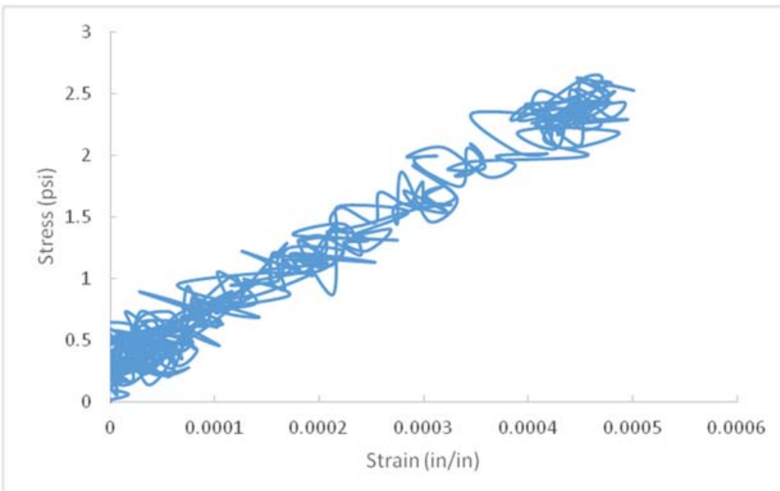

Figure A.7 D4-1, OC= 66.4%, CF= 200 pcf, T=14 days.

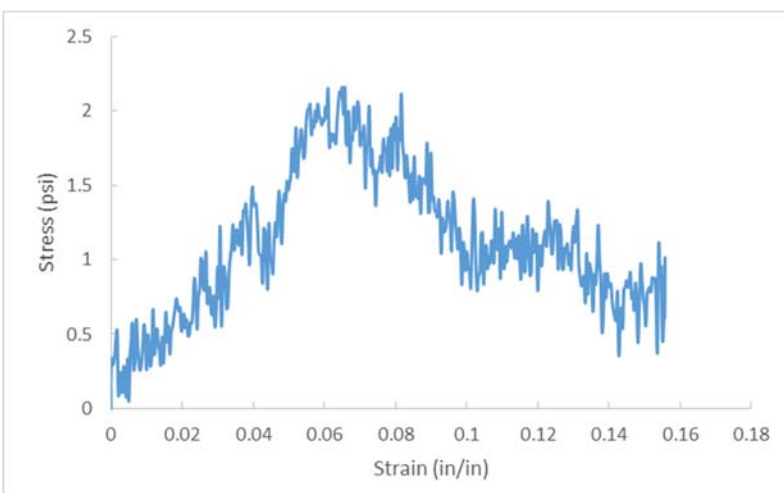

Figure A.8 D4-2, OC= 66.4%, CF= 200 pcf, T=14 days.

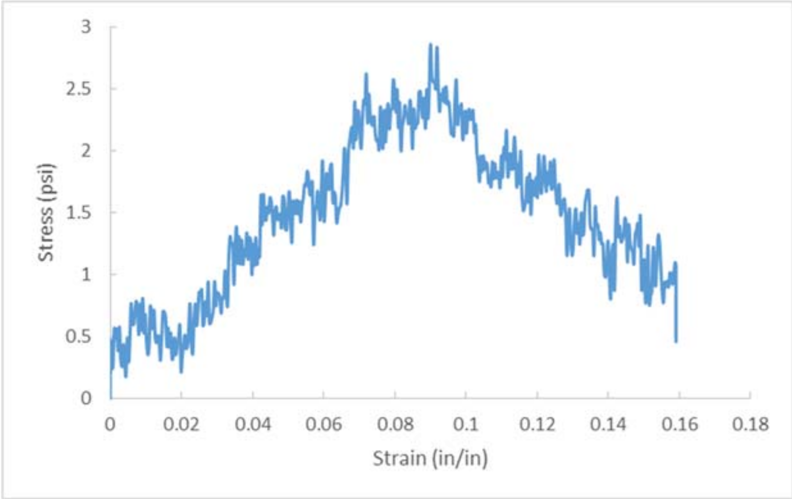


Figure A.9 D4-3, OC= 66.4%, CF= 200 pcf, T=14 days.

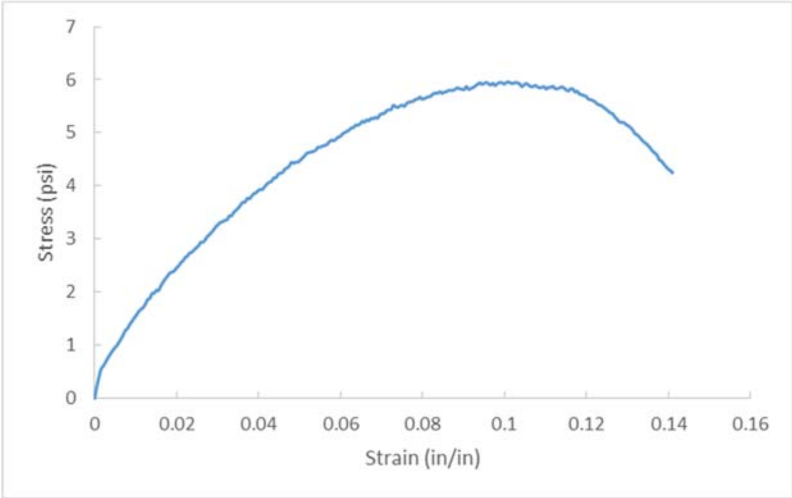


Figure A.10 D8-1, OC= 65.9%, CF= 300 pcf, T=14 days.

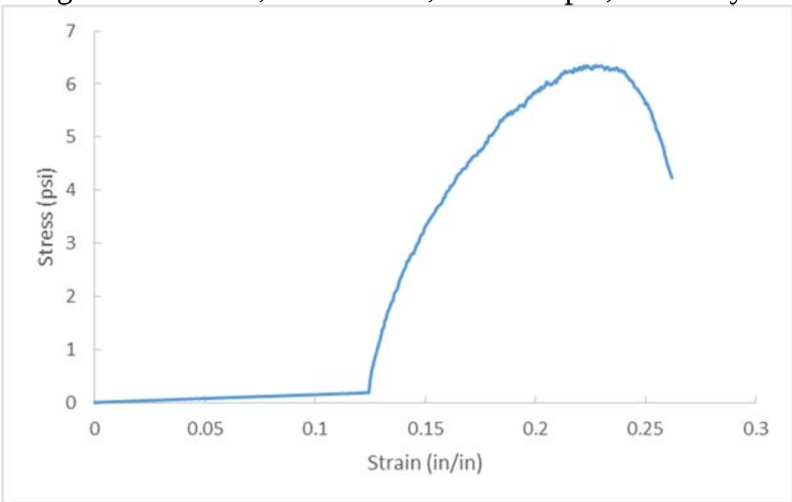


Figure A.11 D8-2, OC= 65.9%, CF= 300 pcf, T=14 days.

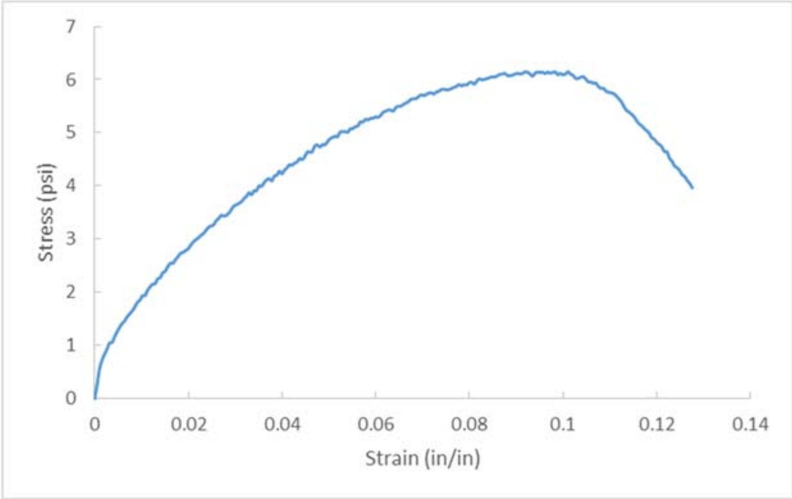

Figure A.12 D8-3, OC= 65.9%, CF= 300 pcf, T=14 days.

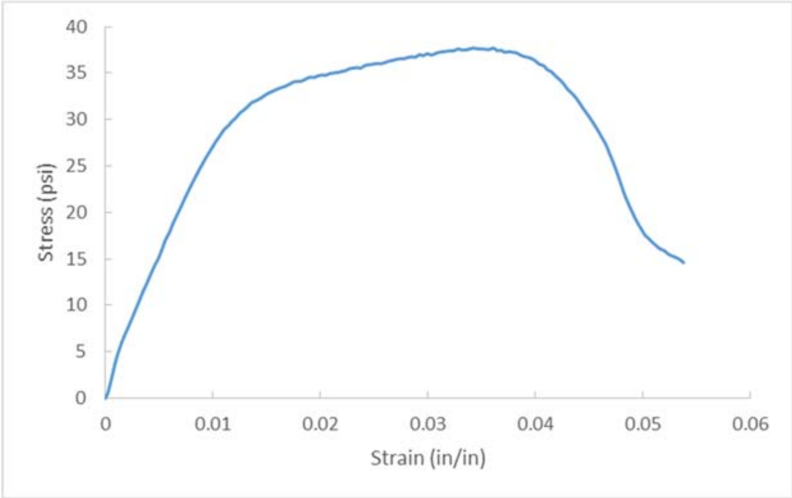

Figure A.13 D9-1, OC= 65.9%, CF= 400 pcf, T=14 days.

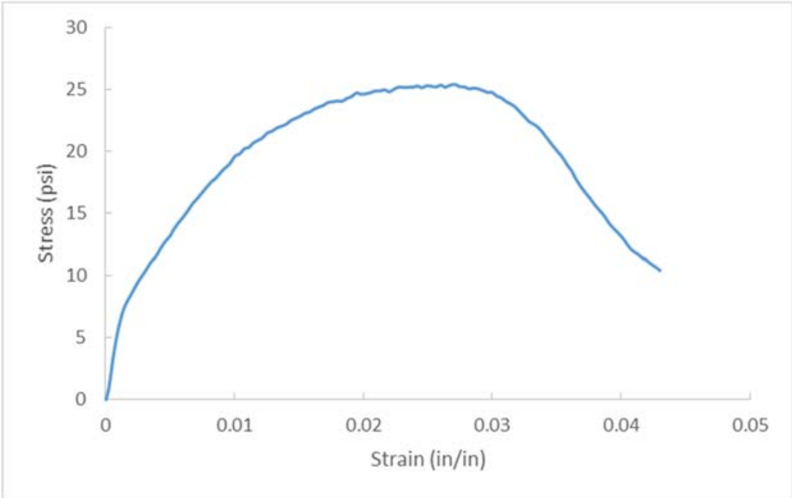

Figure A.14 D9-2, OC=65.9%, CF=400 pcf, T=14 days.

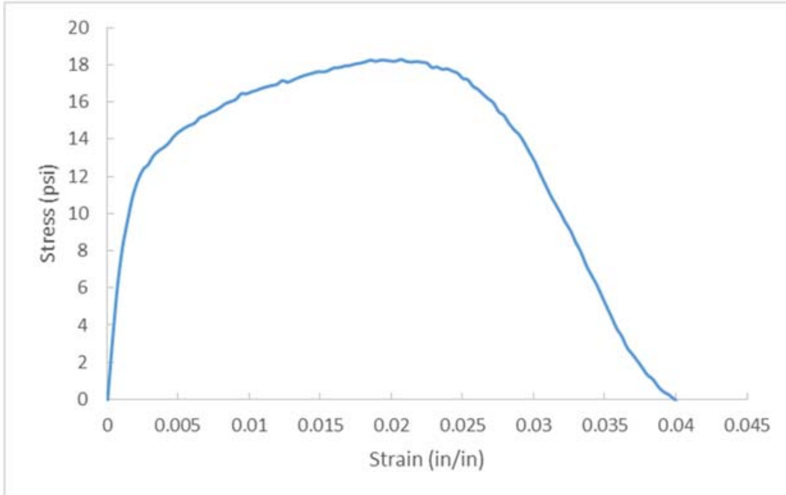


Figure A.15 D9-3, OC= 65.9%, CF= 400 pcf, T=14 days.

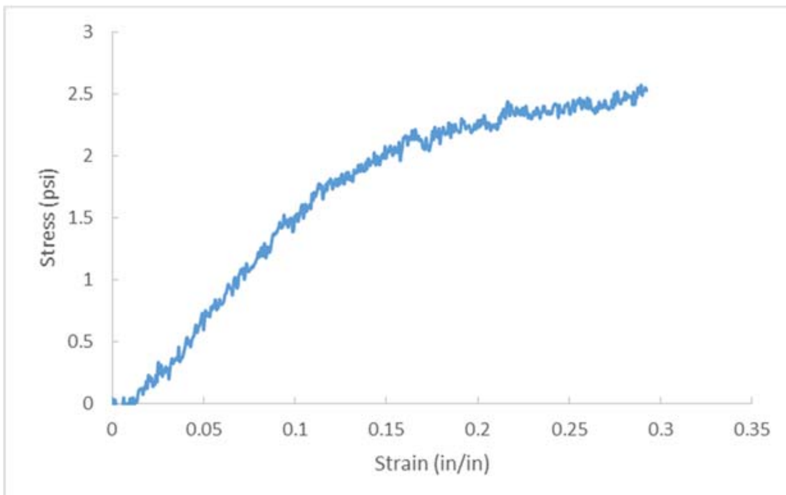


Figure A.16 D10-1, OC=41.3%, CF=300 pcf, T=14 days.

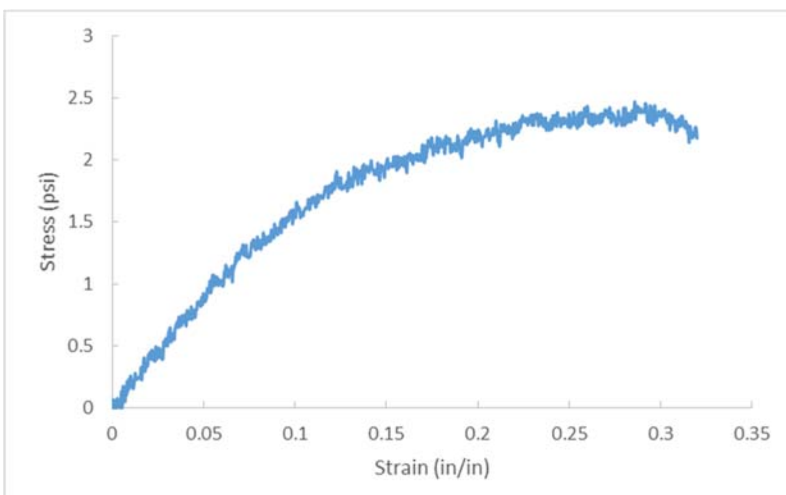


Figure A.17 D10-2, OC= 41.3%, CF= 300 pcf, T=14 days.

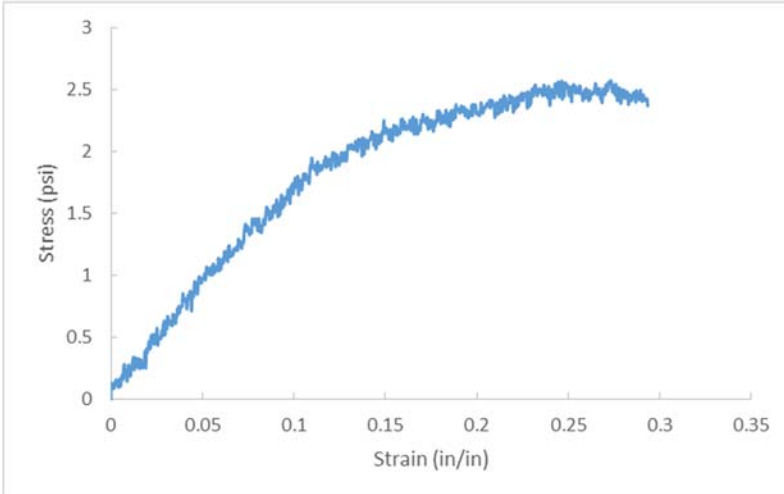


Figure A.18 D10-3, OC= 41.3%, CF= 300 pcf, T=14 days.

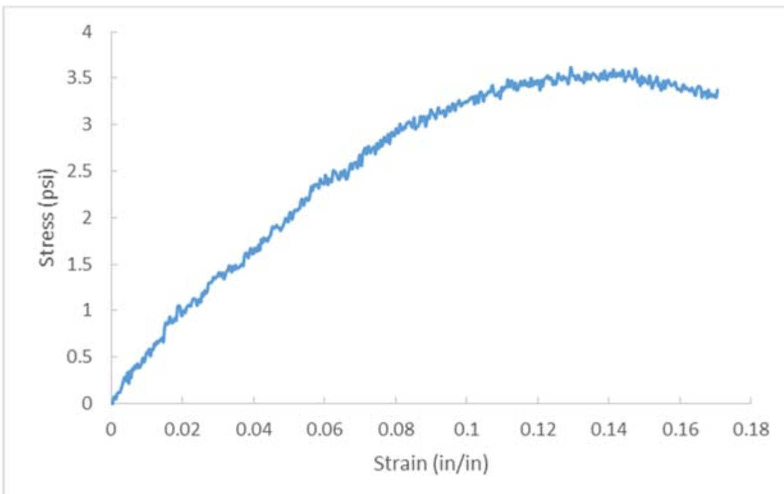


Figure A.19 D11-1, OC= 27.8%, CF= 300 pcf, T=14 days.

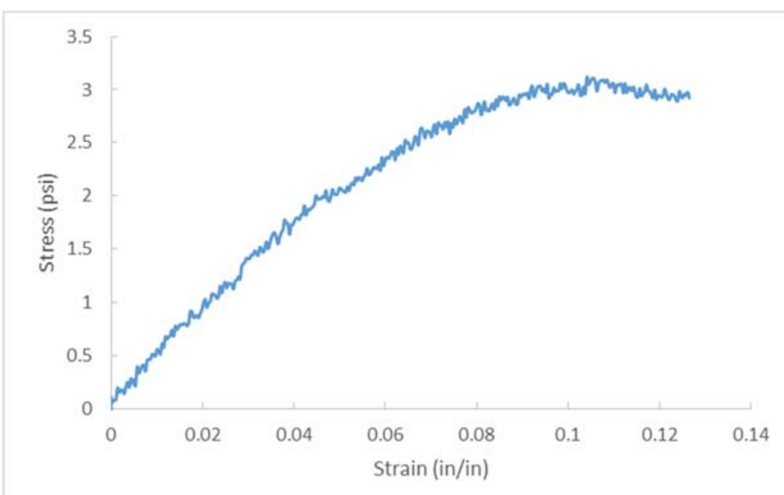


Figure A.20 D11-2, OC=27.8%, CF=300 pcf, T=14 days.

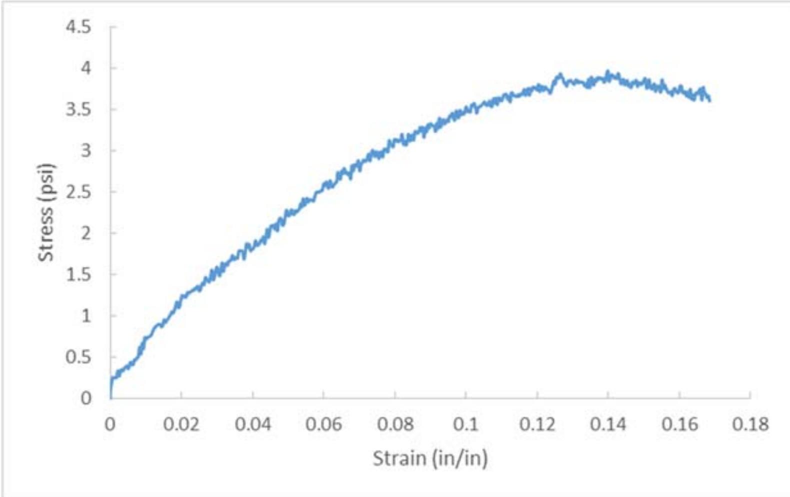


Figure A.21 D11-3, OC= 27.8%, CF= 300 pcf, T=14 days.

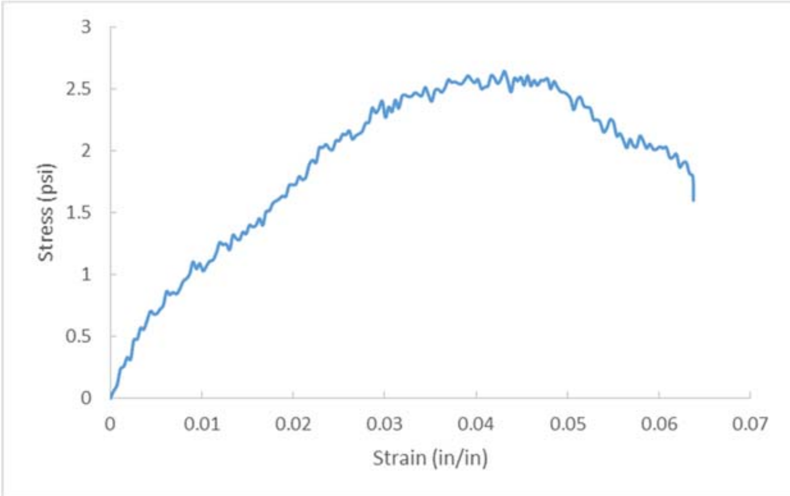


Figure A.22 D12-1, OC= 24.1%, CF= 300 pcf, T=14 days.

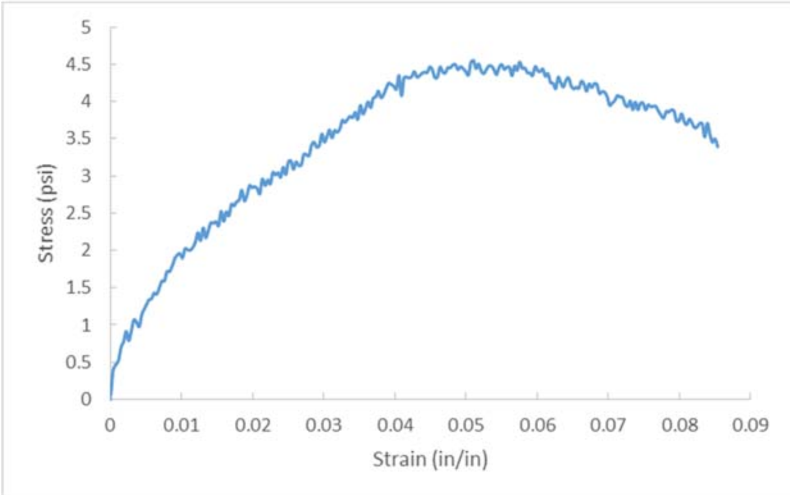


Figure A.23 D12-2, OC= 24.1%, CF= 300 pcf, T=14 days.

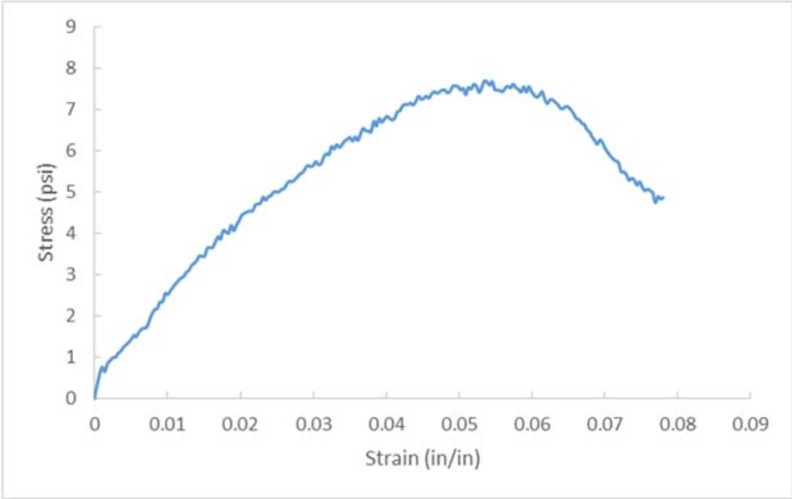

Figure A.24 D12-3, OC= 24.1%, CF= 300 pcf, T=14 days.

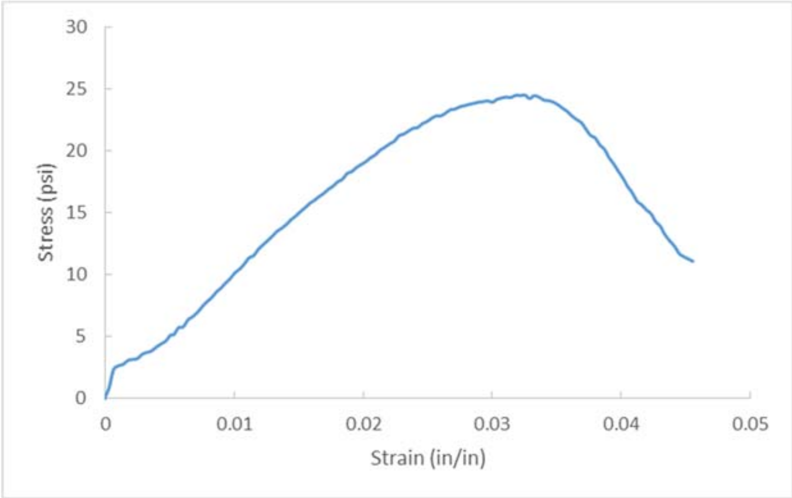

Figure A.25 D13-1, OC= 11.2%, CF= 300 pcf, T=14 days.

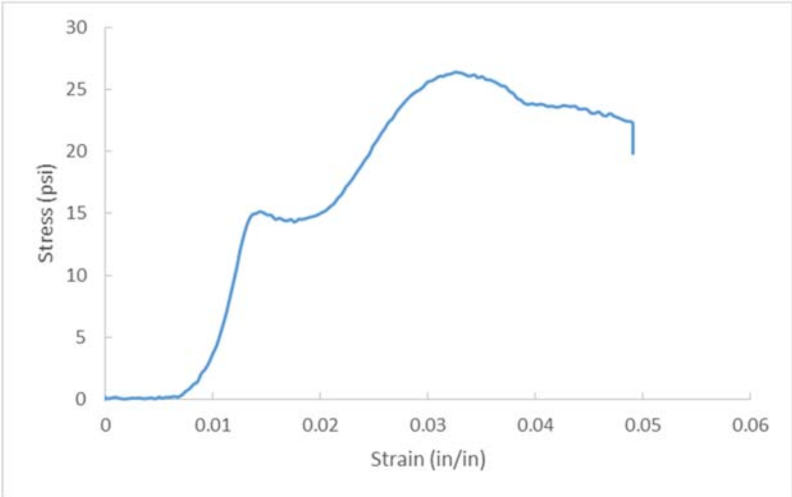

Figure A.26 D13-2, OC= 11.2%, CF= 300 pcf, T=14 days.

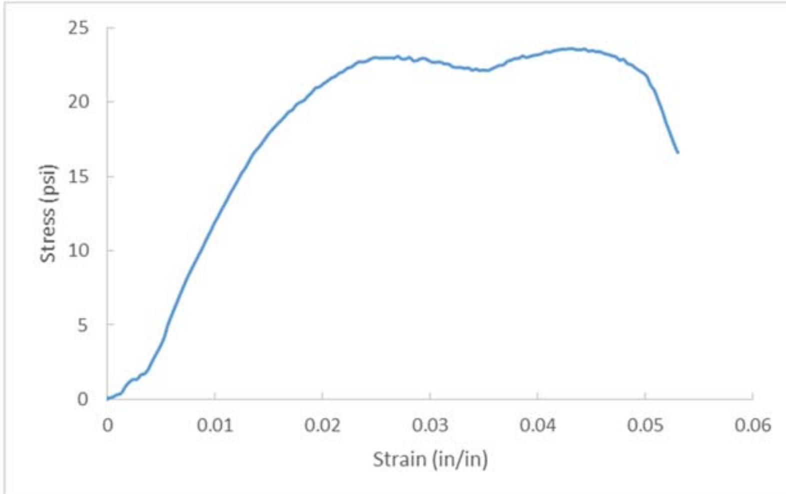


Figure A.27 D13-3, OC= 11.2%, CF= 300 pcf, T=14 days.

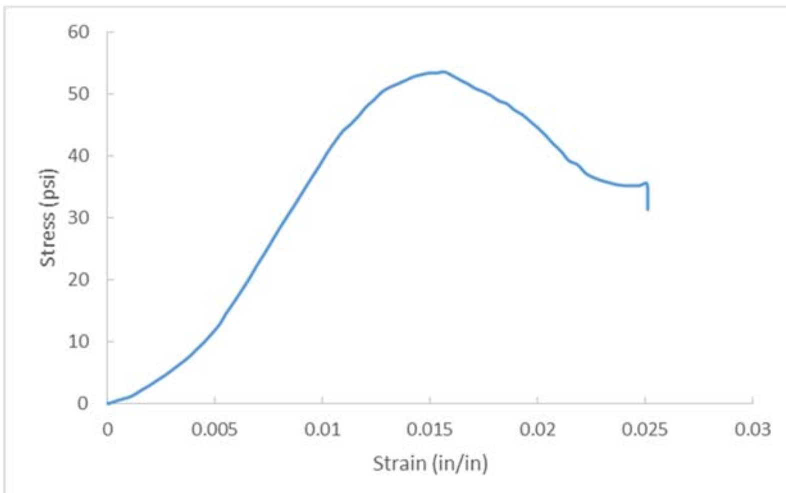


Figure A.28 D14-1, OC= 4.6%, CF= 300 pcf, T=14 days.

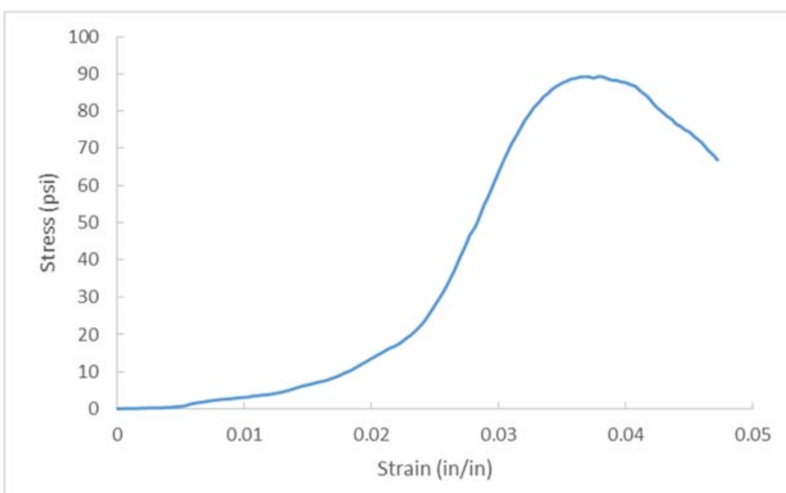


Figure A.29 D14-2, OC= 4.6%, CF= 300 pcf, T=14 days.

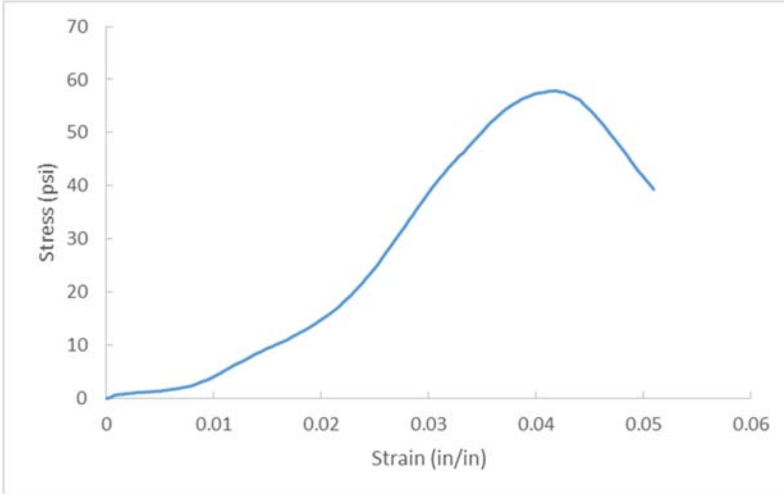


Figure A.30 D14-3, OC= 4.6%, CF= 300 pcf, T=14 days.

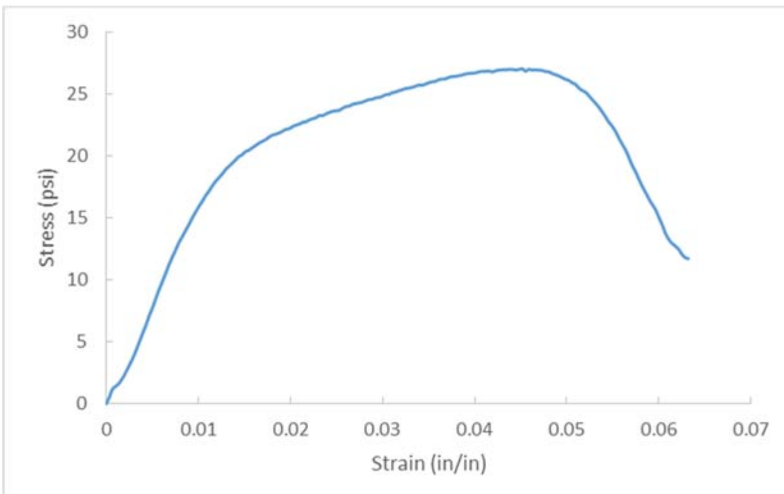


Figure A.31 D15-1, OC= 40.5%, CF= 300 pcf, T=14 days.

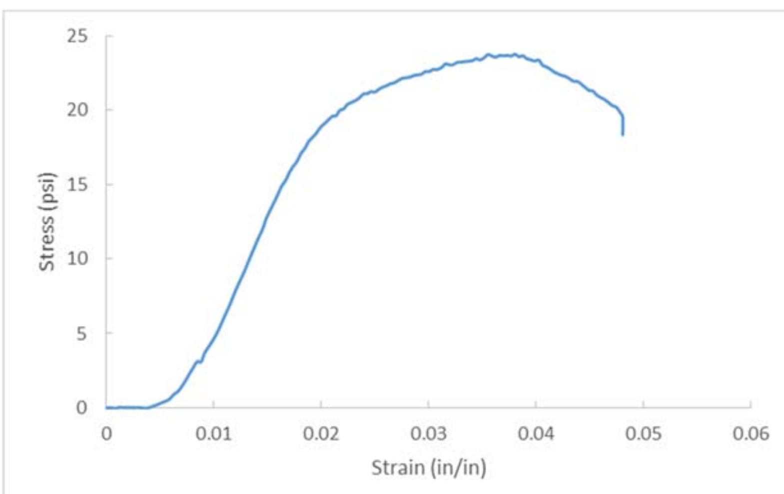


Figure A.32 D15-2, OC= 40.5%, CF= 300 pcf, T=14 days.

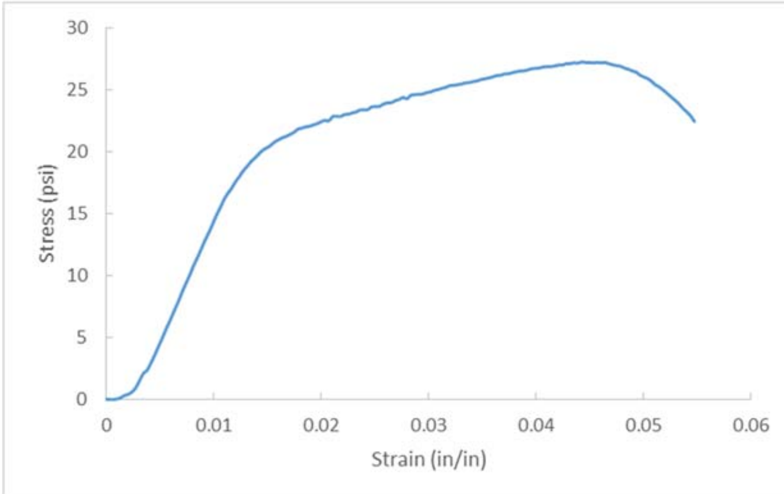

Figure A.33 D15-3, OC= 40.5%, CF= 300 pcf, T=14 days.

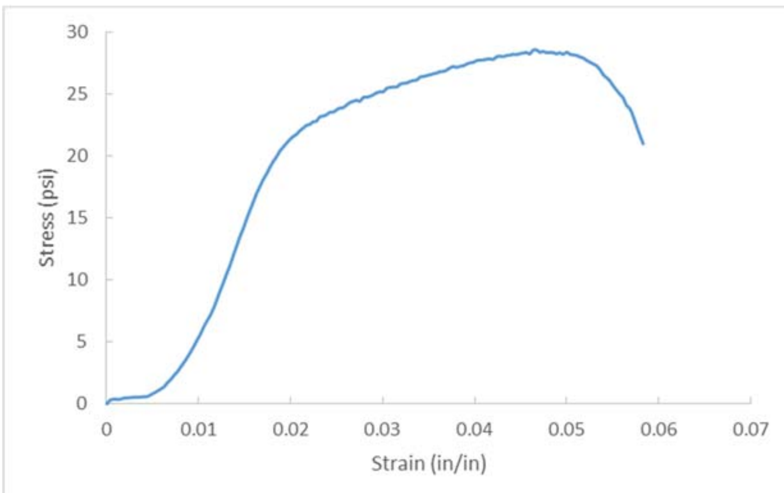

Figure A.34 D16-1, OC= 34.7%, CF= 300 pcf, T=14 days.

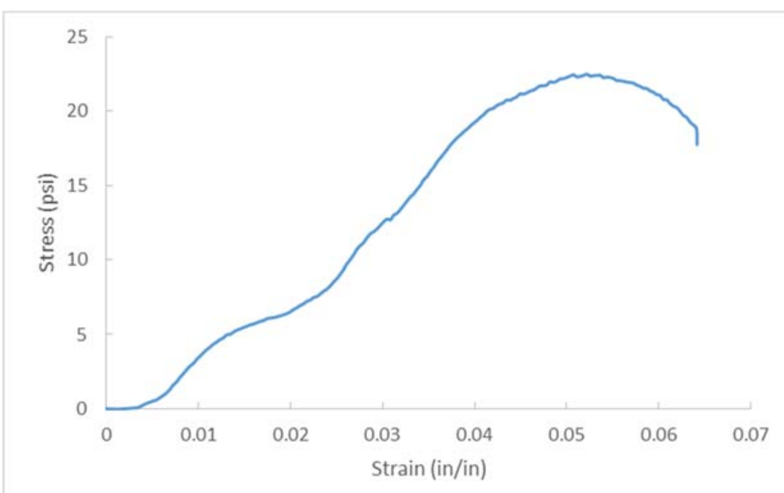

Figure A.35 D16-2, OC= 34.7%, CF= 300 pcf, T=14 days.

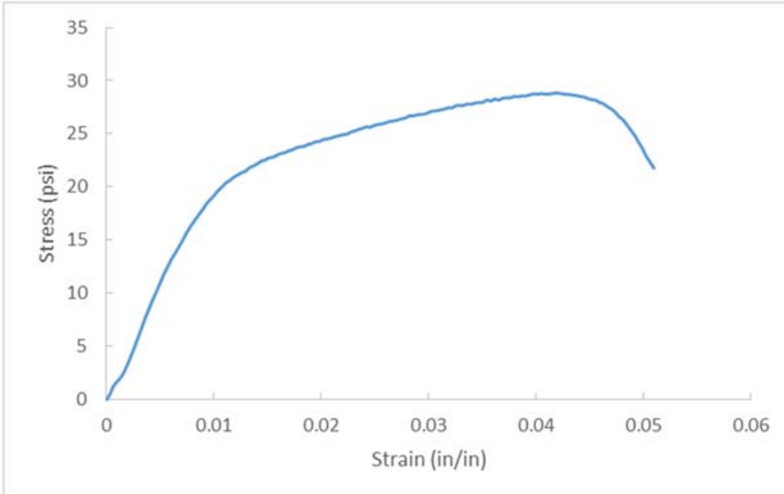

Figure A.36 D16-3, OC= 34.7%, CF= 300 pcf, T=14 days.

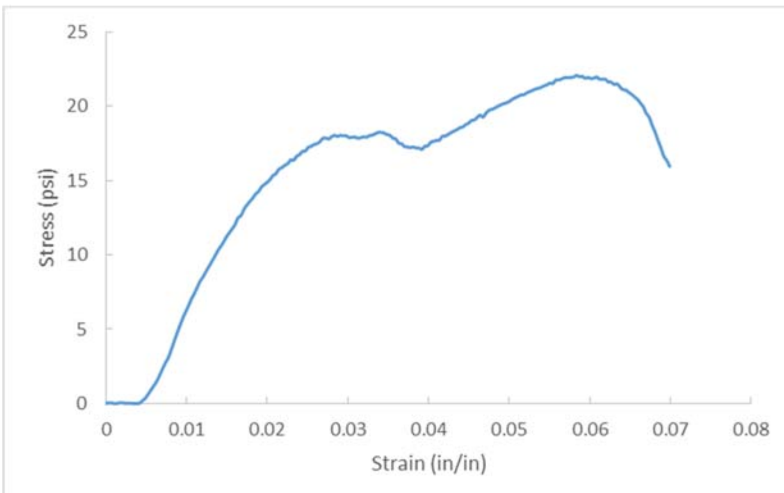

Figure A.37 D17-1, OC= 19.2%, CF= 300 pcf, T=14 days.

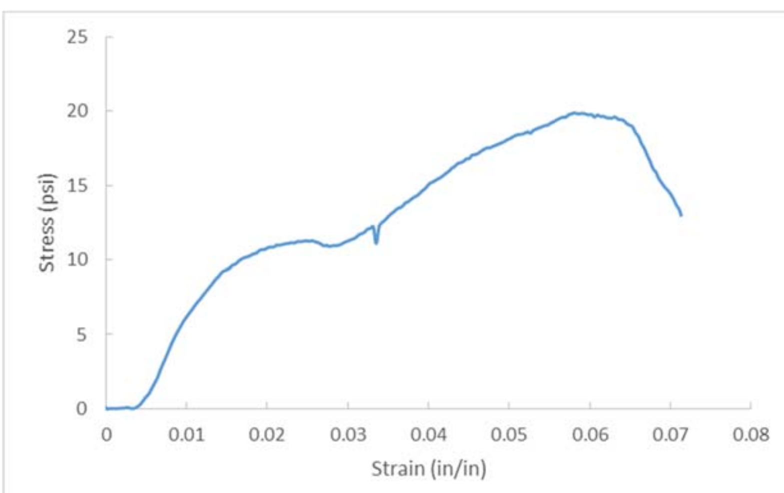

Figure A.38 D17-2, OC= 19.2%, CF= 300 pcf, T=14 days.

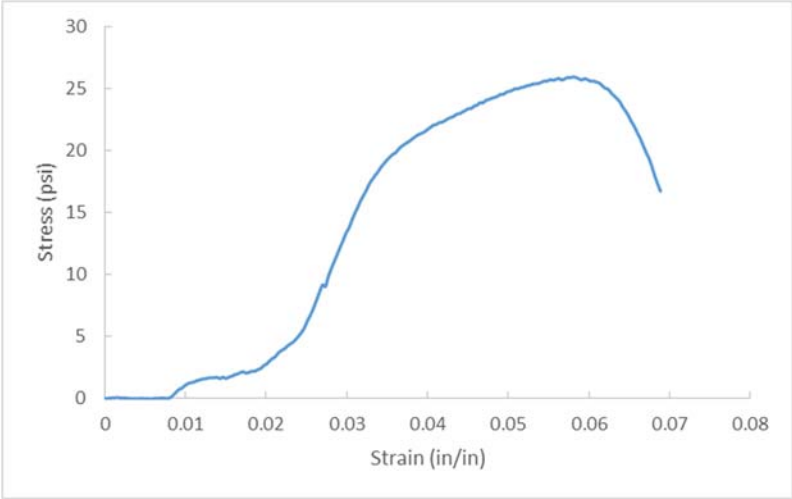

Figure A.39 D17-3, OC= 19.2%, CF= 300 pcf, T=14 days.

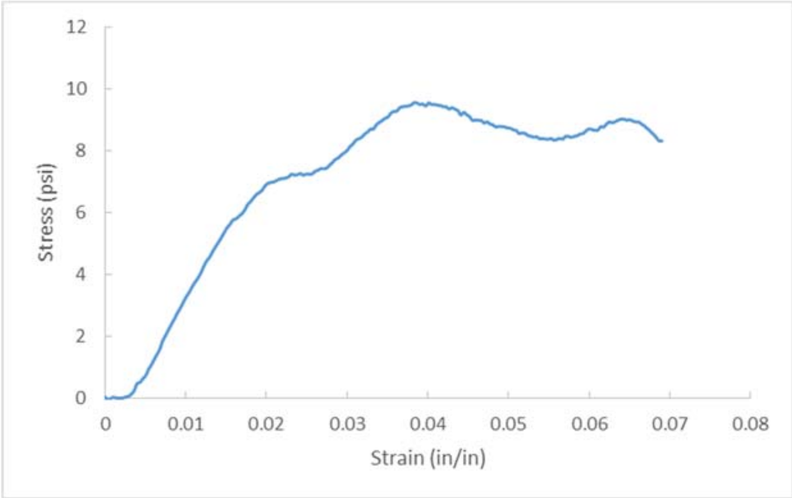

Figure A.40 D18-1, OC= 18.9%, CF= 300 pcf, T=14 days.

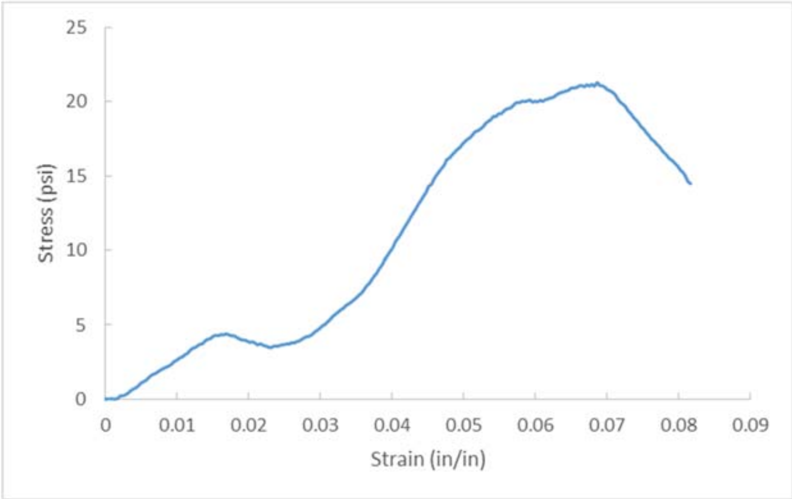

Figure A.41 D18-2, OC= 18.9%, CF= 300 pcf, T=14 days.

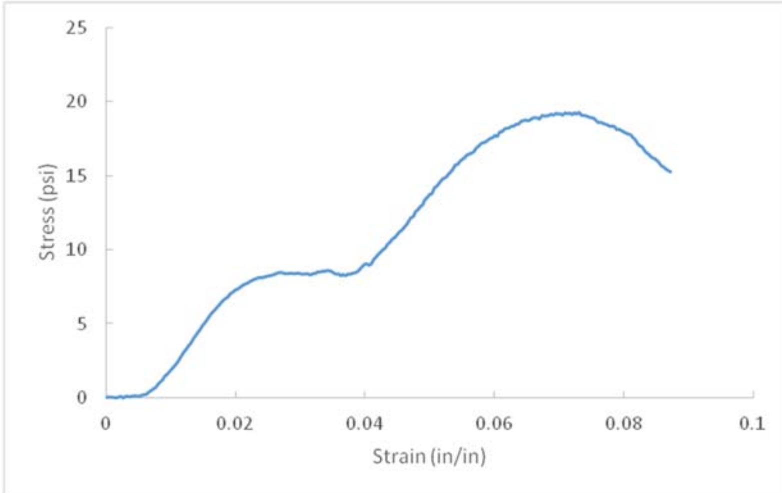


Figure A.42 D18-3, OC= 18.9%, CF= 300 pcf, T=14 days.

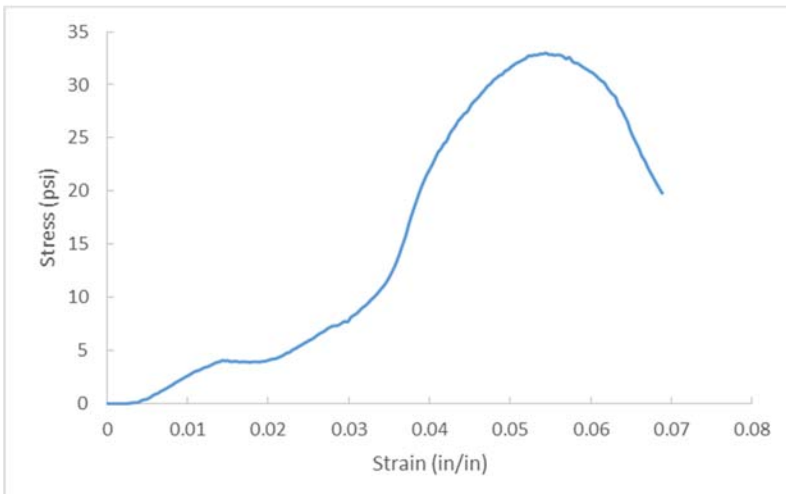


Figure A.43 D19-1, OC= 8.5%, CF= 300 pcf, T=14 days.

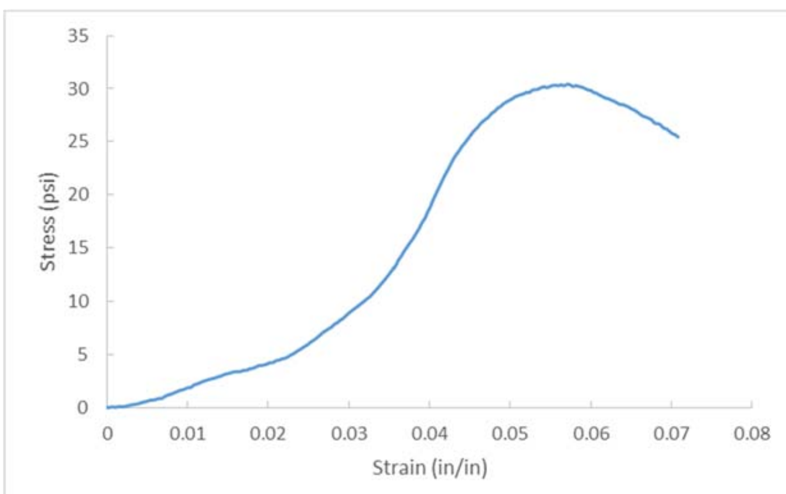


Figure A.44 D19-2, OC= 8.5%, CF= 300 pcf, T=14 days.

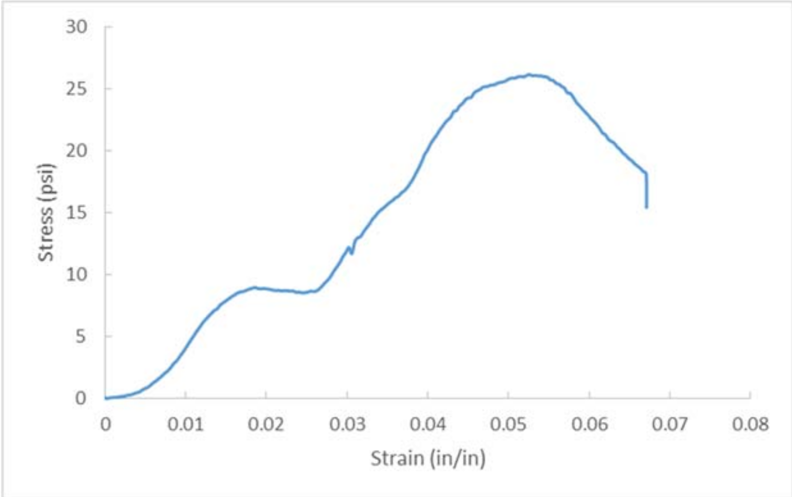

Figure A.45 D19-3, OC= 8.5%, CF= 300 pcf, T=14 days.

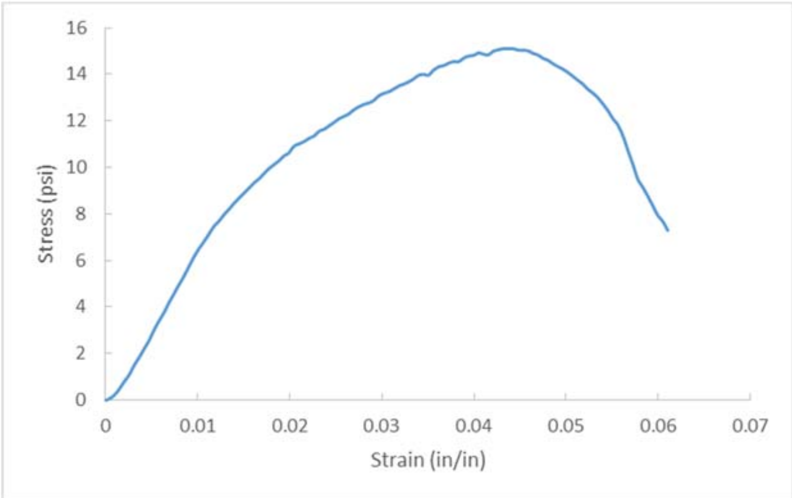

Figure A.46 D25-1, OC= 41.2%, CF= 400 pcf, T=14 days.

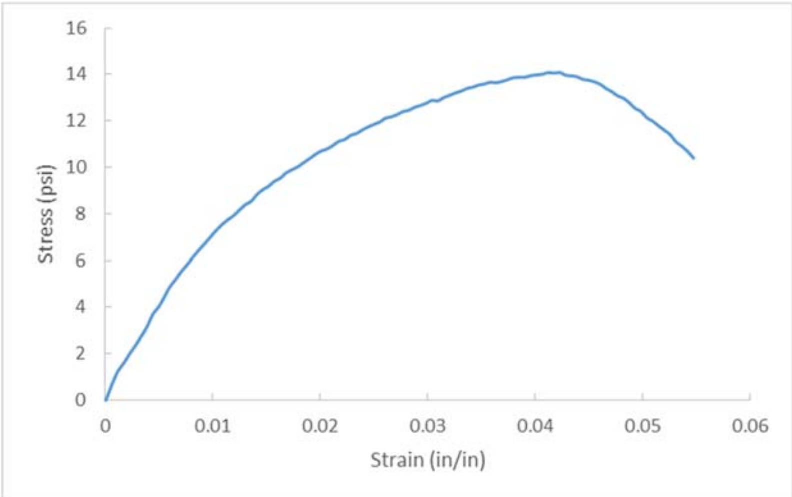

Figure A.47 D25-2, OC= 41.2%, CF= 400 pcf, T=14 days.

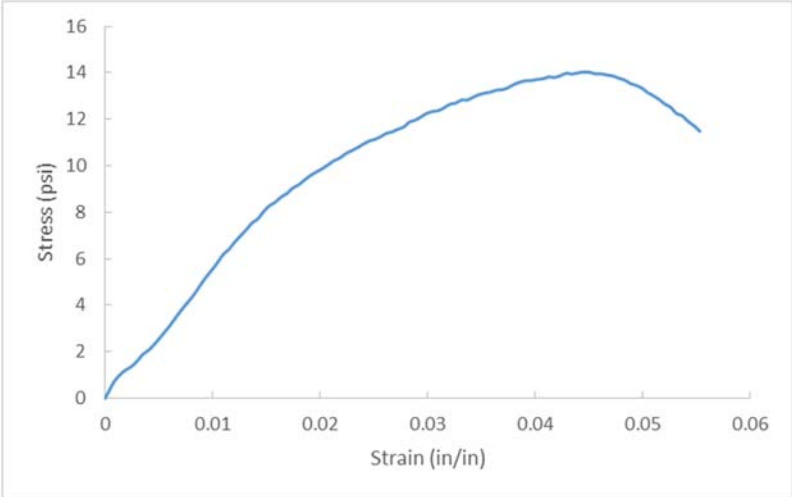

Figure A.48 D25-3, OC= 41.2%, CF= 400 pcf, T=14 days.

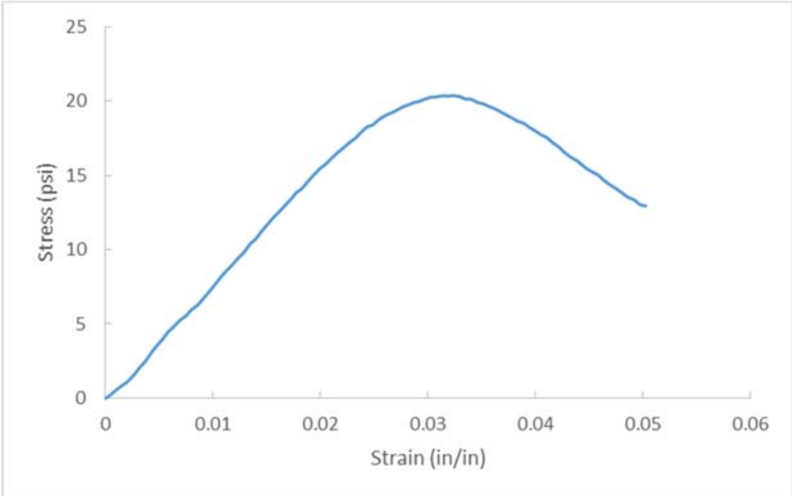

Figure A.49 D26-1, OC= 29.8%, CF= 400 pcf, T=14 days.

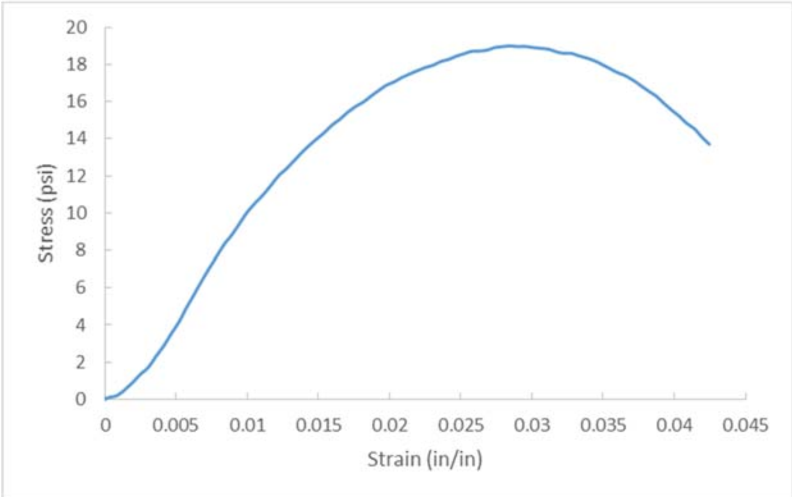

Figure A.50 D26-2, OC= 29.8%, CF= 400 pcf, T=14 days.

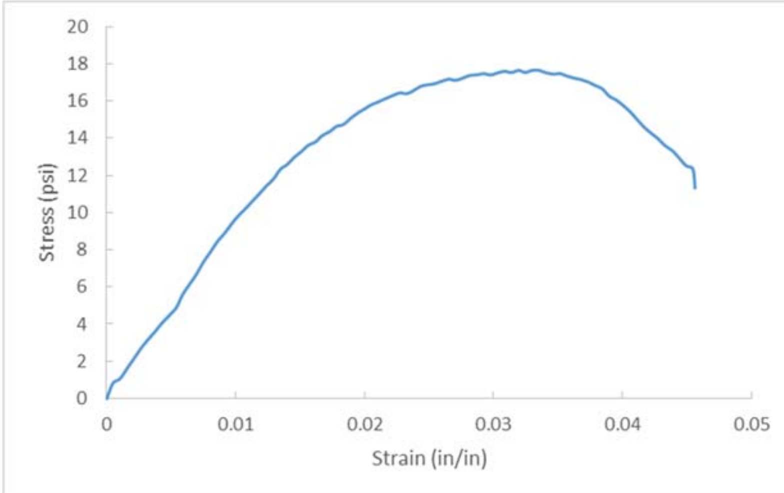


Figure A.51 D26-3, OC= 29.8%, CF= 400 pcf, T=14 days.

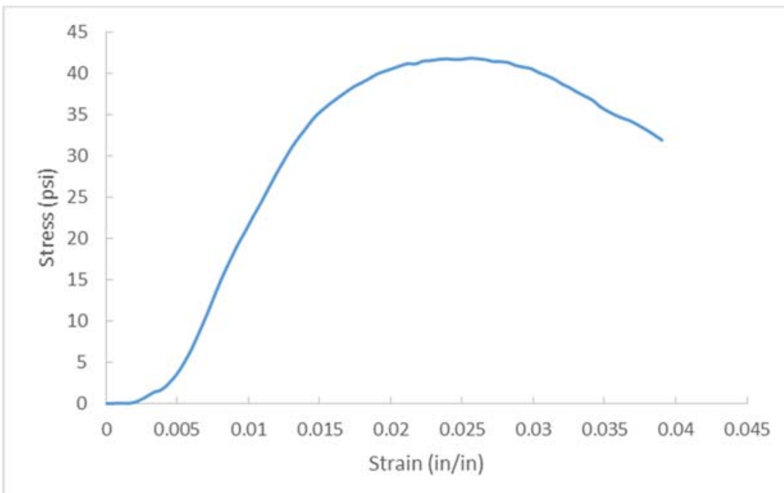


Figure A.52 D27-1, OC= 21.1%, CF= 400 pcf, T=14 days.

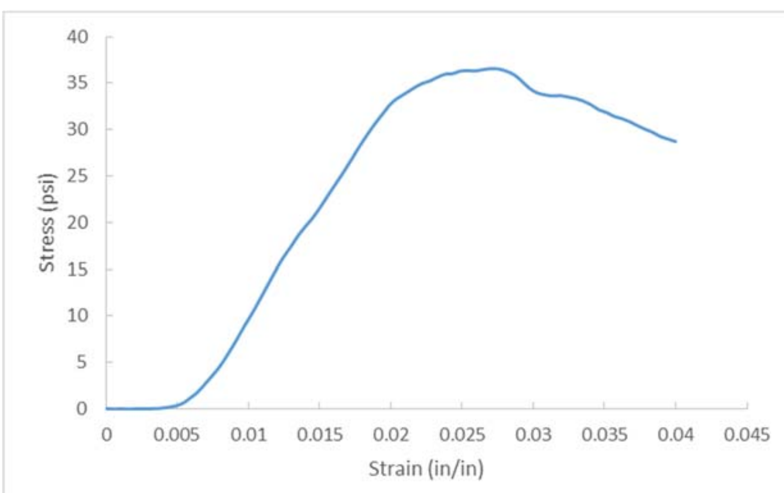


Figure A.53 D27-2, OC= 21.1%, CF= 400 pcf, T=14 days.

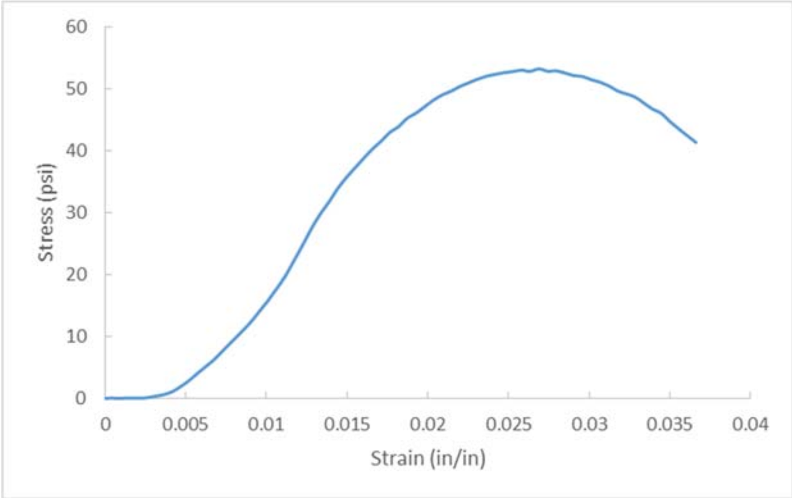

Figure A.54 D27-3, OC= 21.1%, CF= 400 pcf, T=14 days.

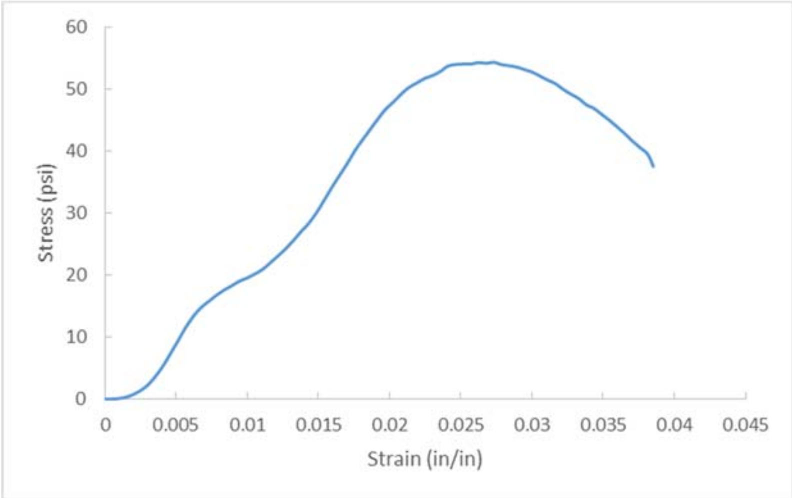

Figure A.55 D28-1, OC= 12.6%, CF= 400 pcf, T=14 days.

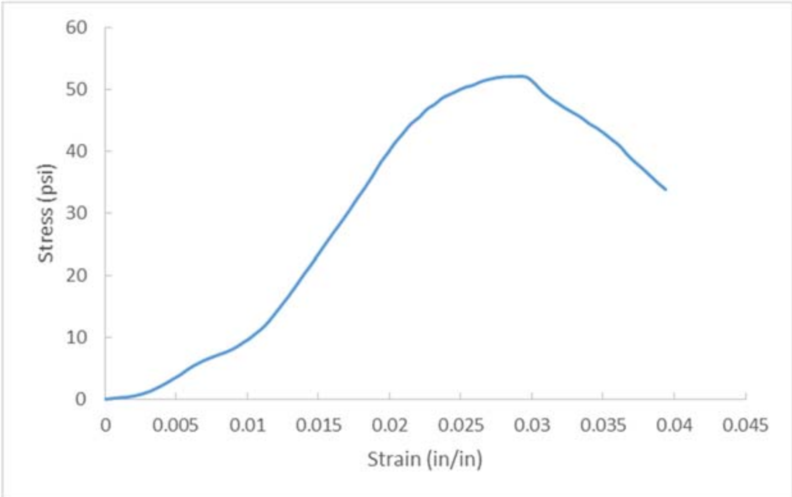

Figure A.56 D28-2, OC= 12.6%, CF= 400 pcf, T=14 days.

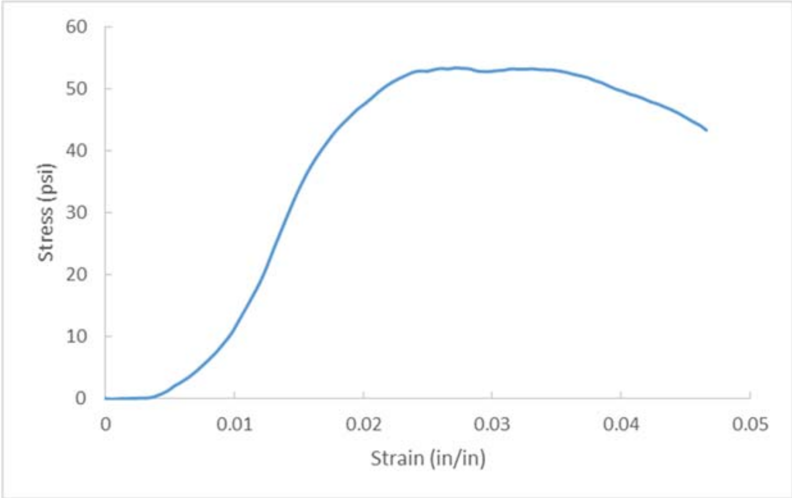

Figure A.57 D28-3, OC= 12.6%, CF= 400 pcf, T=14 days.

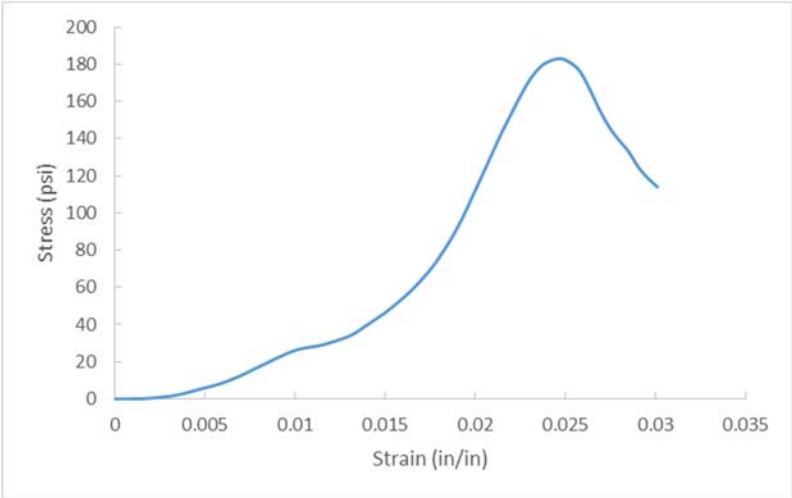

Figure A.58 D29-1, OC= 4.2%, CF= 400 pcf, T=14 days.

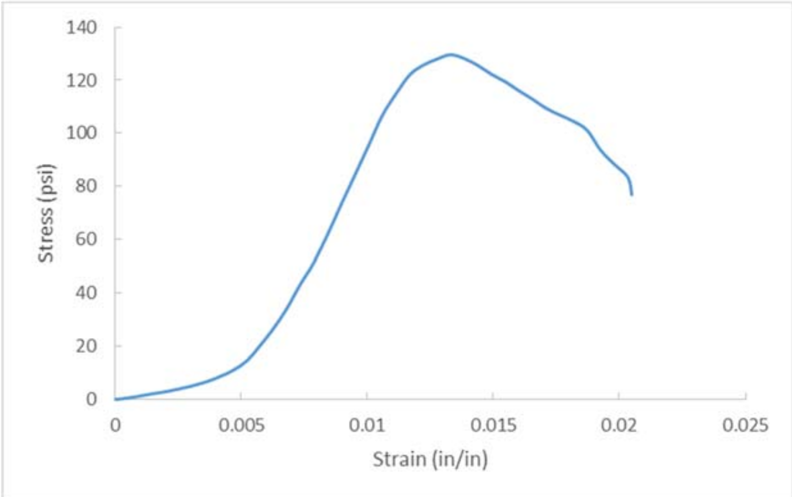

Figure A.59 D29-2, OC= 4.2%, CF= 400 pcf, T=14 days.

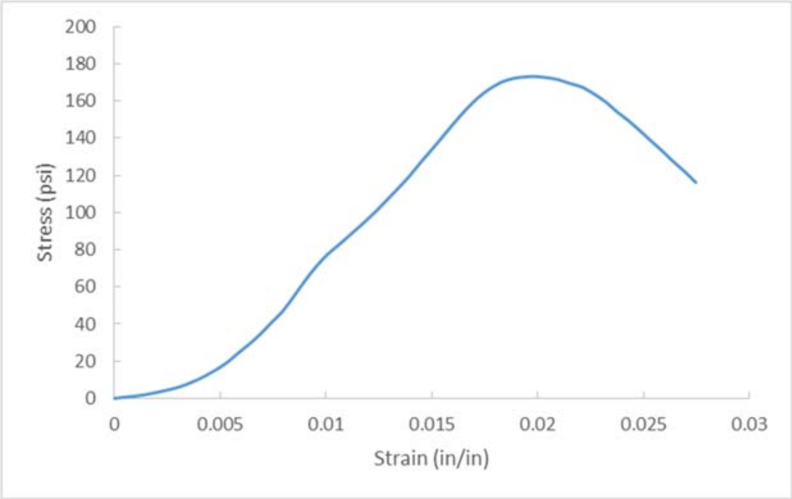


Figure A.60 D29-3, OC= 4.2%, CF= 400 pcf, T=14 days.

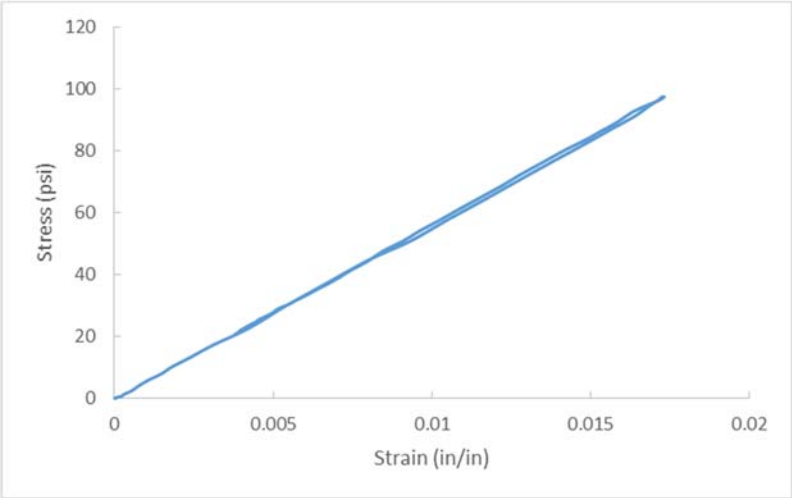


Figure A.61 D30-1, OC= 4.9%, CF= 400 pcf, T=14 days.

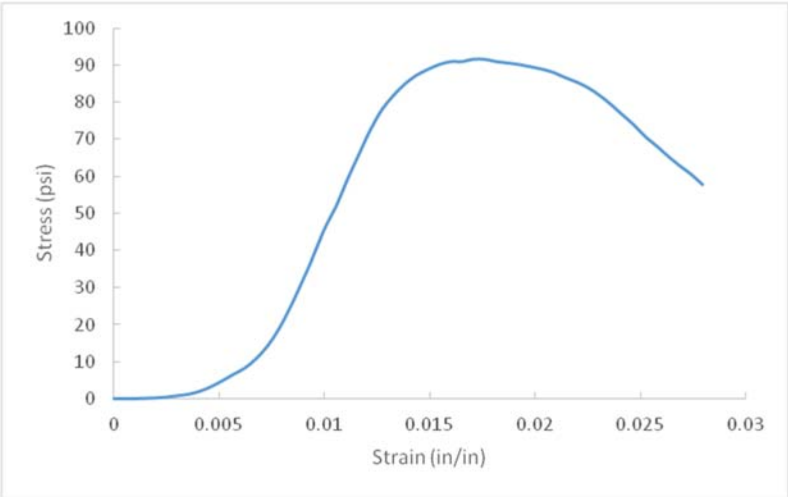


Figure A.62 D30-2, OC= 4.9%, CF= 400 pcf, T=14 days.

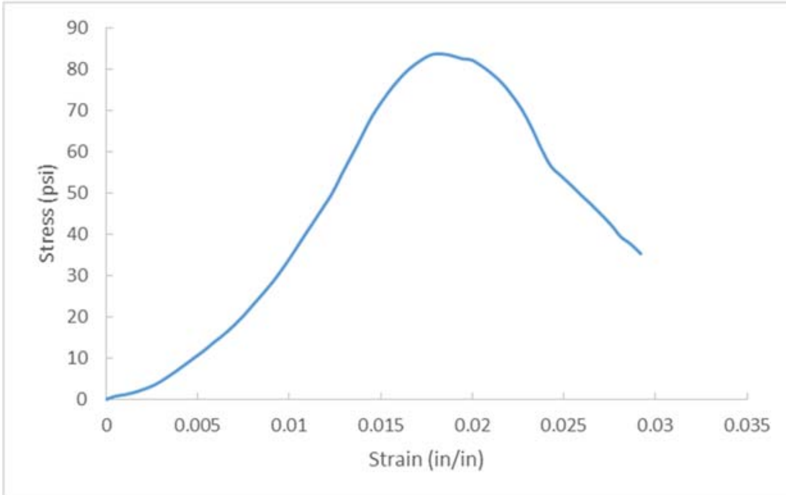


Figure A.63 D30-3, OC= 4.9%, CF= 400 pcf, T=14 days.

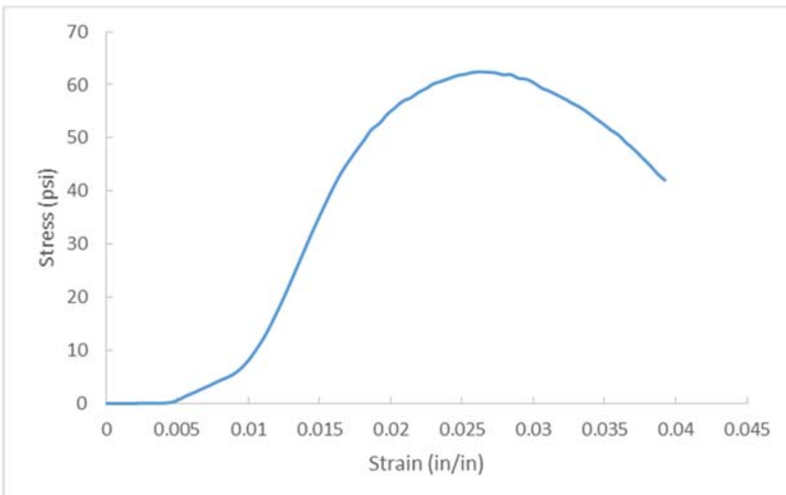


Figure A.64 D31-1, OC= 11.8%, CF= 400 pcf, T=14 days.

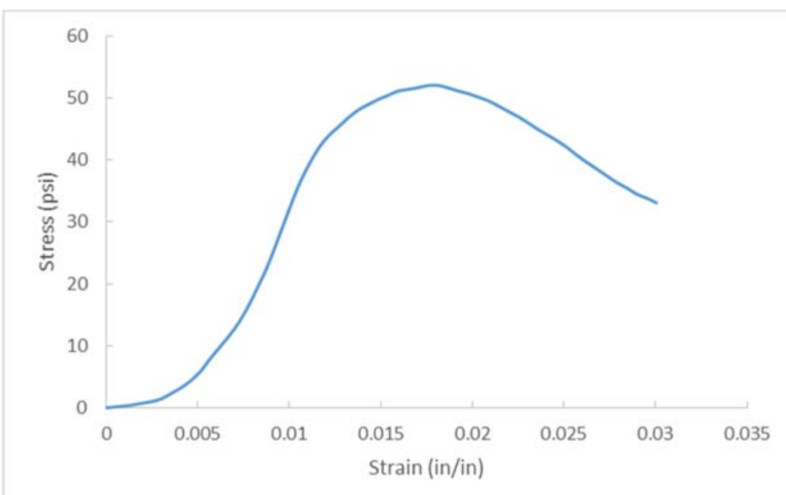


Figure A.65 D31-2, OC= 11.8%, CF= 400 pcf, T=14 days.

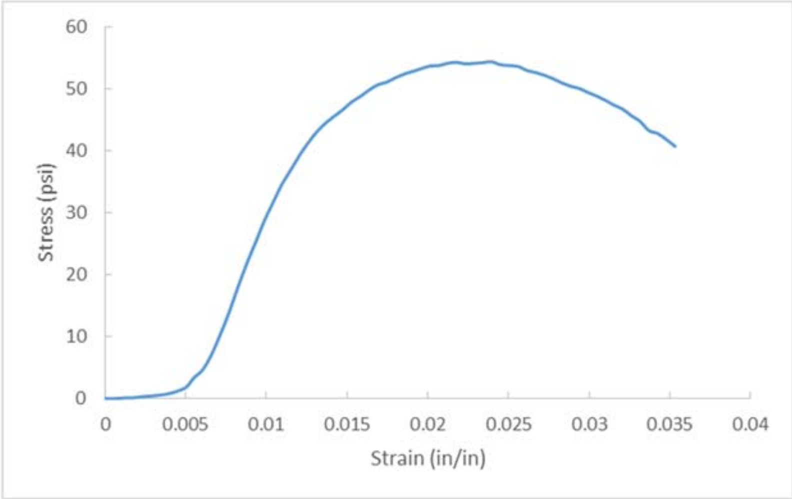

Figure A.66 D31-3, OC= 11.8%, CF= 400 pcf, T=14 days.

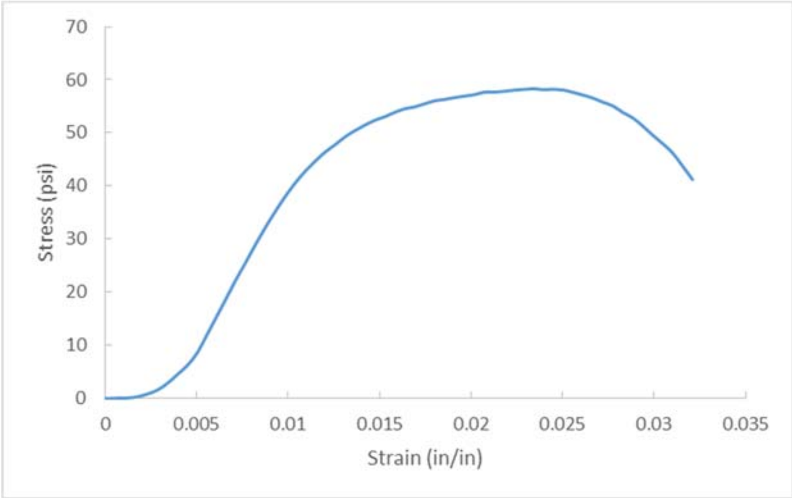

Figure A.67 D32-1, OC= 17.2%, CF= 400 pcf, T=14 days.

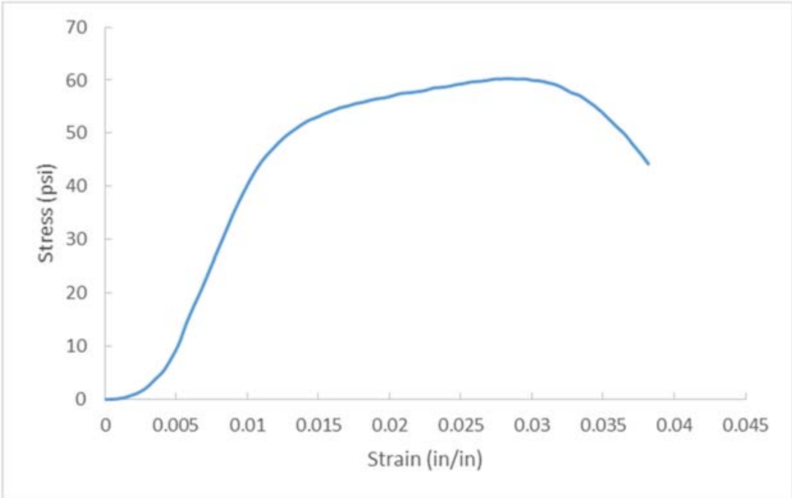

Figure A.68 D32-2, OC= 17.2%, CF= 400 pcf, T=14 days.

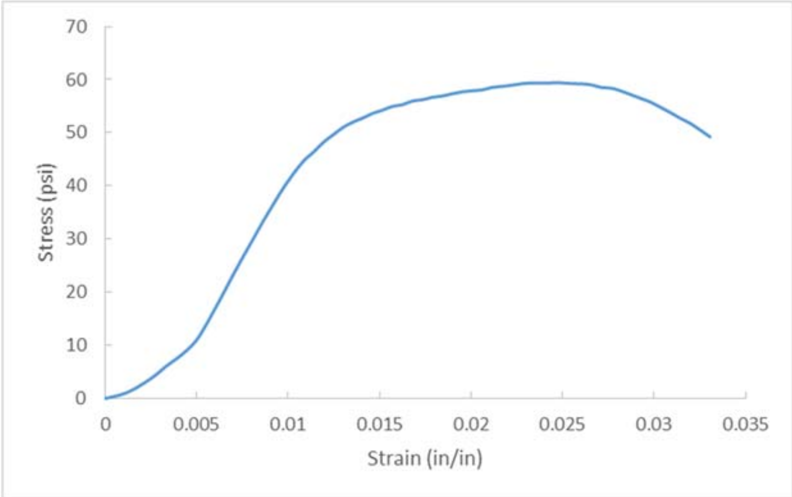

Figure A.69 D32-3, OC= 17.2%, CF= 400 pcf, T=14 days.

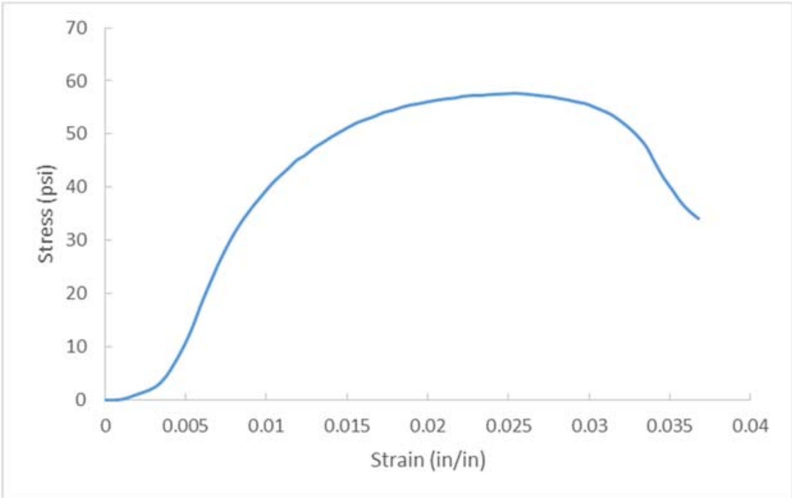

Figure A.70 D33-1, OC= 25.1%, CF= 400 pcf, T=14 days.

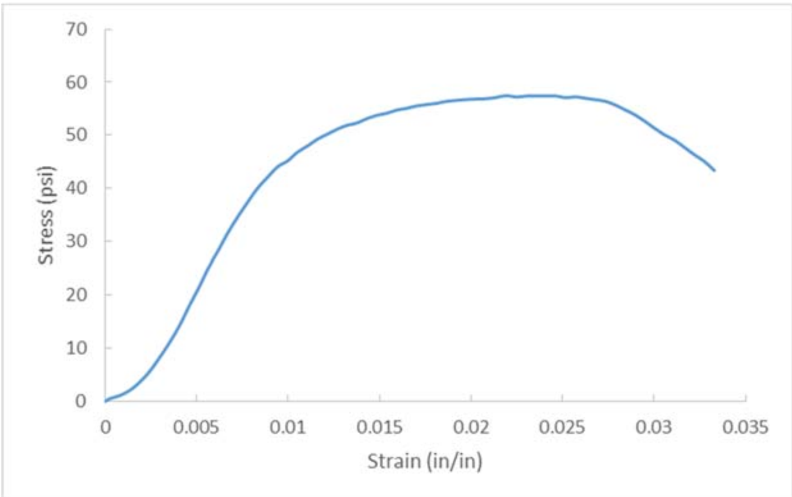

Figure A.71 D33-2, OC= 25.1%, CF= 400 pcf, T=14 days.

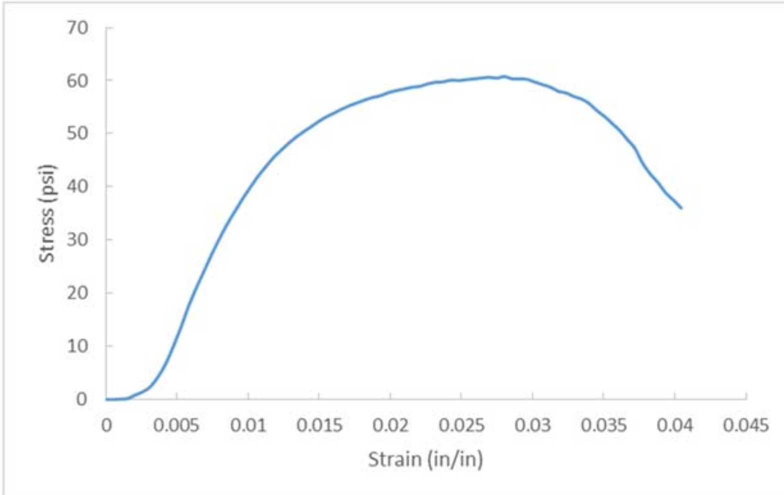

Figure A.72 D33-3, OC= 25.1%, CF= 400 pcf, T=14 days.

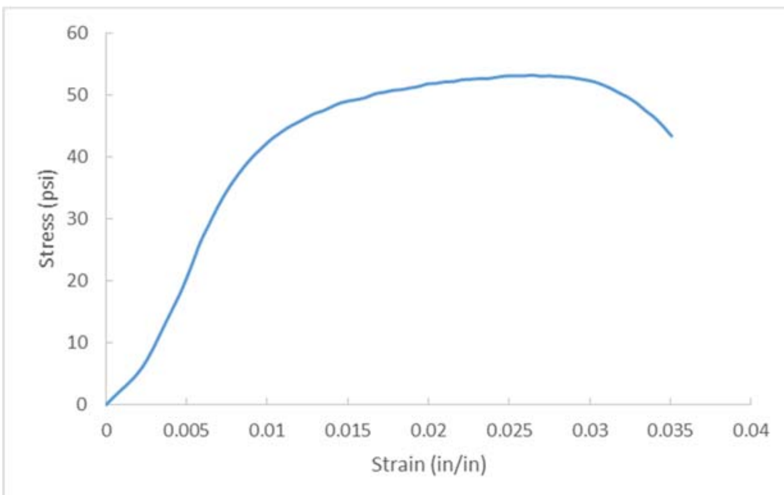

Figure A.73 D34-1, OC= 40.9%, CF= 400 pcf, T=14 days.

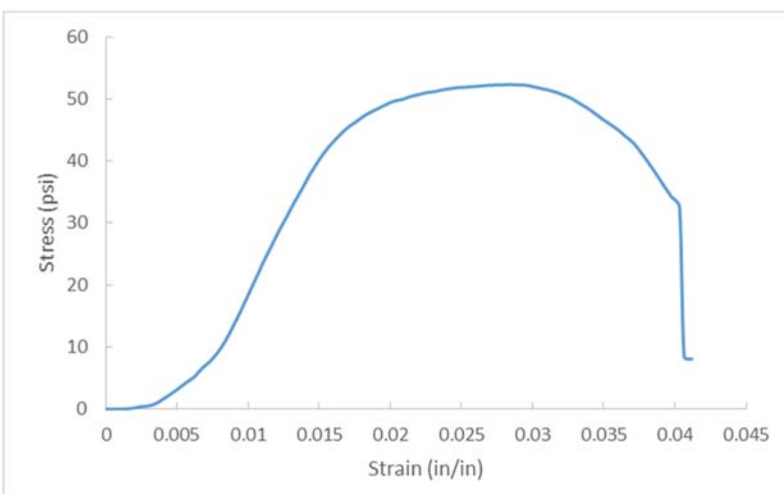

Figure A.74 D34-4, OC= 40.9%, CF= 400 pcf, T=14 days.

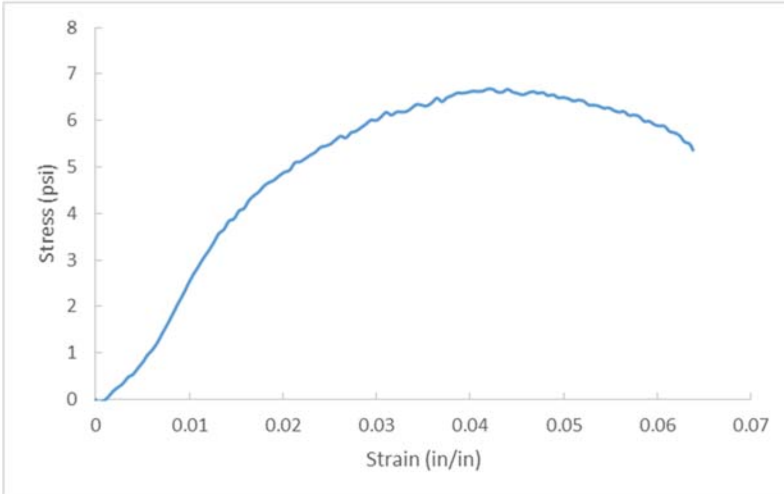


Figure A.75 D35-4, OC= 39.6%, CF= 200 pcf, T=14 days.

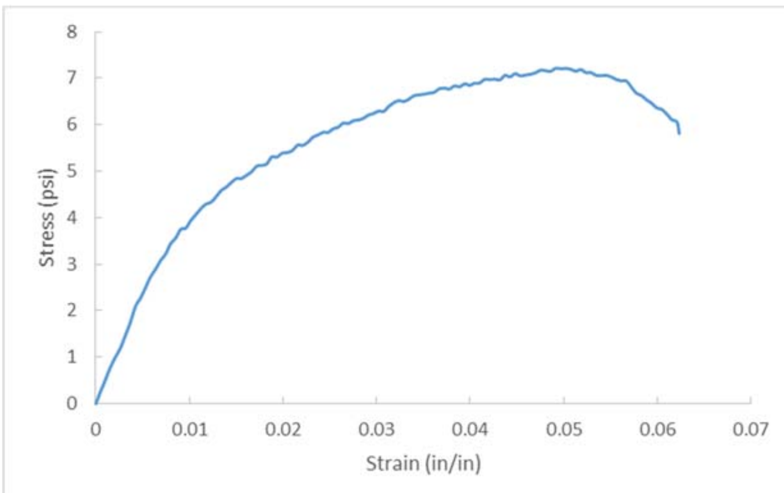


Figure A.76 D35-5, OC= 39.6%, CF= 200 pcf, T=14 days.

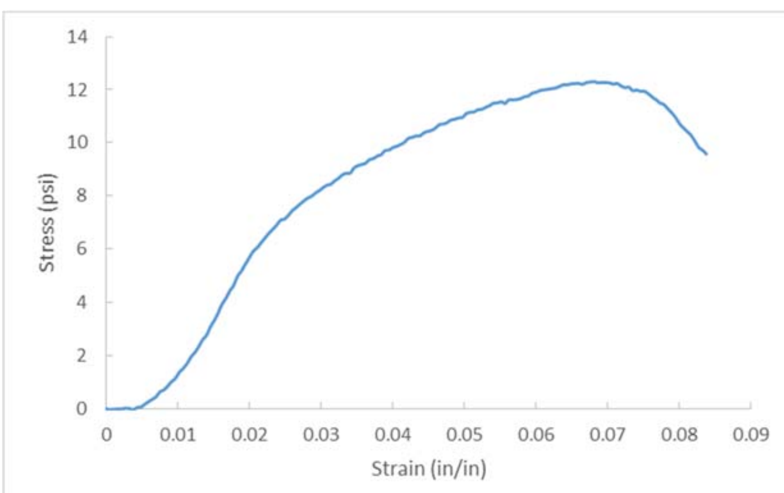


Figure A.77 D36-2, OC= 25.6%, CF= 200 pcf, T=14 days.

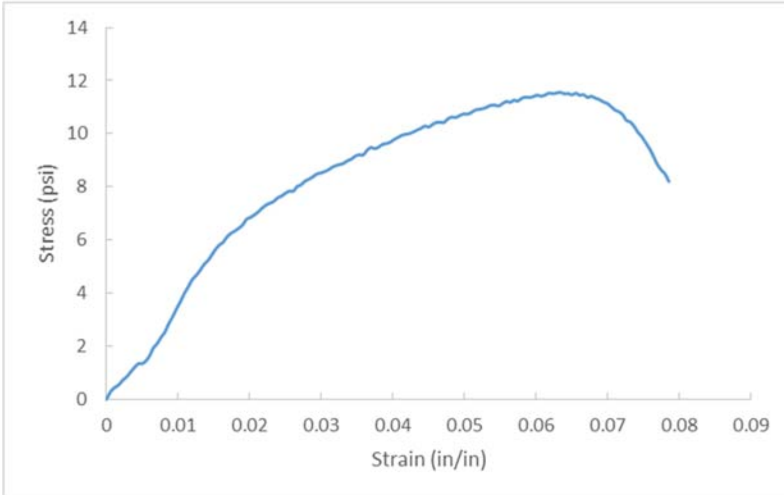

Figure A.78 D36-3, OC= 25.6%, CF= 200 pcf, T=14 days.

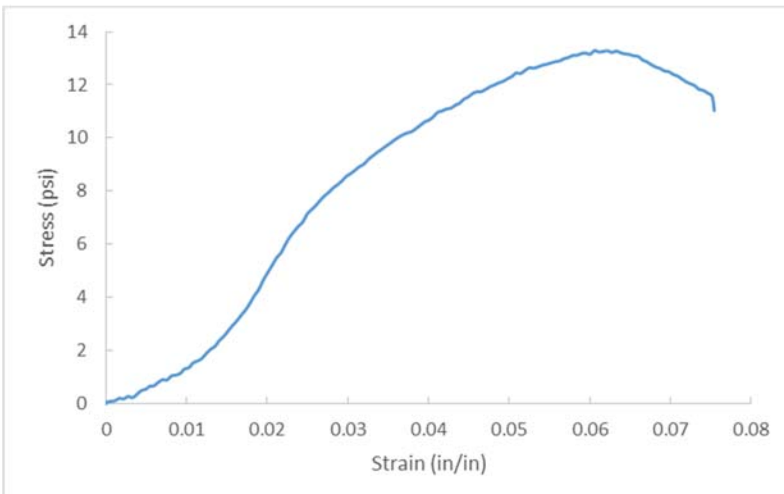

Figure A.79 D37-1, OC= 18.9%, CF= 200 pcf, T=14 days.

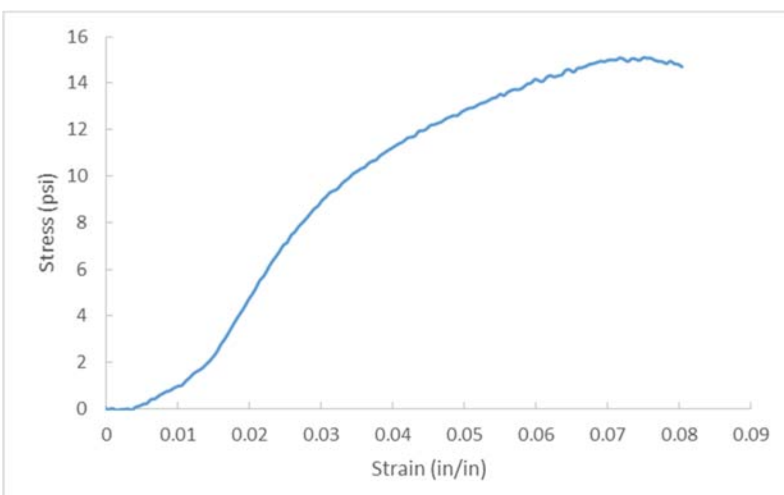

Figure A.80 D37-2, OC= 18.9%, CF= 200 pcf, T=14 days.

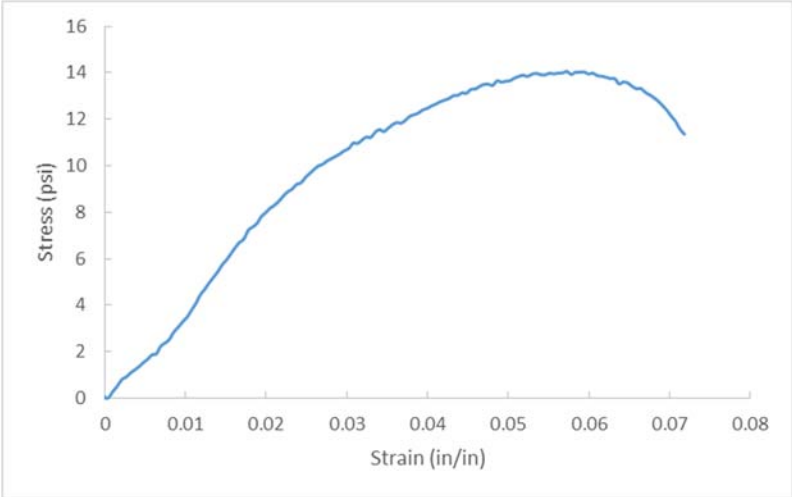

Figure A.81 D37-3, OC= 18.9%, CF= 200 pcf, T=14 days.

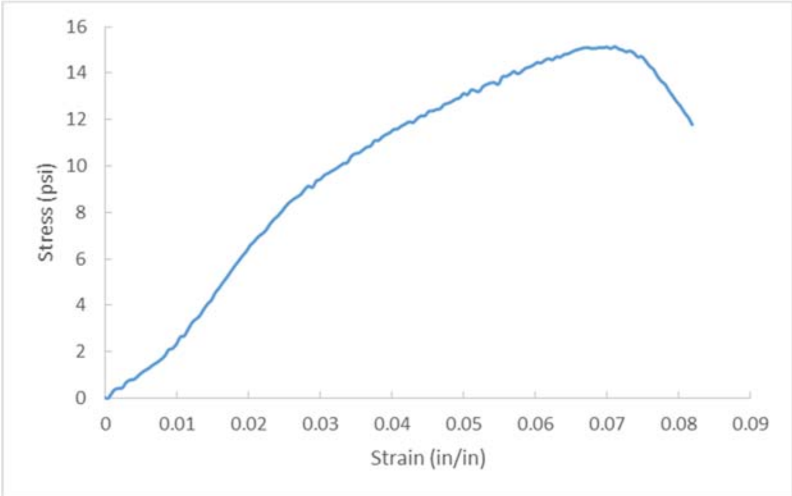

Figure A.82 D38-1, OC= 13.9%, CF= 200 pcf, T=14 days.

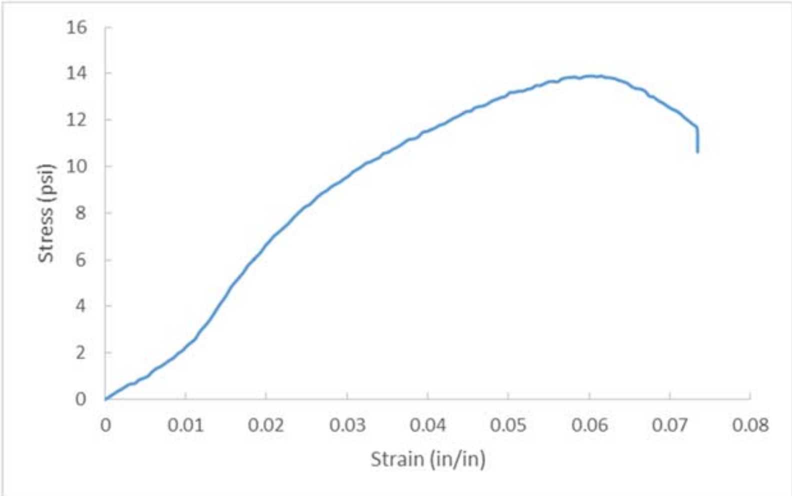

Figure A.83 D38-2, OC= 13.9%, CF= 200 pcf, T=14 days.

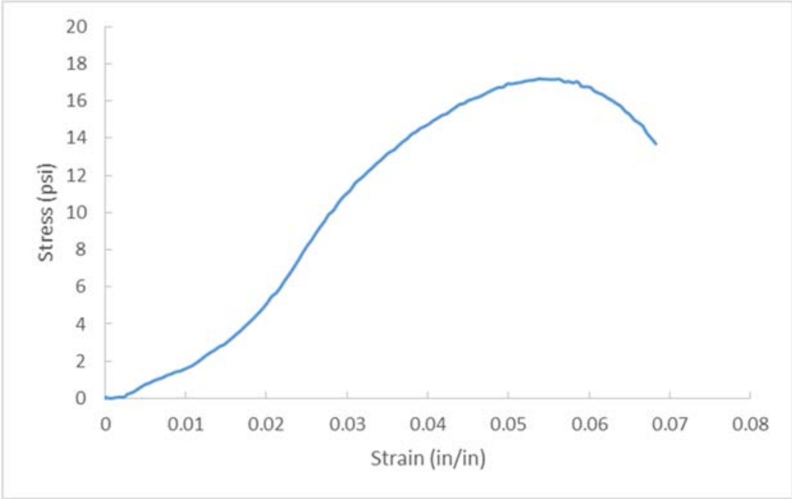

Figure A.84 D39-1, OC= 3.9%, CF= 200 pcf, T=14 days.

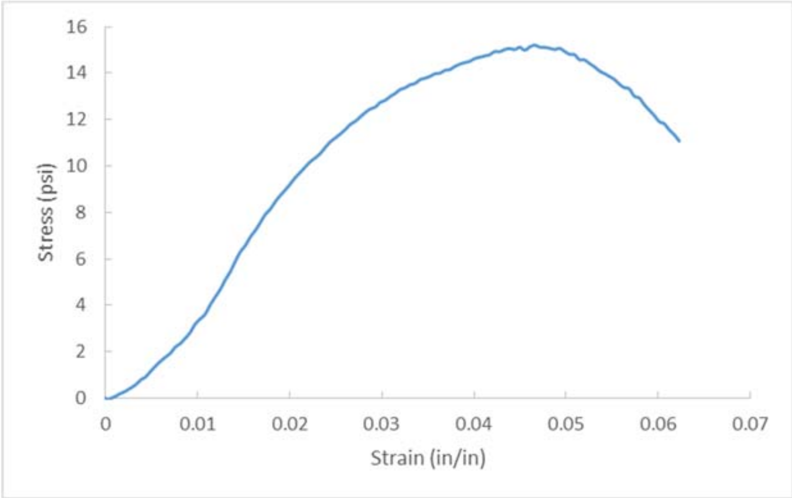

Figure A.85 D39-2, OC= 3.9%, CF= 200 pcf, T=14 days.

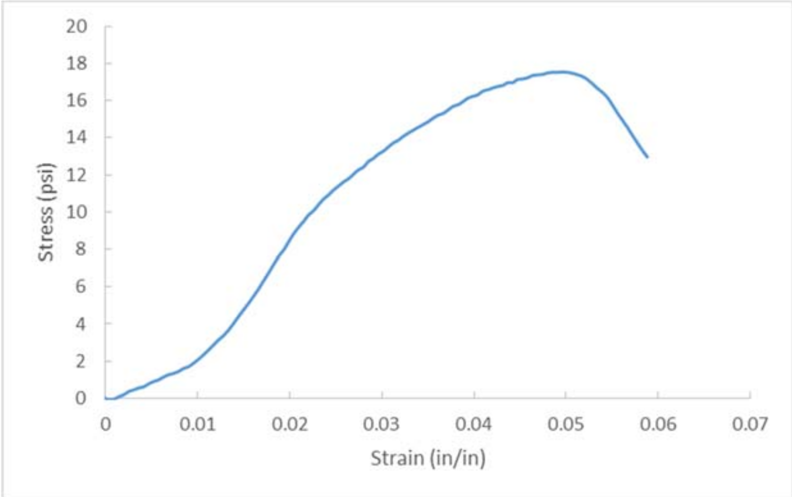

Figure A.86 D39-3, OC= 3.9%, CF= 200 pcf, T=14 days.

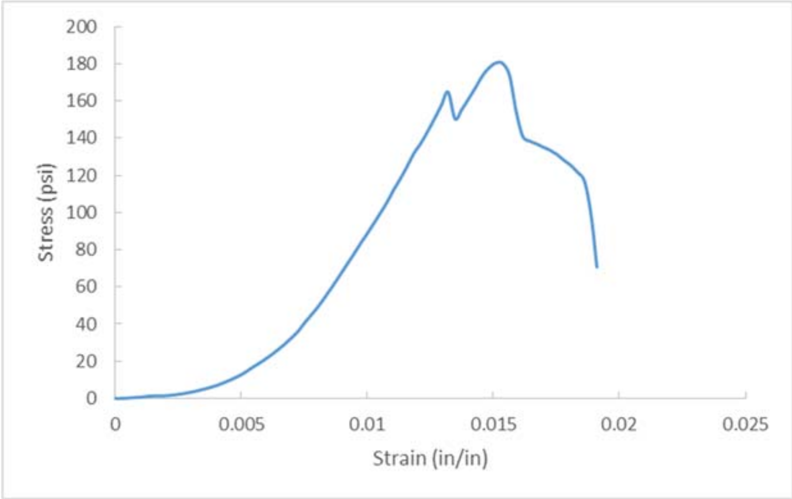


Figure A.87 D45-1, OC= 0.0%, CF= 400 pcf, T=14 days.

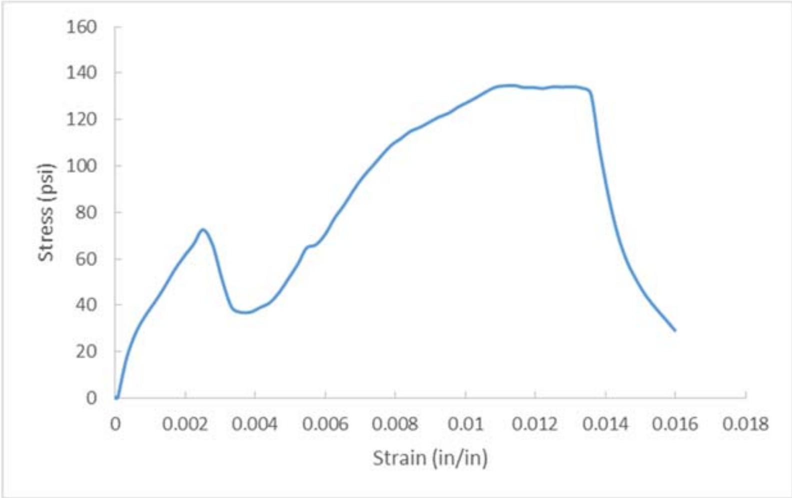


Figure A.88 D45-2, OC= 0.0%, CF= 400 pcf, T=14 days.

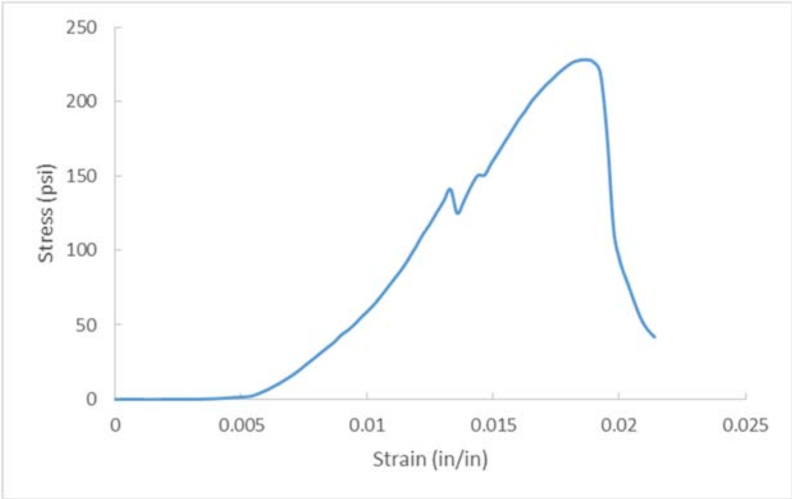


Figure A.89 D45-3, OC= 0.0%, CF= 400 pcf, T=14 days.

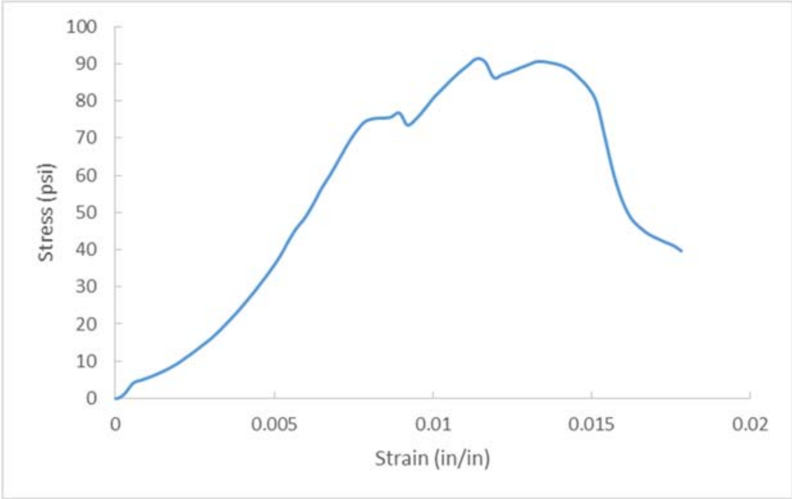

Figure A.90 D46-1, OC= 0.0%, CF= 300 pcf, T=14 days.

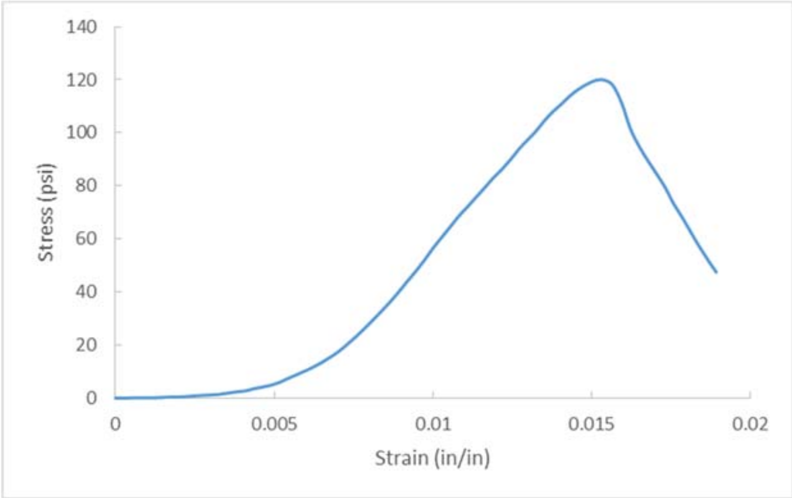

Figure A.91 D46-2, OC= 0.0%, CF= 300 pcf, T=14 days.

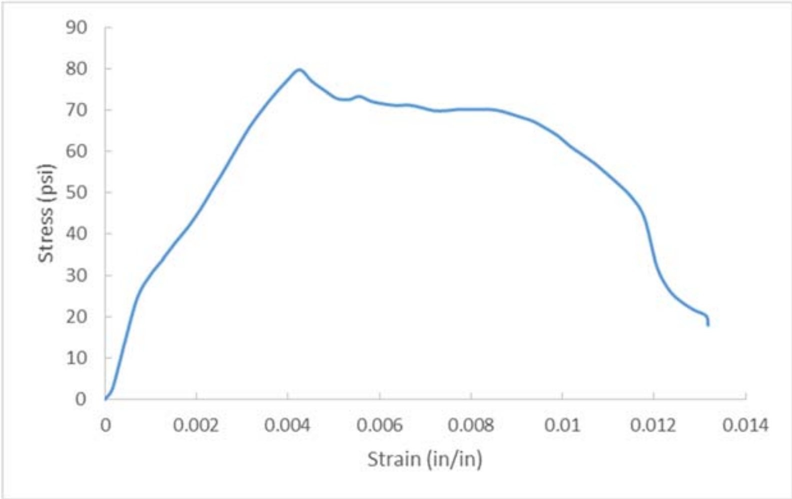

Figure A.92 D46-3, OC= 0.0%, CF= 300 pcf, T=14 days.

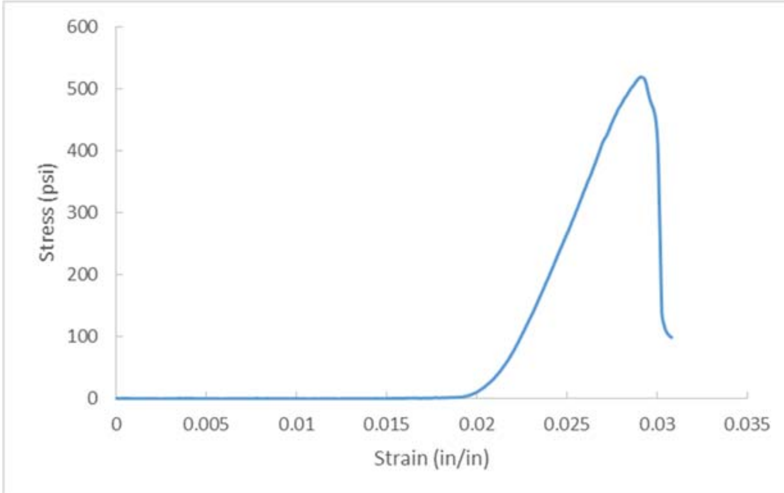

Figure A.93 D47-2, OC= 0.0%, CF= 400 pcf, T=14 days.

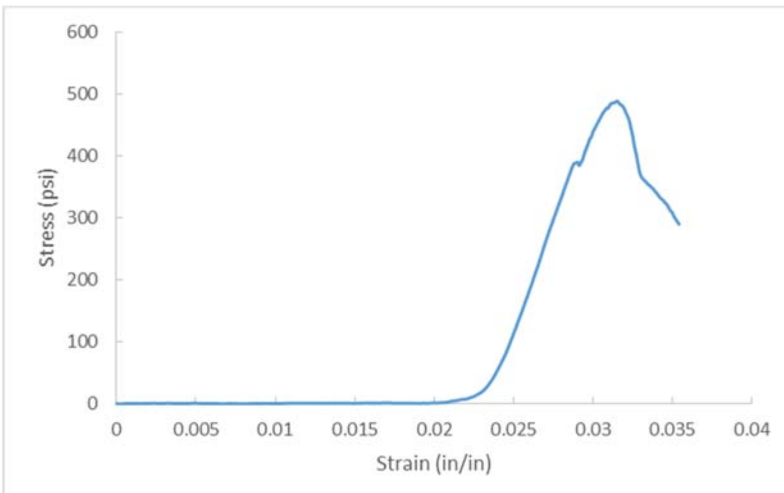

Figure A.94 D47-3, OC= 0.0%, CF= 400 pcf, T=14 days.

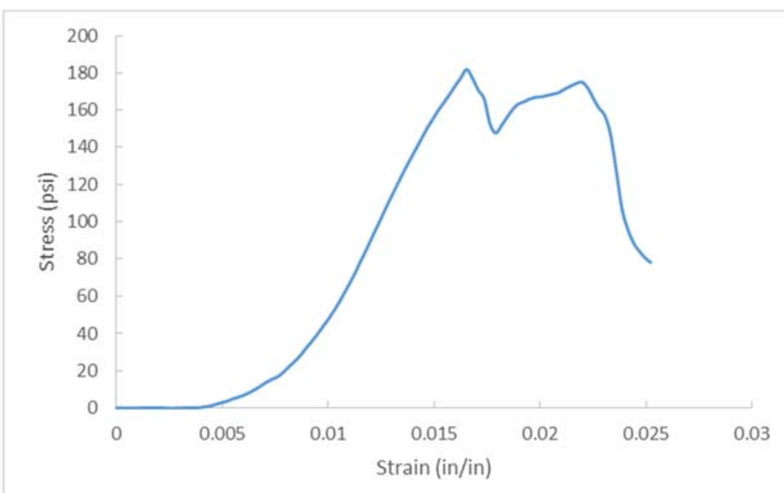

Figure A.95 D48-1, OC= 0.0%, CF= 300 pcf, T=14 days.

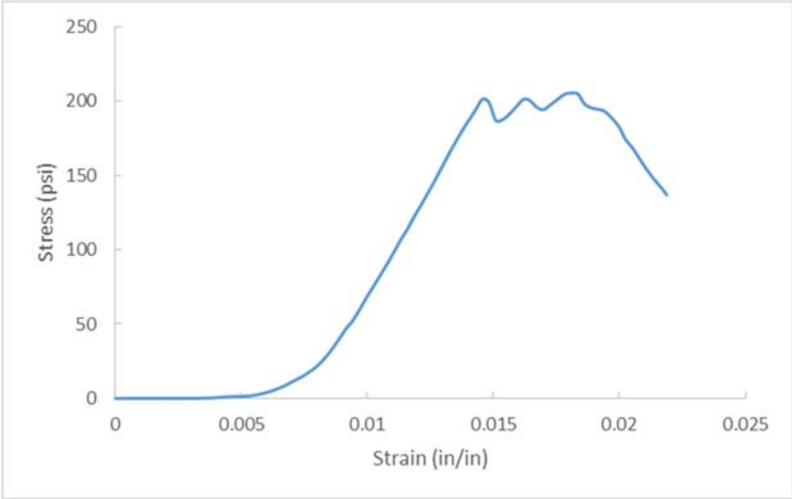

Figure A.96 D48-2, OC= 0.0%, CF= 300 pcf, T=14 days.

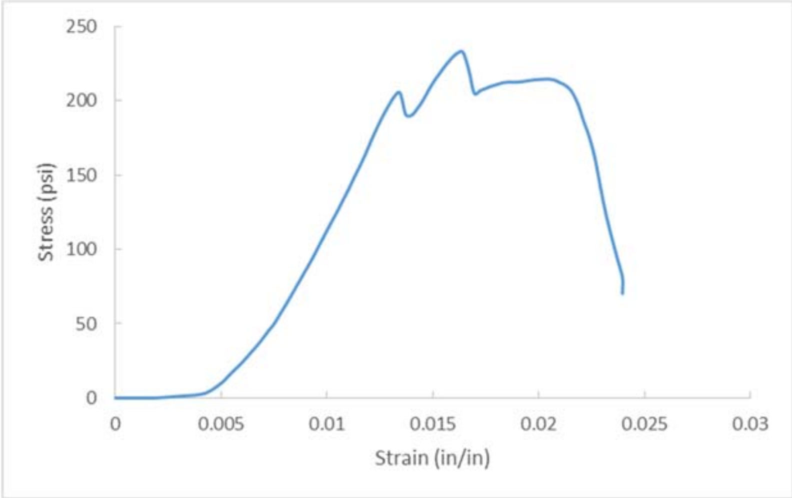

Figure A.97 D48-3, OC= 0.0%, CF= 300 pcf, T=14 days.

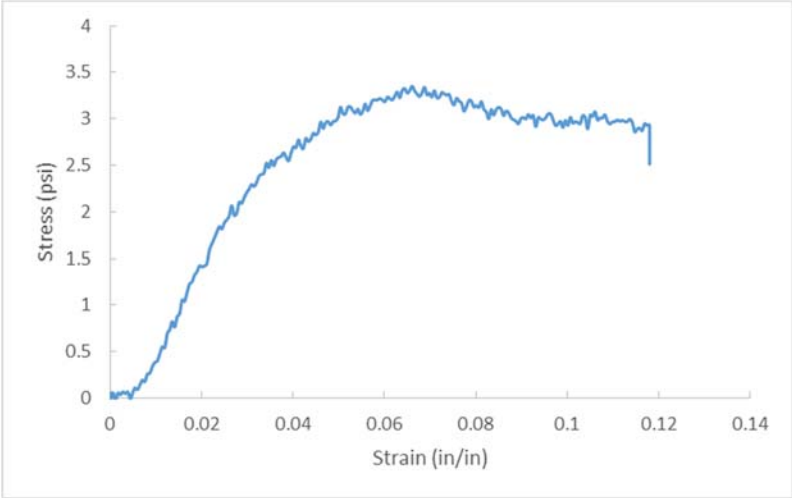

Figure A.98 W49-1, OC= 43.8%, CF= 300 pcf, T=14 days.

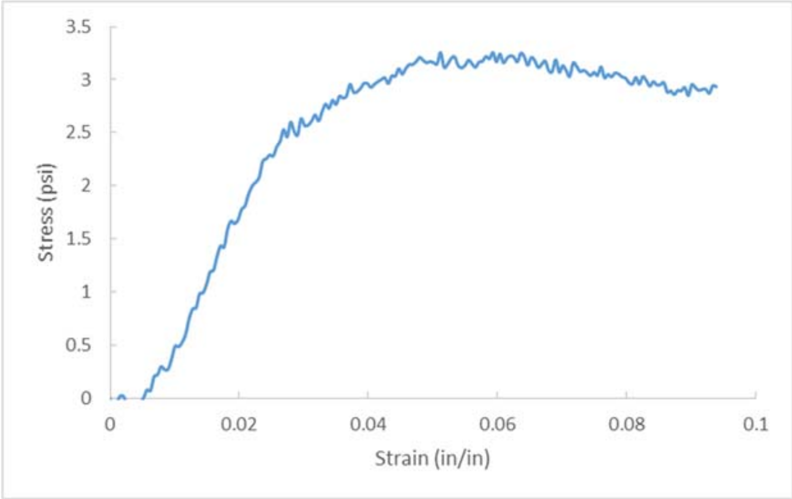

Figure A.99 W49-3, OC= 43.8%, CF= 300 pcf, T=14 days.

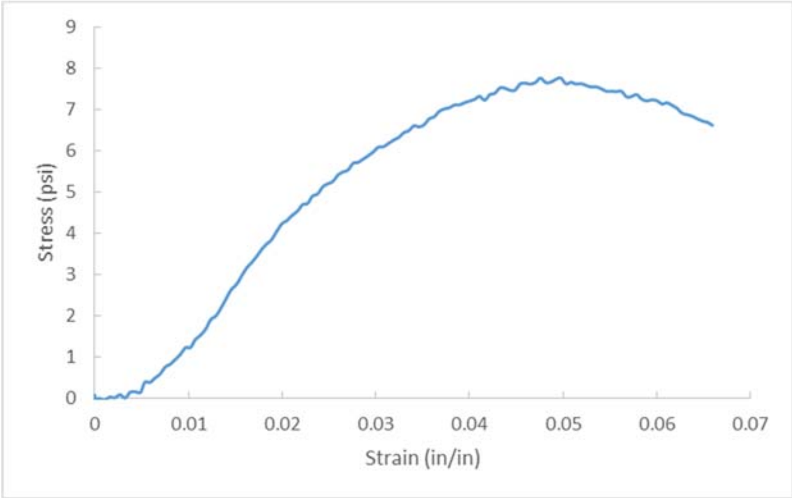

Figure A.100 W50-1, OC= 43.8%, CF= 400 pcf, T=14 days.

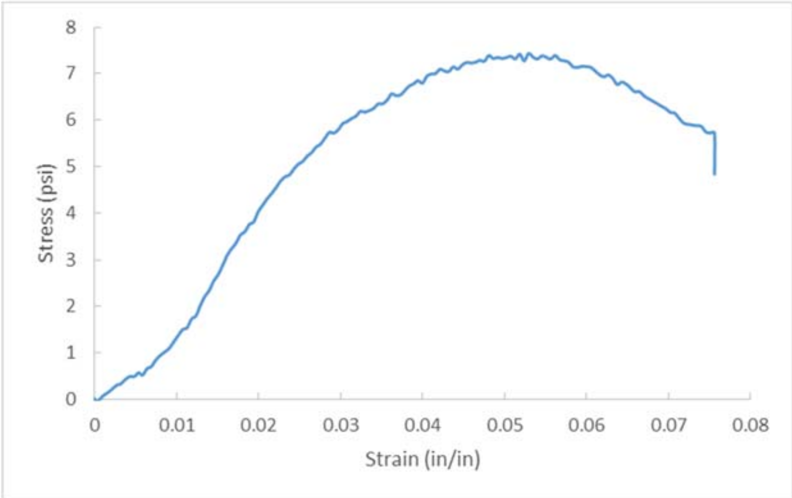

Figure A.101 W50-2, OC= 43.8%, CF= 400 pcf, T=14 days.

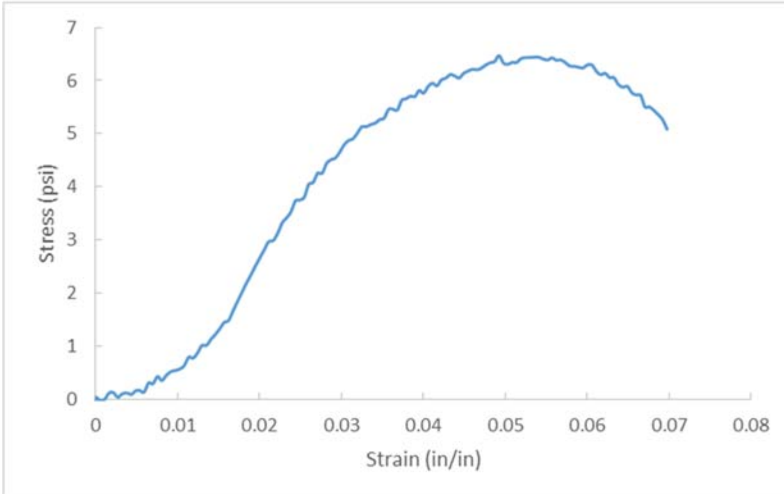

Figure A.102 W50-3, OC= 43.8%, CF= 400 pcf, T=14 days.

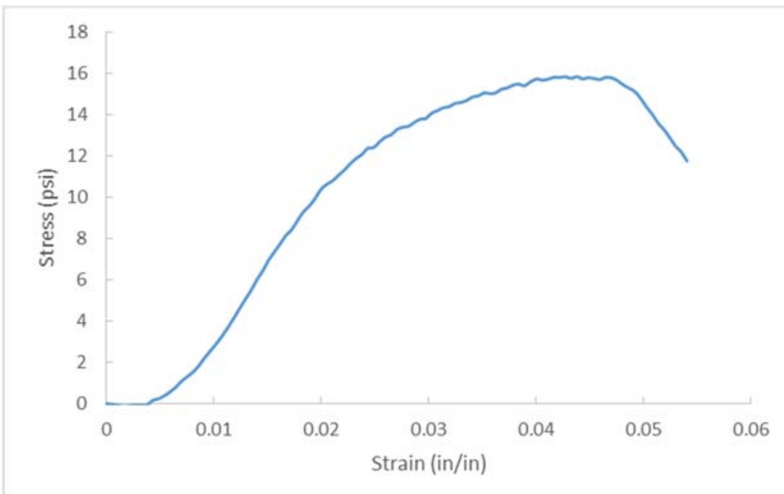

Figure A.103 W51-1, OC= 43.8%, CF= 500 pcf, T=14 days.

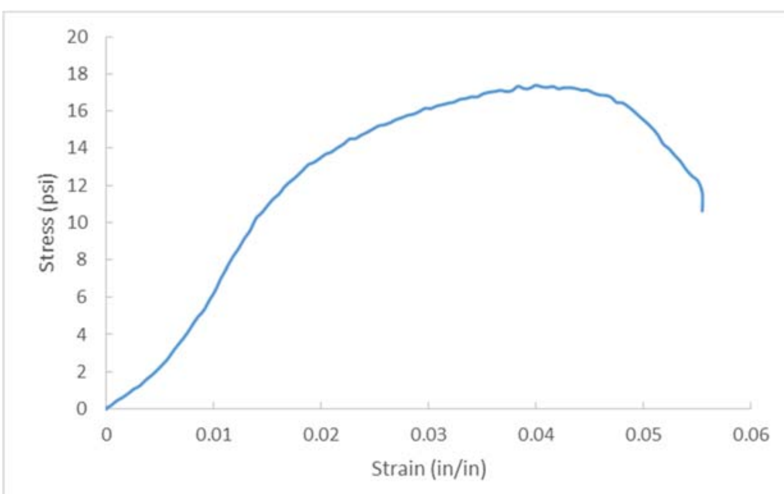

Figure A.104 W51-2, OC= 43.8%, CF= 500 pcf, T=14 days.

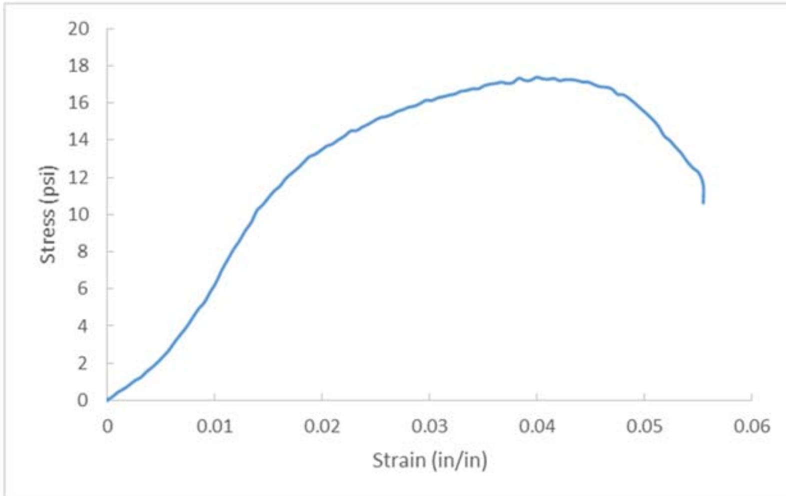

Figure A.105 W51-3, OC= 43.8%, CF= 500 pcf, T=14 days.

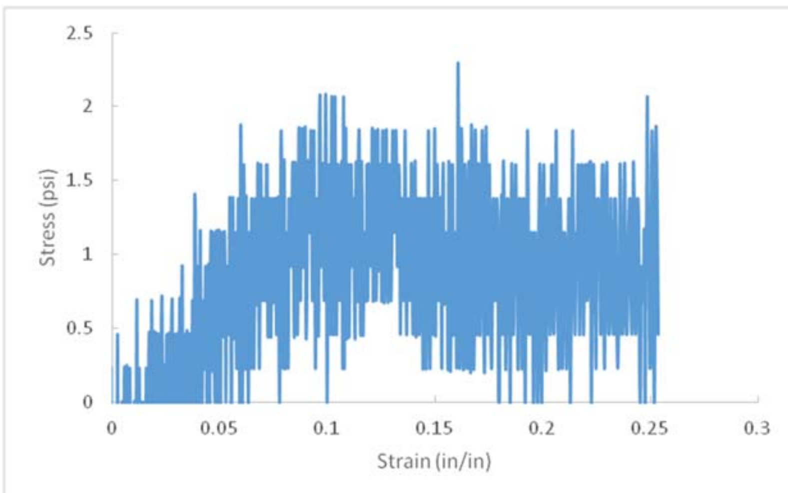

Figure A.106 D2-5, OC= 66.4%, CF= 300 pcf, T=28 days.

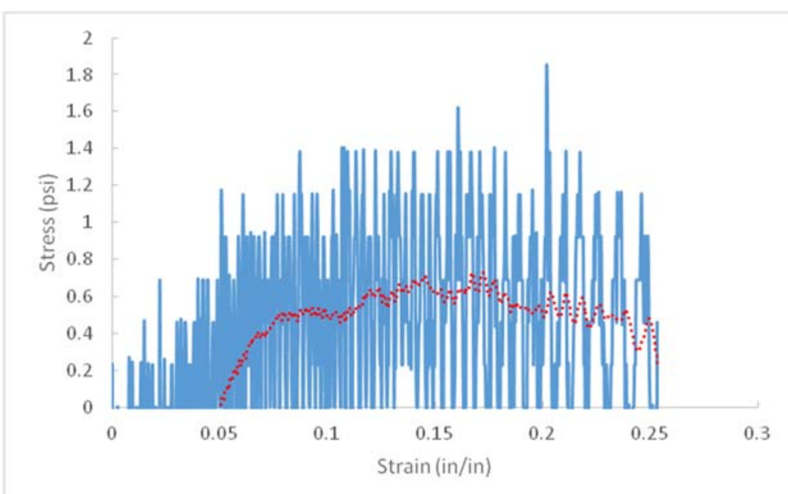

Figure A.107 D2-6, OC= 66.4%, CF= 300 pcf, T=28 days.

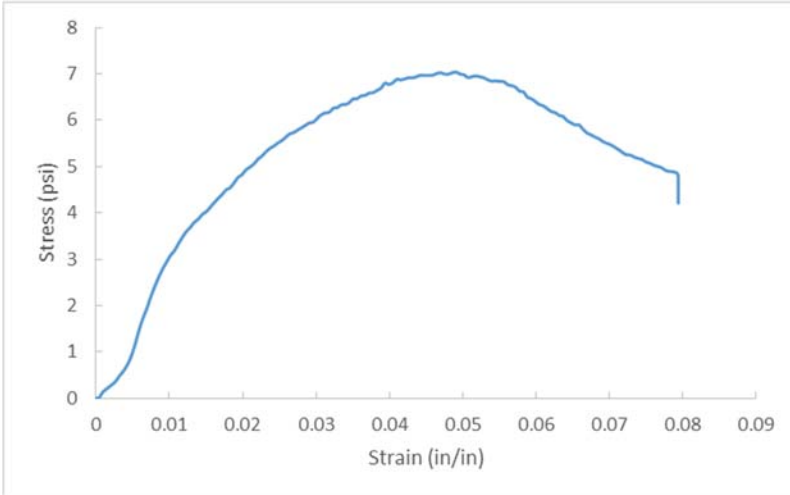


Figure A.108 D3-4, OC= 66.4%, CF= 400 pcf, T=28 days.

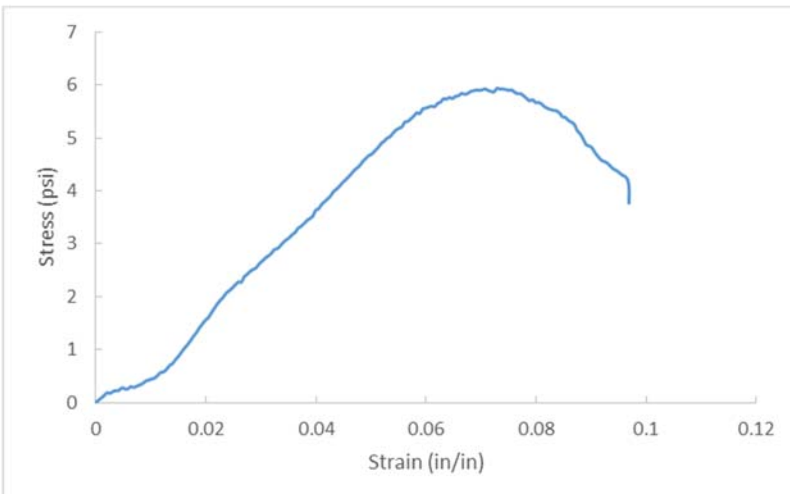


Figure A.109 D3-5, OC= 66.4%, CF= 400 pcf, T=28 days.

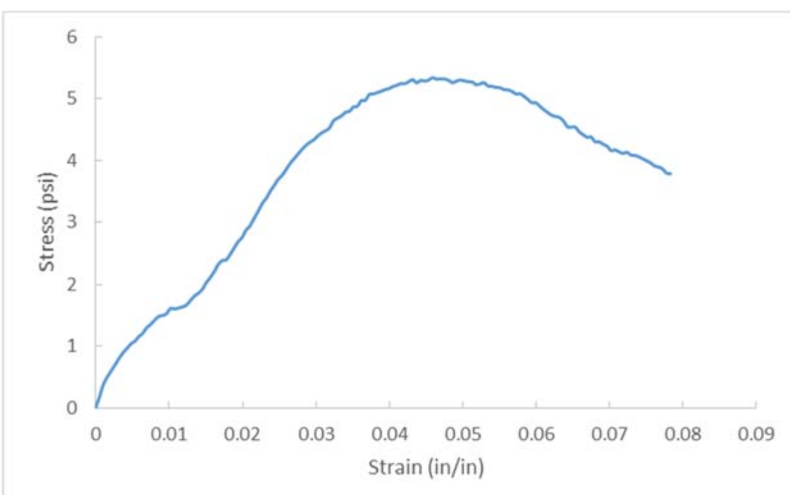


Figure A.110 D3-6, OC= 66.4%, CF= 400 pcf, T=28 days.

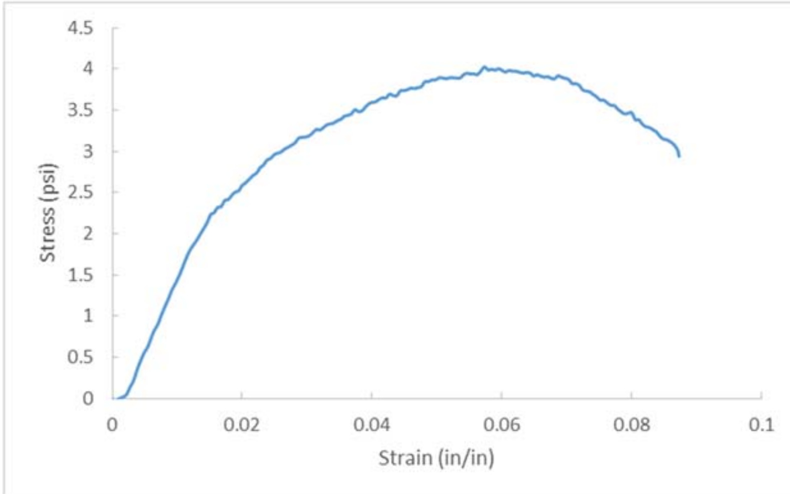


Figure A.111 D4-4, OC= 66.4%, CF= 200 pcf, T=28 days.

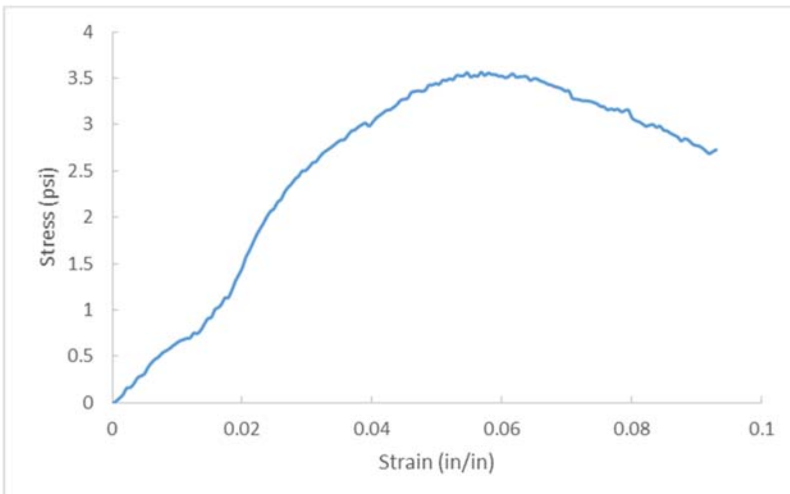


Figure A.112 D4-5, OC= 66.4%, CF= 200 pcf, T=28 days.

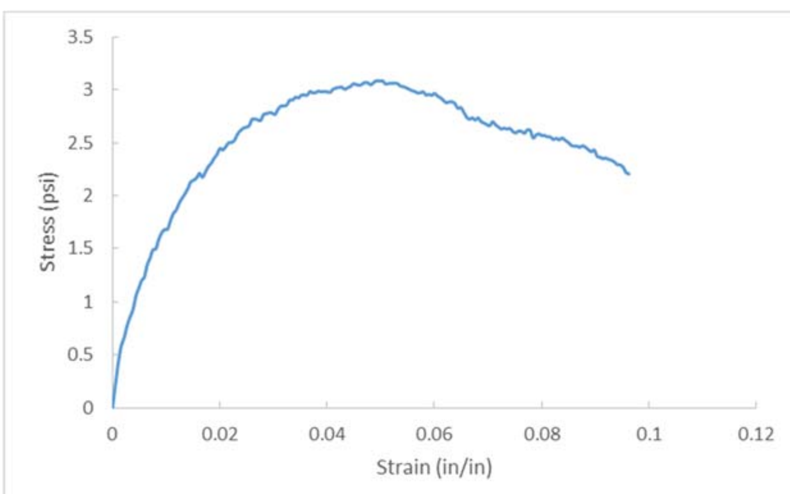


Figure A.113 D4-6, OC= 66.4%, CF= 200 pcf, T=28 days.

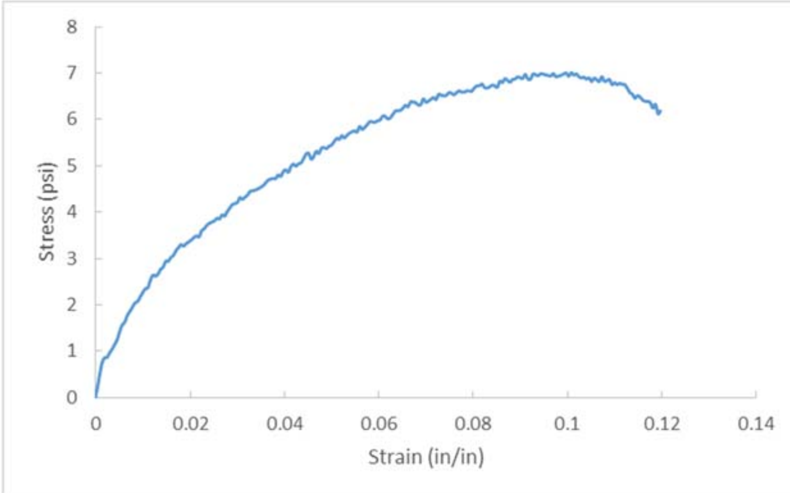

Figure A.114 D8-4, OC= 65.9%, CF= 300 pcf, T=28 days.

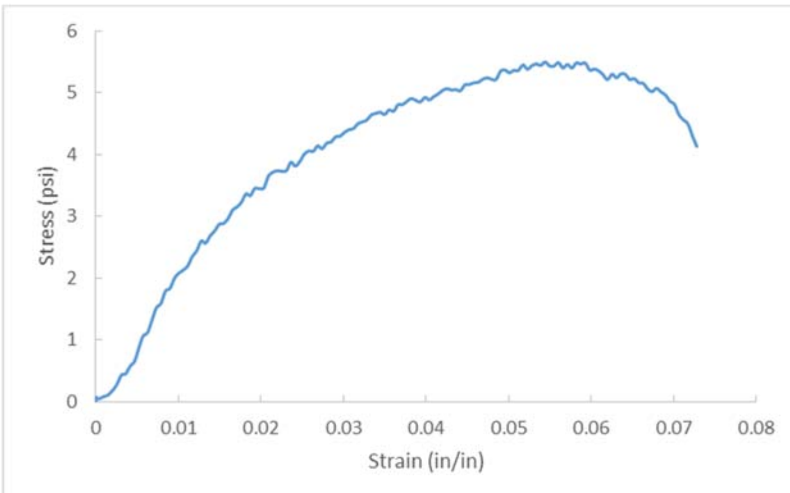

Figure A.115 D8-5, OC= 65.9%, CF= 300 pcf, T=28 days.

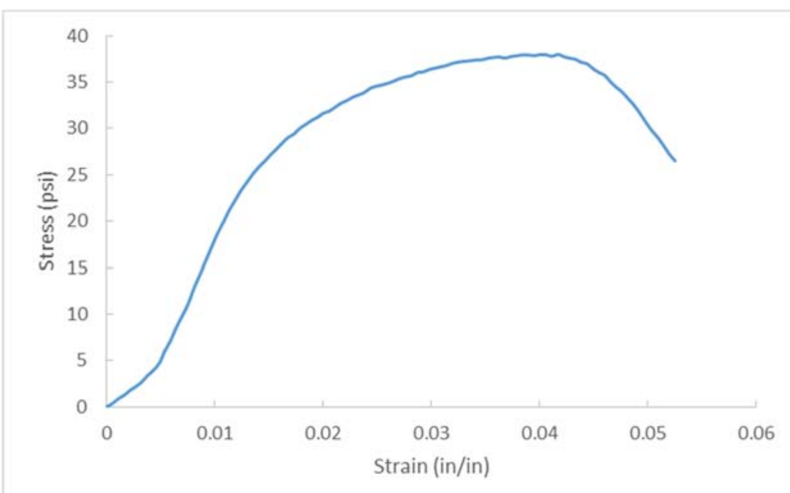

Figure A.116 D9-4, OC= 65.9%, CF= 400 pcf, T=28 days.

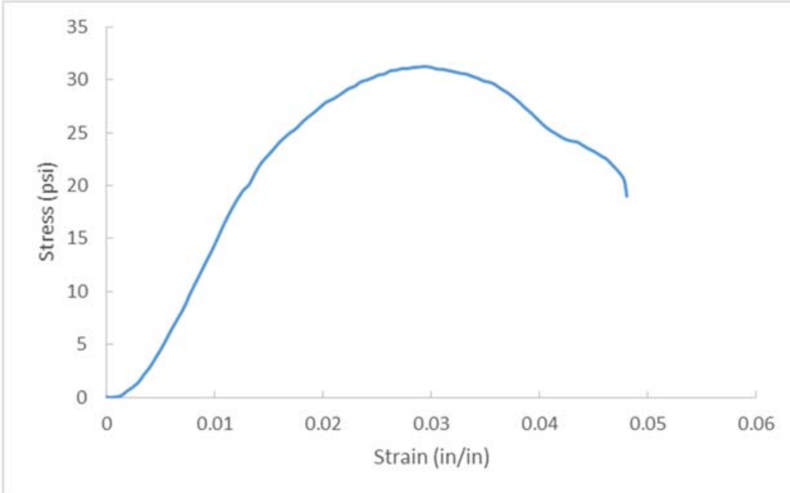


Figure A.117 D9-5, OC= 65.9%, CF= 400 pcf, T=28 days.

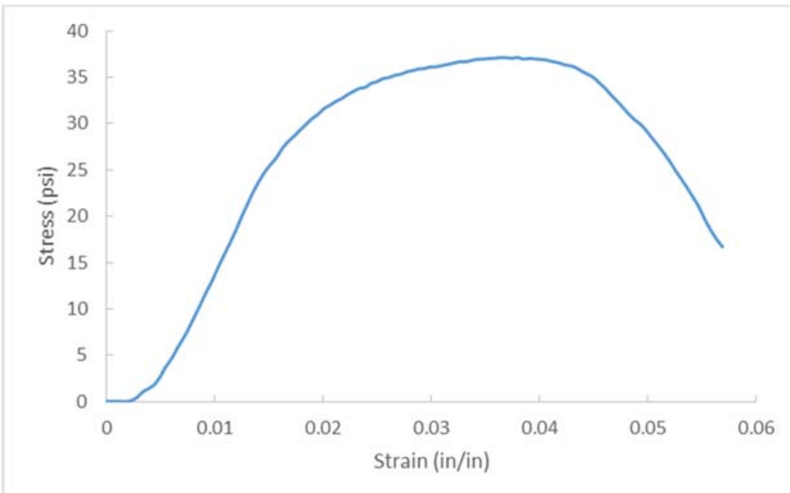


Figure A.118 D9-6, OC= 65.9%, CF= 400 pcf, T=28 days.

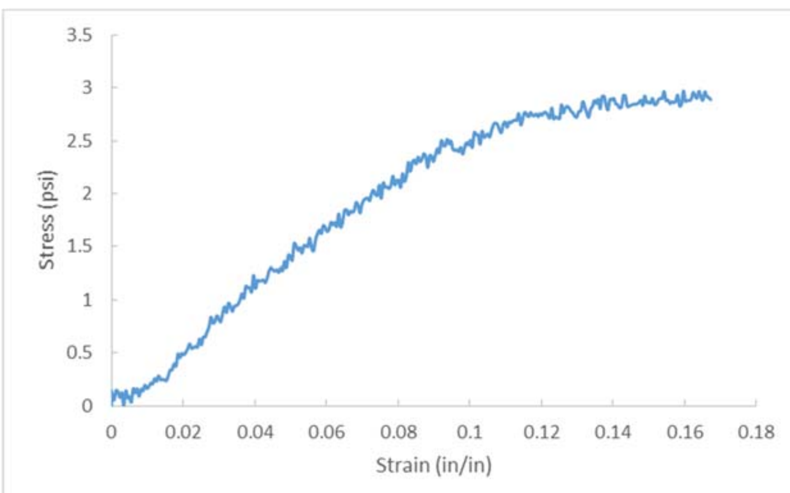


Figure A.119 D10-5, OC= 41.3%, CF= 300 pcf, T=28 days.

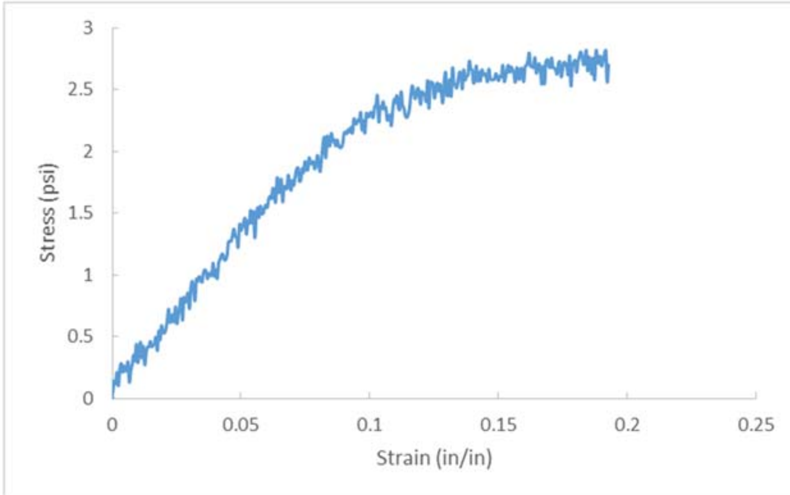

Figure A.120 D10-6, OC= 41.3%, CF= 300 pcf, T=28 days.

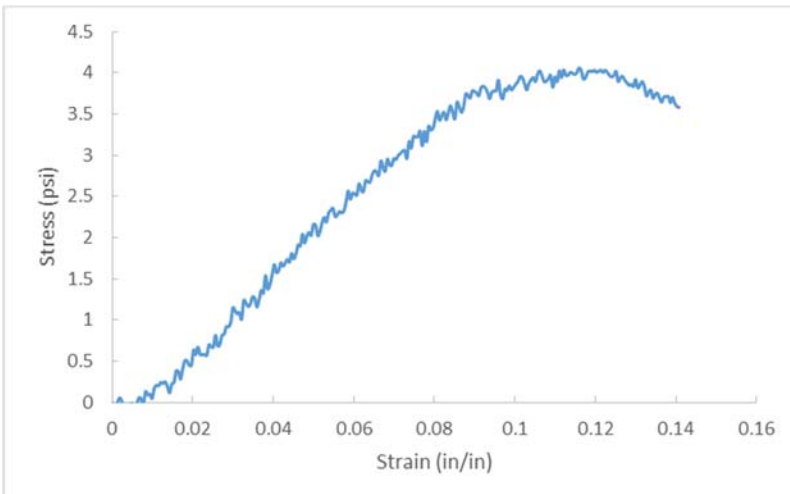

Figure A.121 D11-4, OC= 27.8%, CF= 300 pcf, T=28 days.

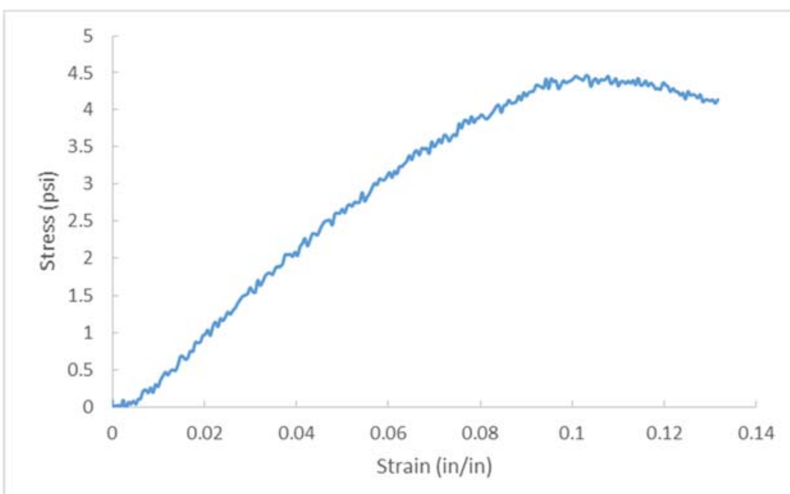

Figure A.122 D11-6, OC= 27.8%, CF= 300 pcf, T=28 days.

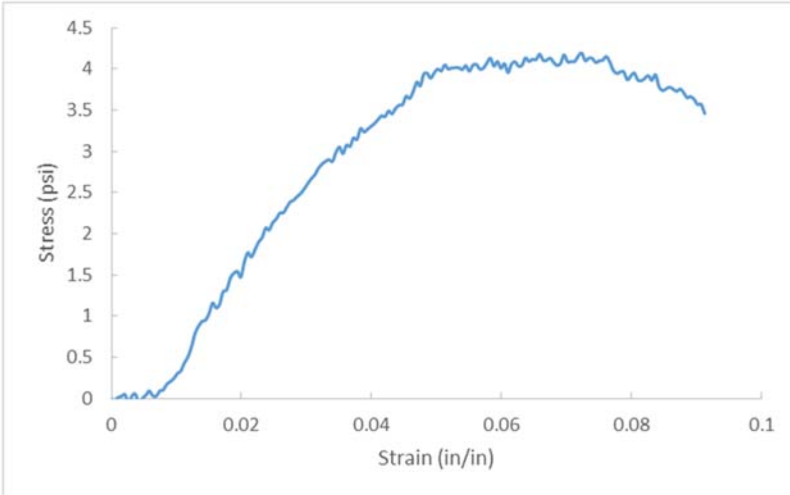

Figure A.123 D12-4, OC= 24.1%, CF= 300 pcf, T=28 days.

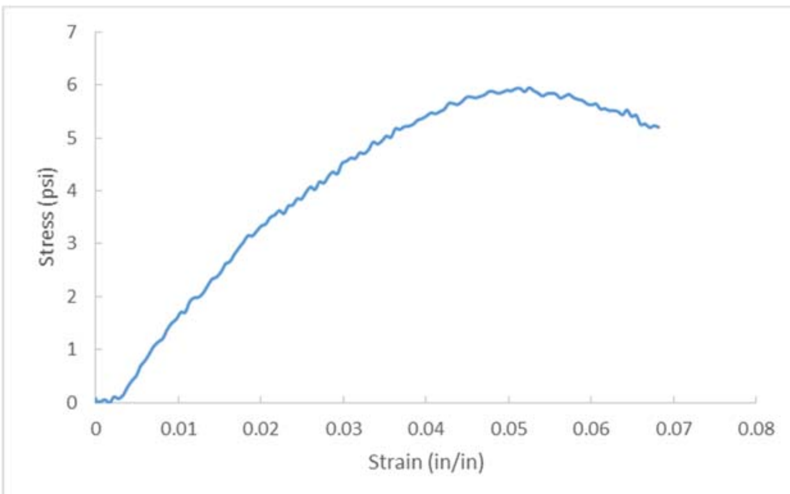

Figure A.124 D12-5, OC= 24.1%, CF= 300 pcf, T=28 days.

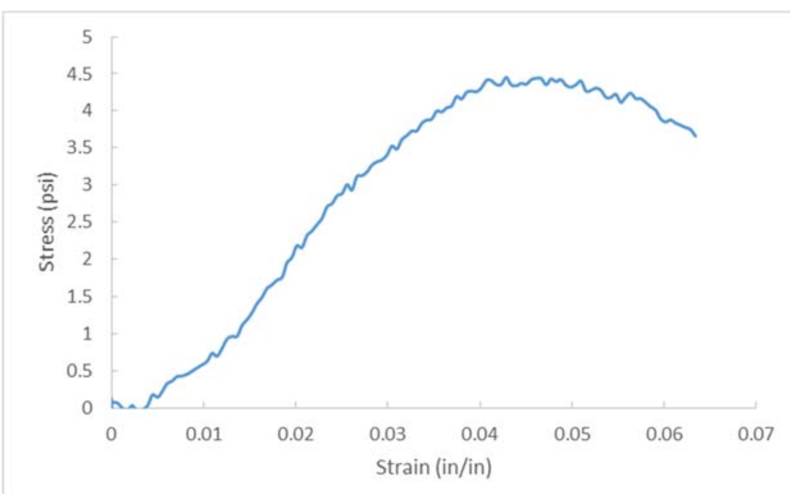

Figure A.125 D12-6, OC= 24.1%, CF= 300 pcf, T=28 days.

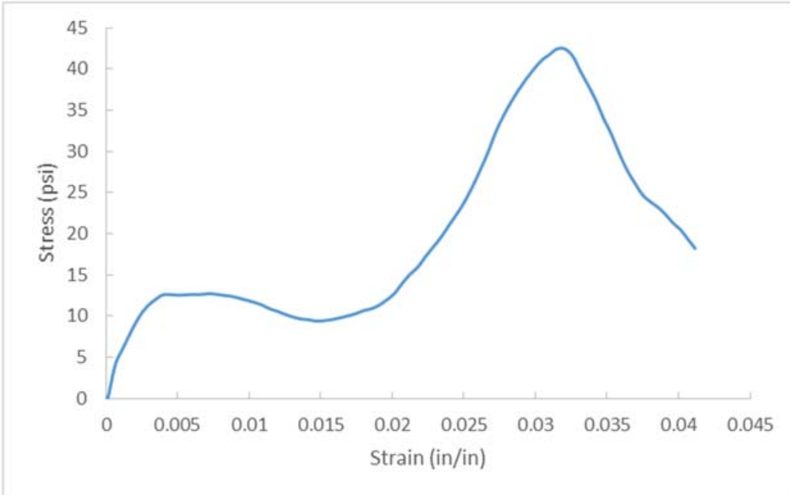

Figure A.126 D13-4, OC= 11.2%, CF= 300 pcf, T=28 days.

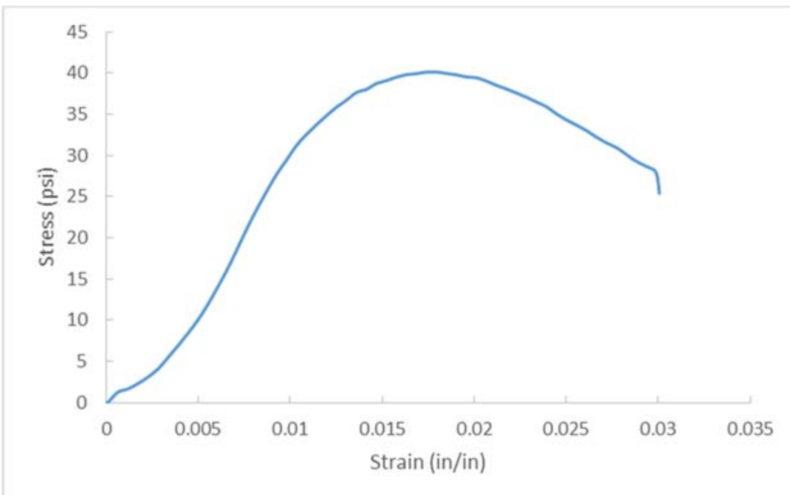

Figure A.127 D13-5, OC= 11.2%, CF= 300 pcf, T=28 days.

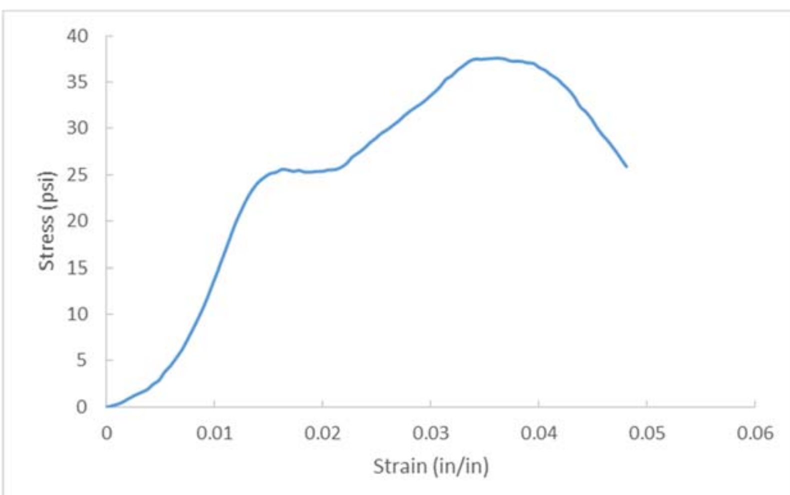

Figure A.128 D13-6, OC= 11.2%, CF= 300 pcf, T=28 days.

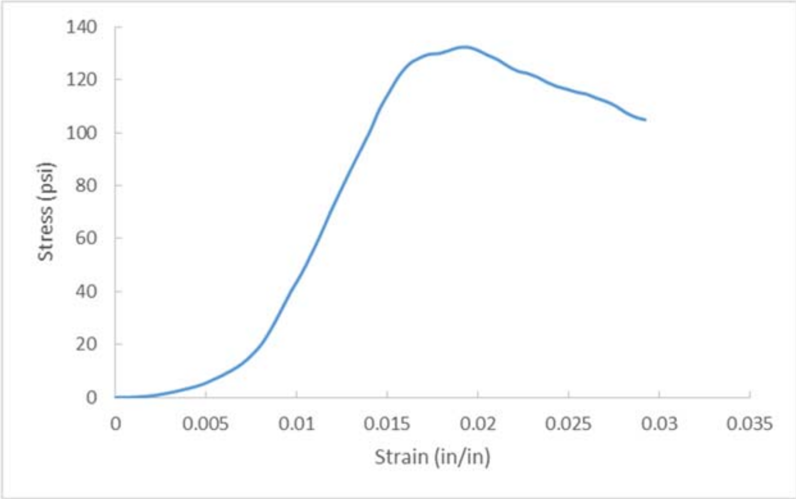


Figure A.129 D14-4, OC= 4.6%, CF= 300 pcf, T=28 days.

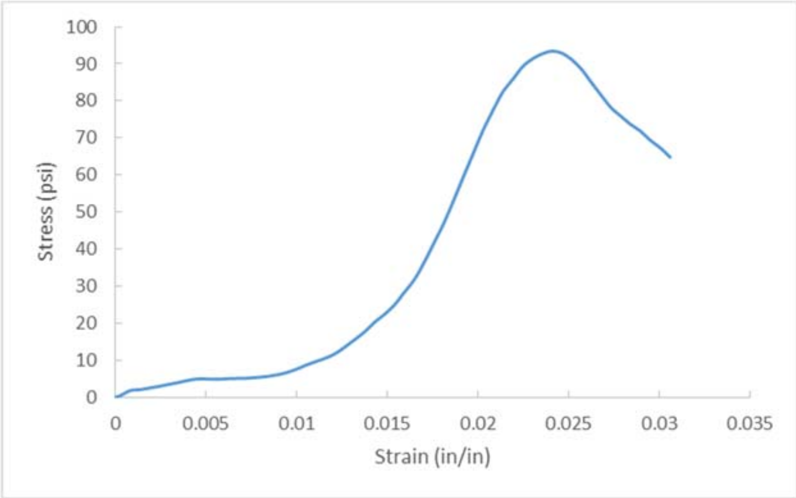


Figure A.130 D14-5, OC= 4.6%, CF= 300 pcf, T=28 days.

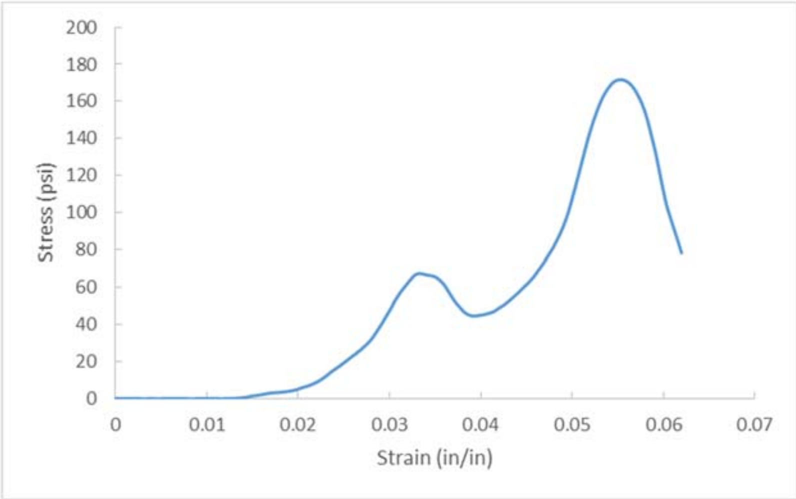


Figure A.131 D14-6, OC= 4.6%, CF= 300 pcf, T=28 days.

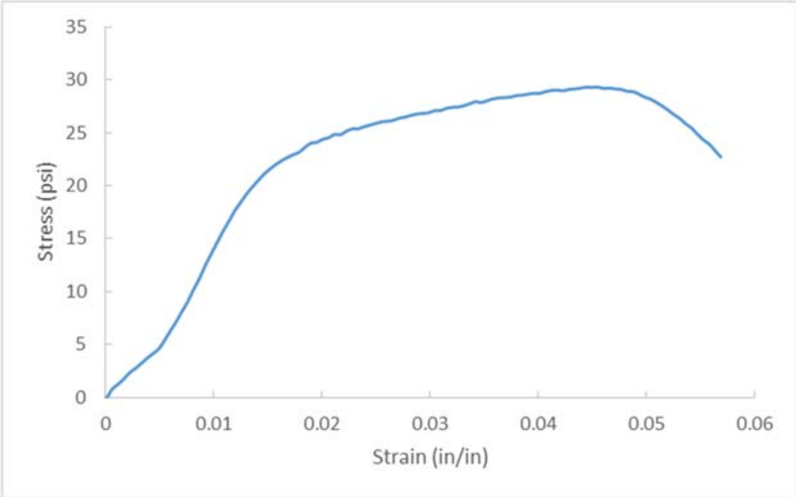

Figure A.132 D15-4, OC= 40.5%, CF= 300 pcf, T=28 days.

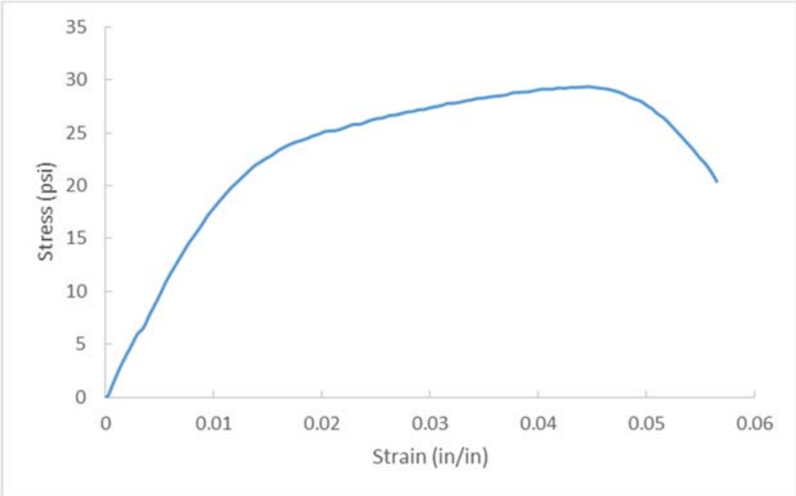

Figure A.133 D15-5, OC= 40.5%, CF= 300 pcf, T=28 days.

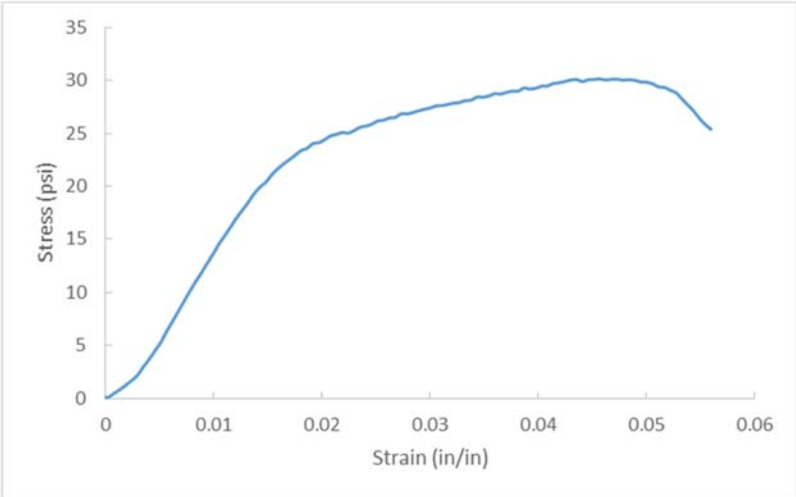

Figure A.134 D15-6, OC= 40.5%, CF= 300 pcf, T=28 days.

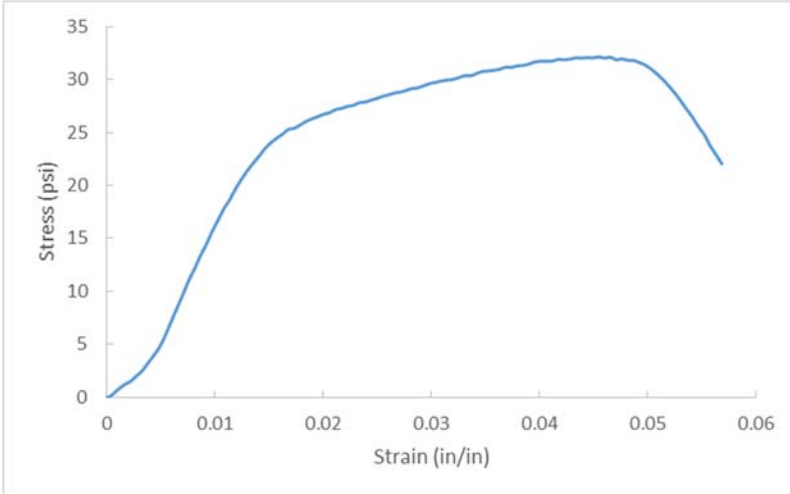

Figure A.135 D16-4, OC= 34.7%, CF= 300 pcf, T=28 days.

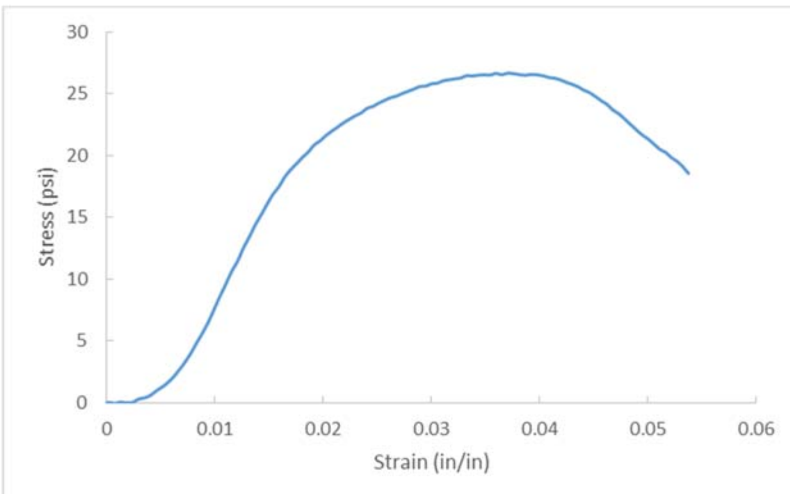

Figure A.136 D16-5, OC= 34.7%, CF= 300 pcf, T=28 days.

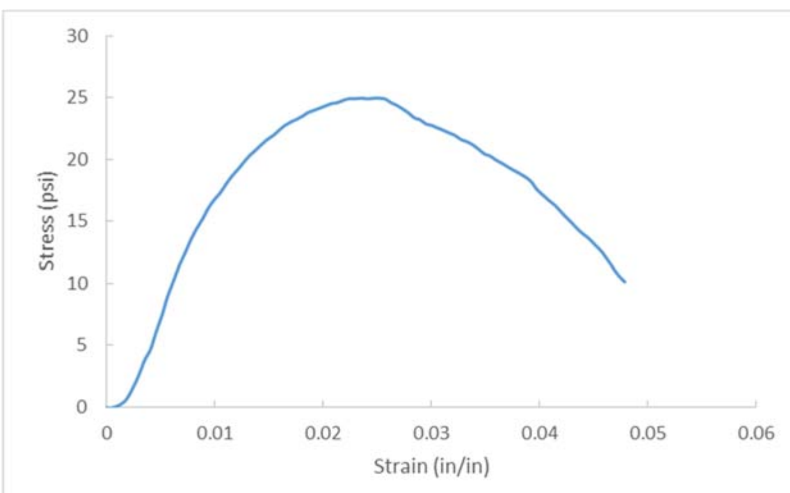

Figure A.137 D16-6, OC= 34.7%, CF= 300 pcf, T=28 days.

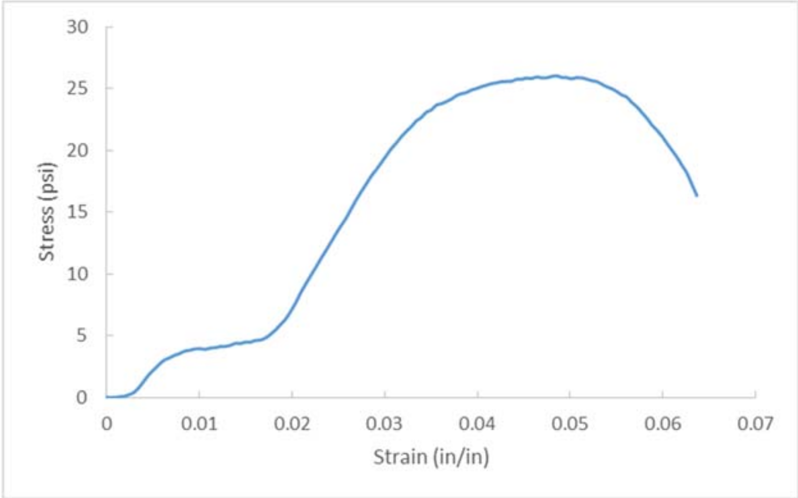

Figure A.138 D17-4, OC= 19.2%, CF= 300 pcf, T=28 days.

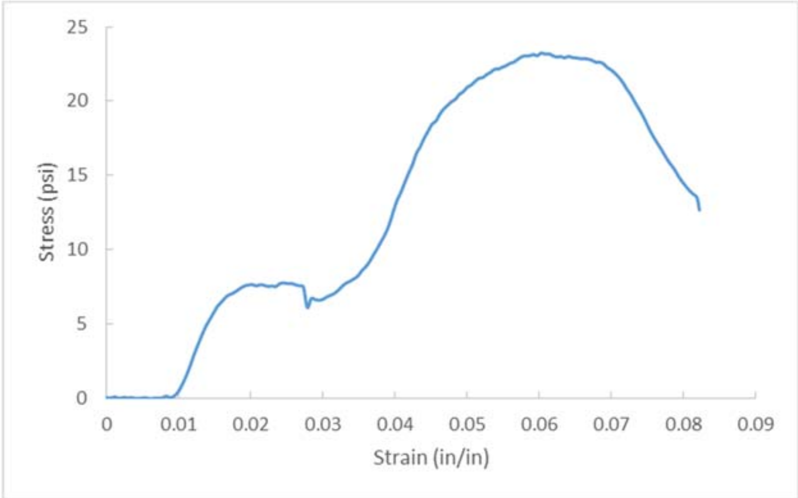

Figure A.139 D17-5, OC= 19.2%, CF= 300 pcf, T=28 days.

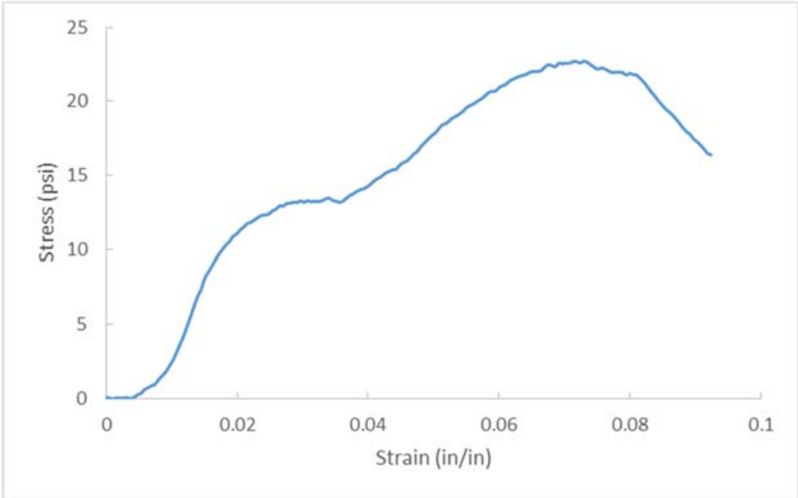

Figure A.140 D17-6, OC= 19.2%, CF= 300 pcf, T=28 days.

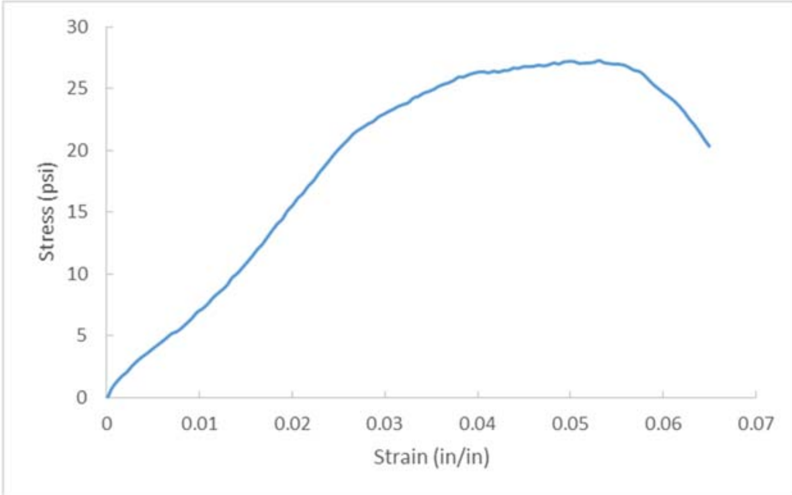

Figure A.141 D18-4, OC= 18.9%, CF= 300 pcf, T=28 days.

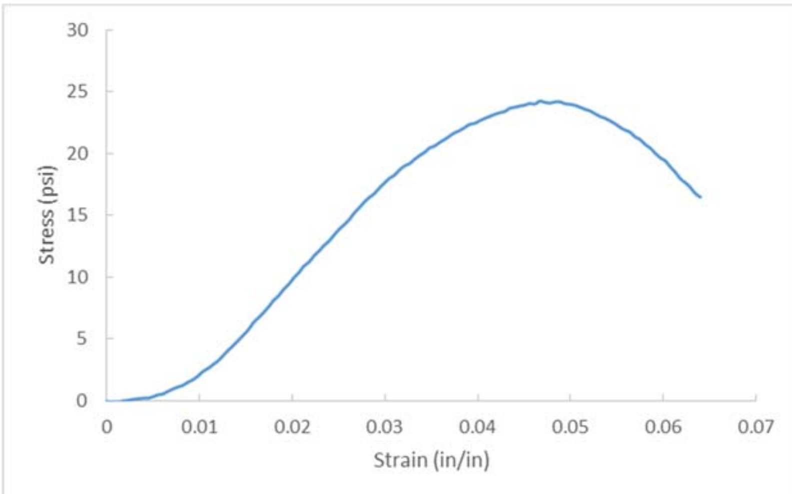

Figure A.142 D18-5, OC= 18.9%, CF= 300 pcf, T=28 days.

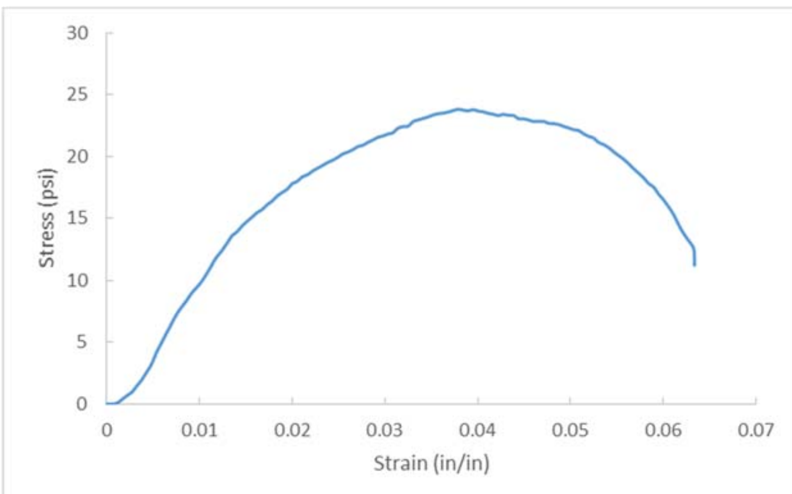

Figure A.143 D18-6, OC= 18.9%, CF= 300 pcf, T=28 days.

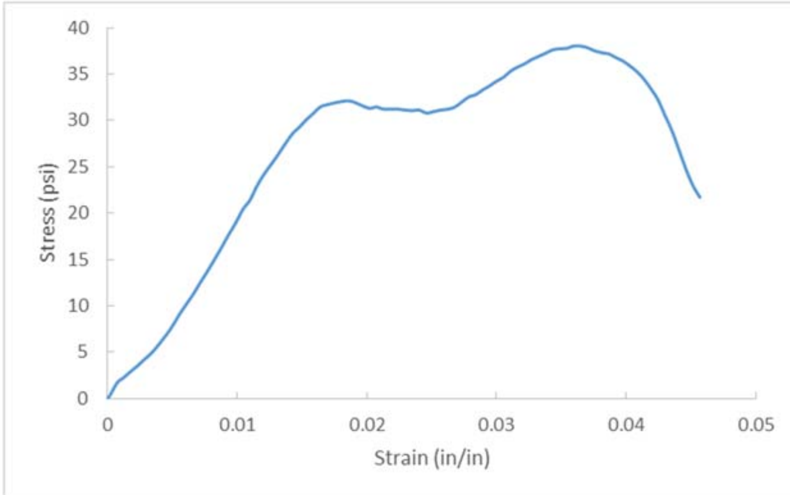


Figure A.144 D19-4, OC= 8.5%, CF= 300 pcf, T=28 days.

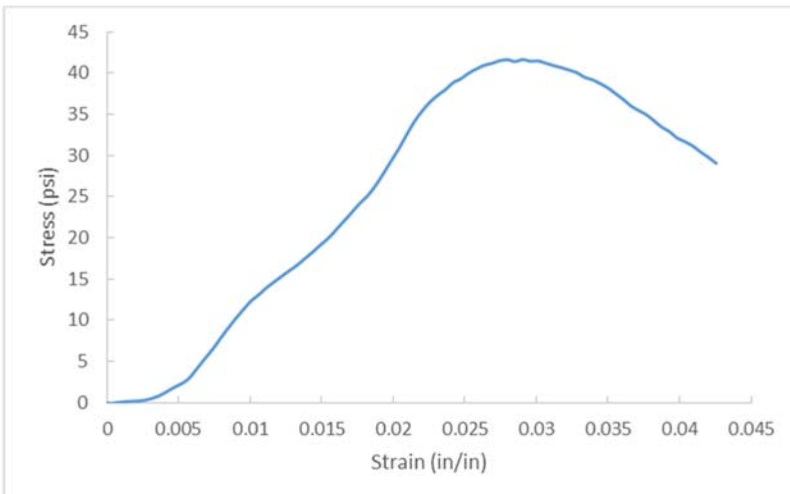


Figure A.145 D19-5, OC= 8.5%, CF= 300 pcf, T=28 days.

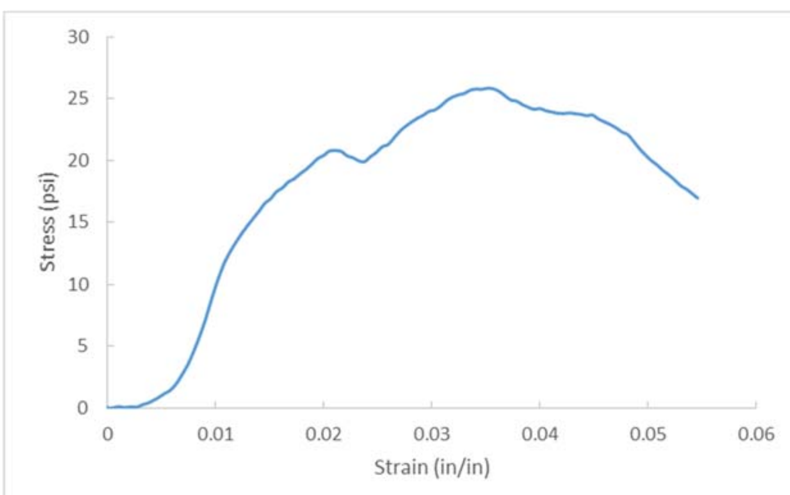


Figure A.146 D19-6, OC= 8.5%, CF= 300 pcf, T=28 days.

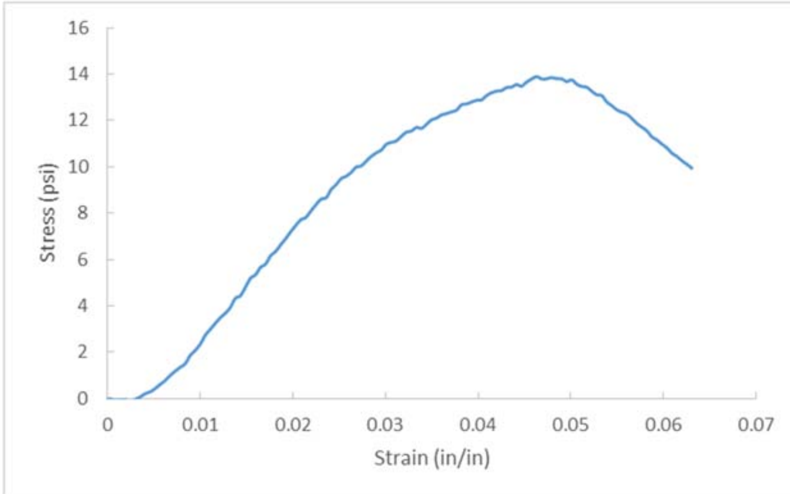

Figure A.147 D25-4, OC= 41.2%, CF= 400 pcf, T=28 days.

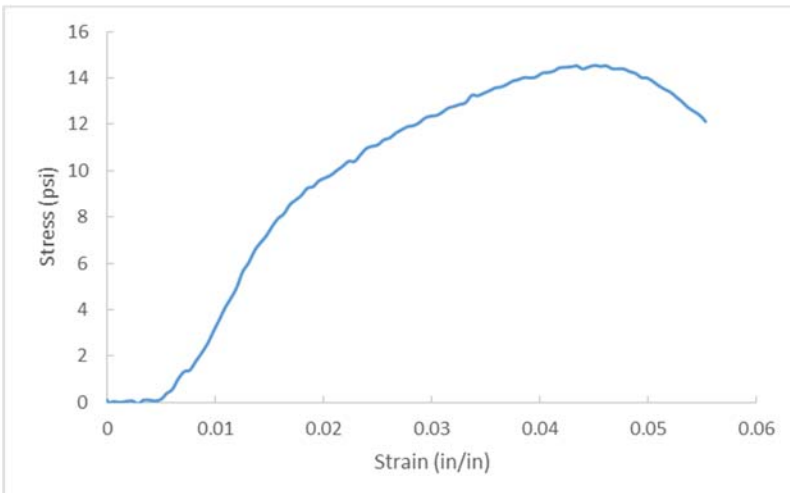

Figure A.148 D25-5, OC= 41.2%, CF= 400 pcf, T=28 days.

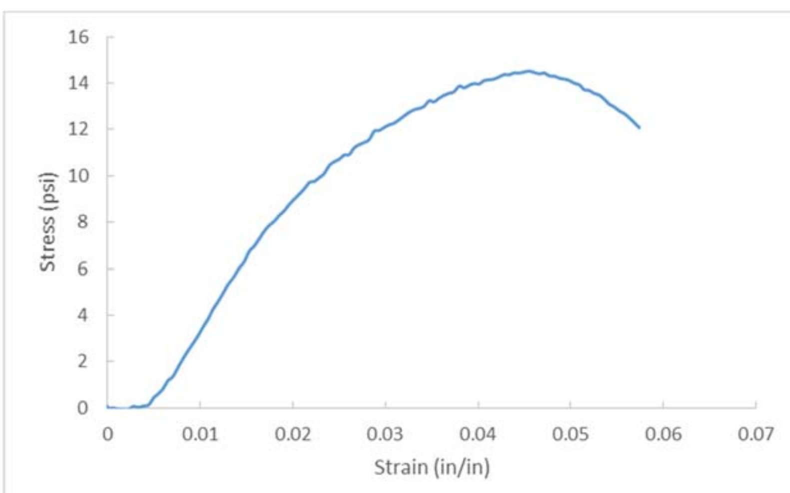

Figure A.149 D25-6, OC= 41.2%, CF= 400 pcf, T=28 days.

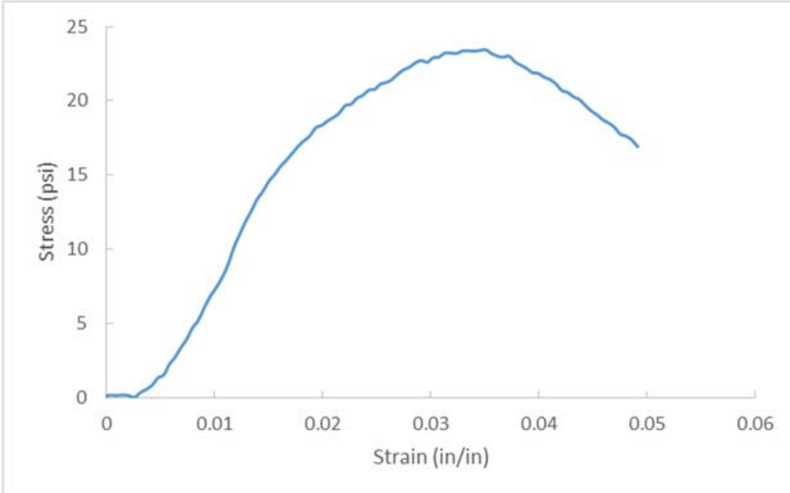

Figure A.150 D26-4, OC= 29.8%, CF= 400 pcf, T=28 days.

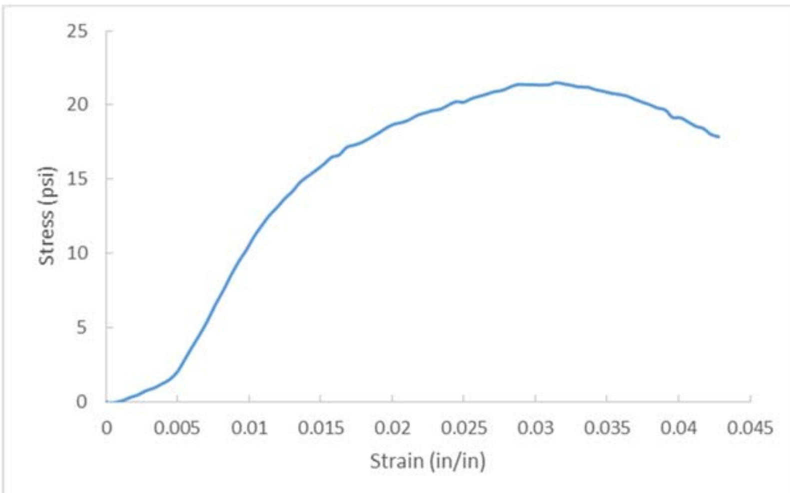

Figure A.151 D26-5, OC= 29.8%, CF= 400 pcf, T=28 days.

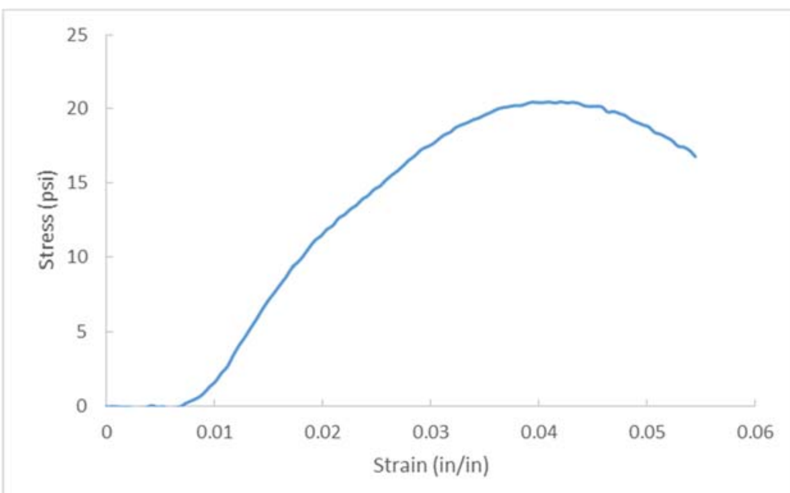

Figure A.152 D26-6, OC= 29.8%, CF= 400 pcf, T=28 days.

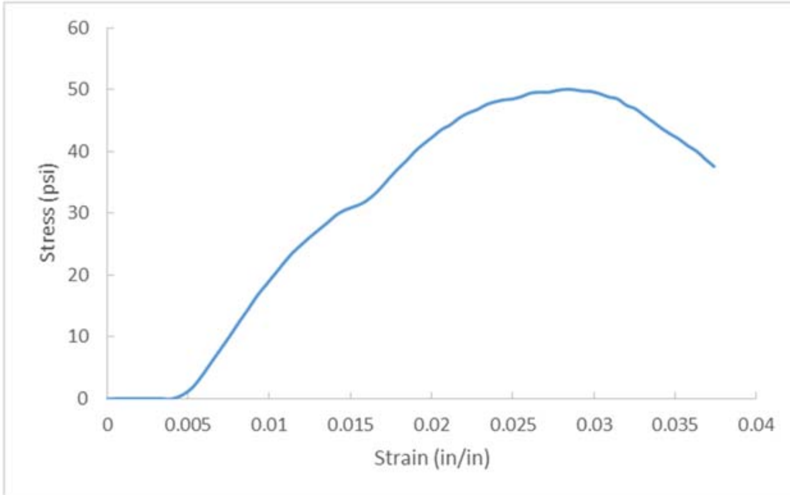


Figure A.153 D27-4, OC= 21.1%, CF= 400 pcf, T=28 days.

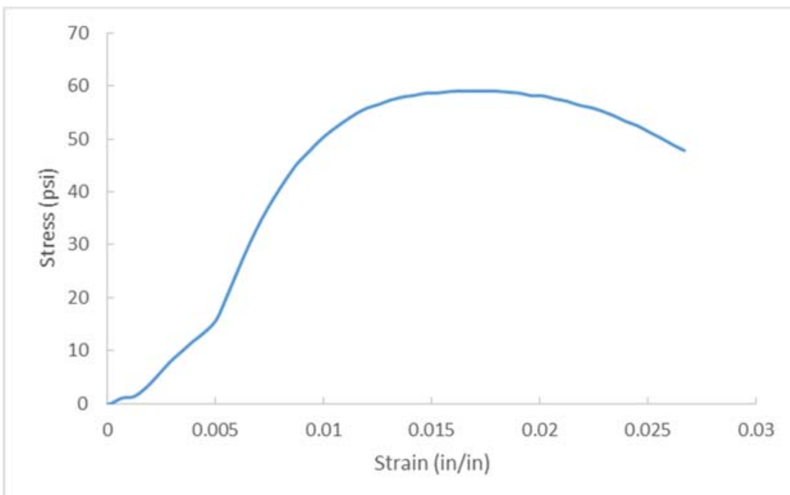


Figure A.154 D27-6, OC= 21.1%, CF= 400 pcf, T=28 days.

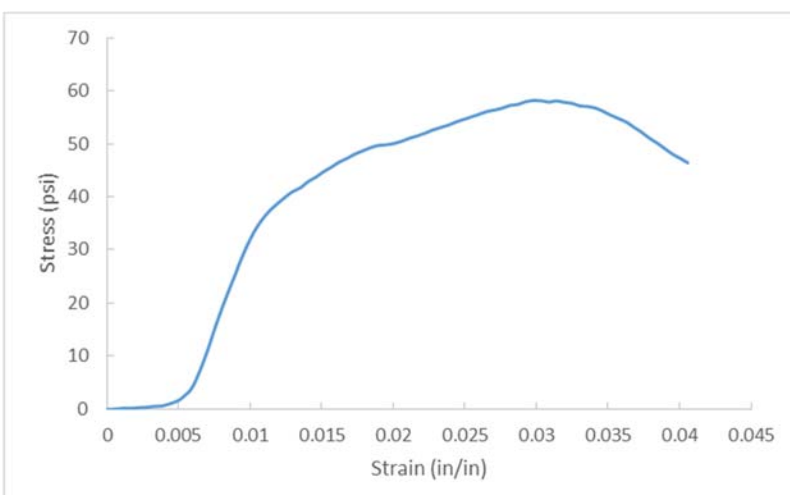


Figure A.155 D28-4, OC= 12.6%, CF= 400 pcf, T=28 days.

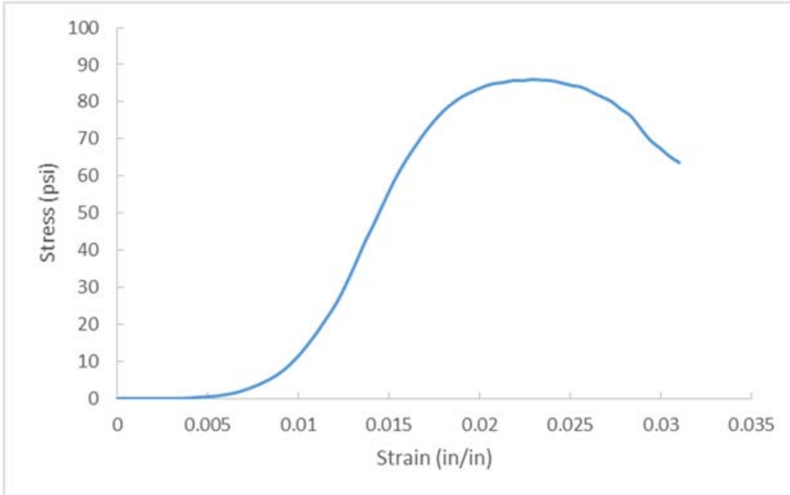


Figure A.156 D28-5, OC= 12.6%, CF= 400 pcf, T=28 days.

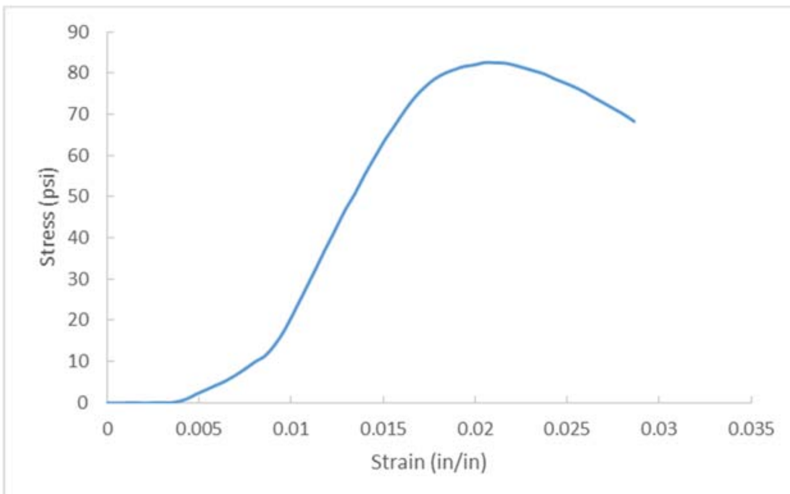


Figure A.157 D28-6, OC= 12.6%, CF= 400 pcf, T=28 days.

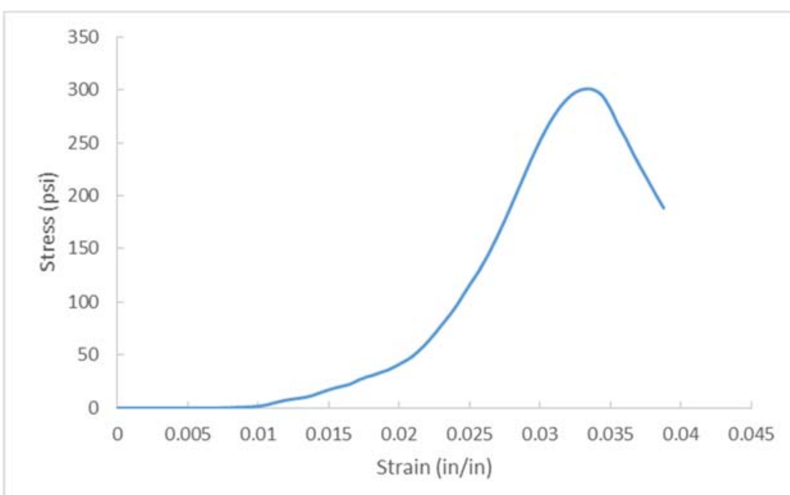


Figure A.158 D29-4, OC= 4.2%, CF= 400 pcf, T=28 days.

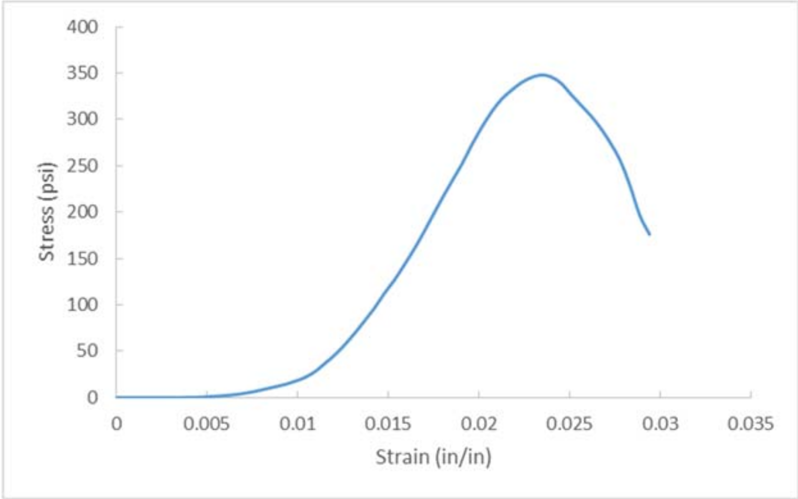

Figure A.159 D29-5, OC= 4.2%, CF= 400 pcf, T=28 days.

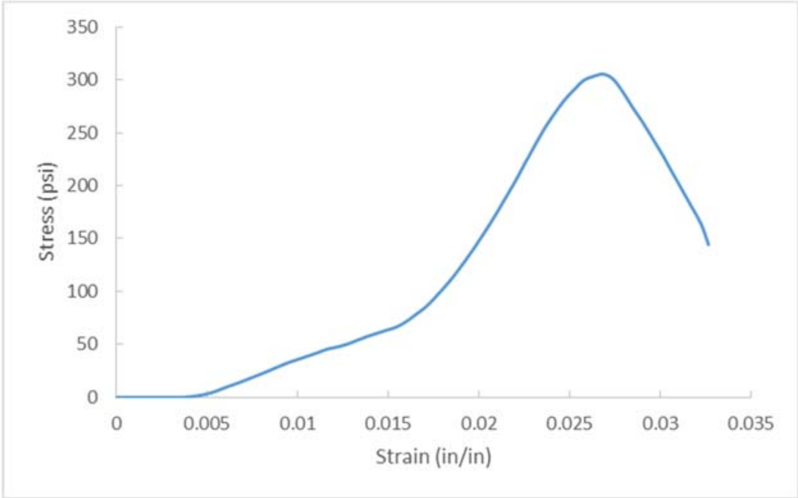

Figure A.160 D29-6, OC= 4.2%, CF= 400 pcf, T=28 days.

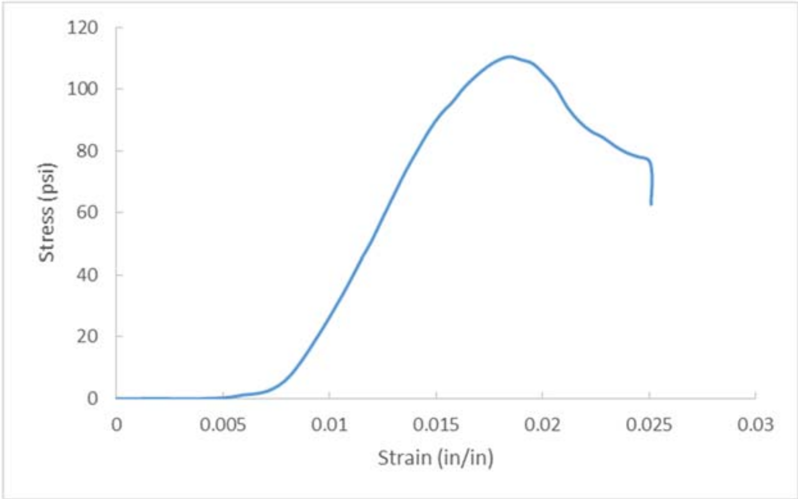

Figure A.161 D30-4, OC= 4.9%, CF= 400 pcf, T=28 days.

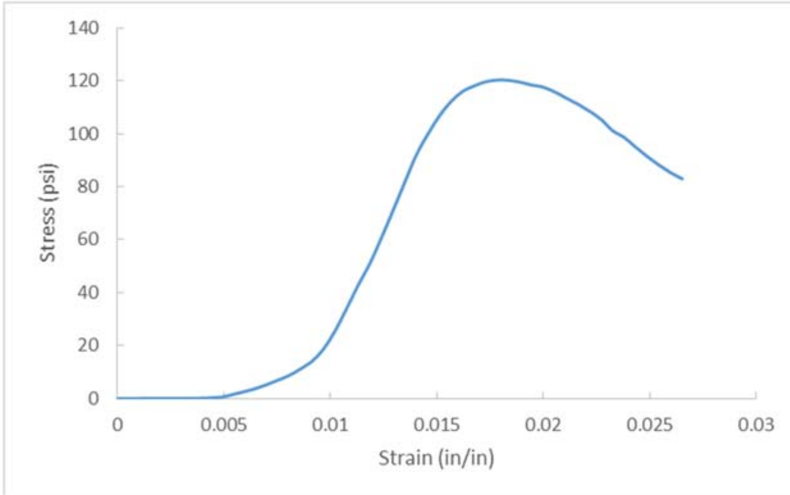


Figure A.162 D30-5, OC= 4.9%, CF= 400 pcf, T=28 days.

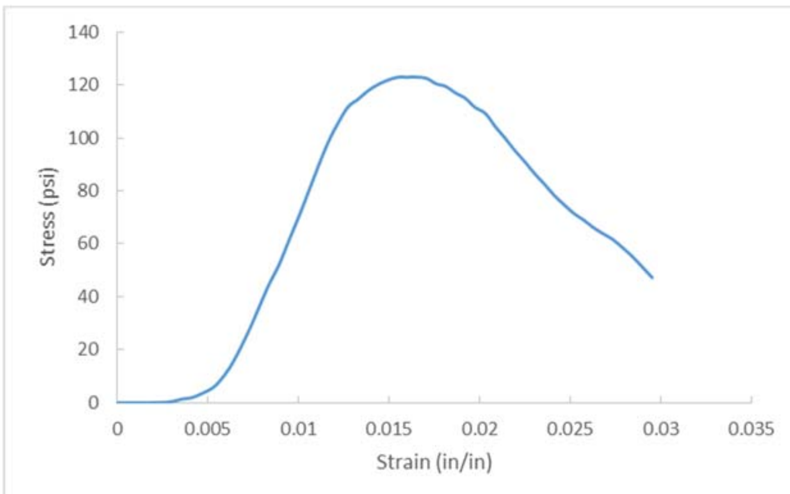


Figure A.163 D30-6, OC= 4.9%, CF= 400 pcf, T=28 days.

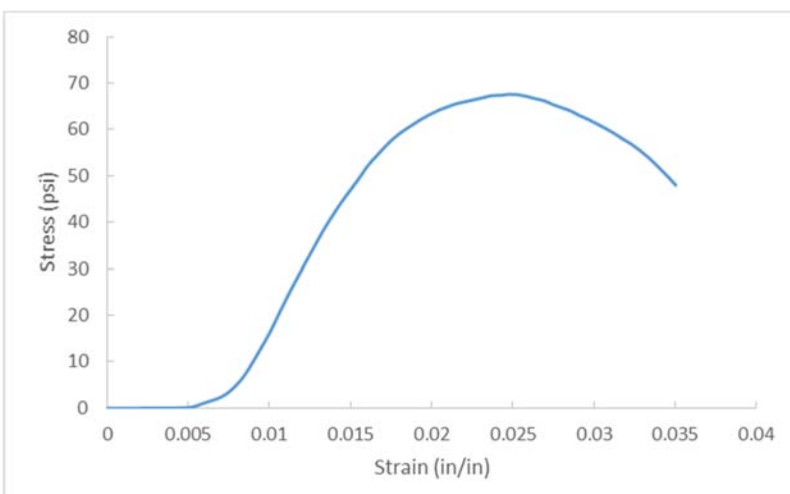


Figure A.164 D31-4, OC= 11.8%, CF= 400 pcf, T=28 days.

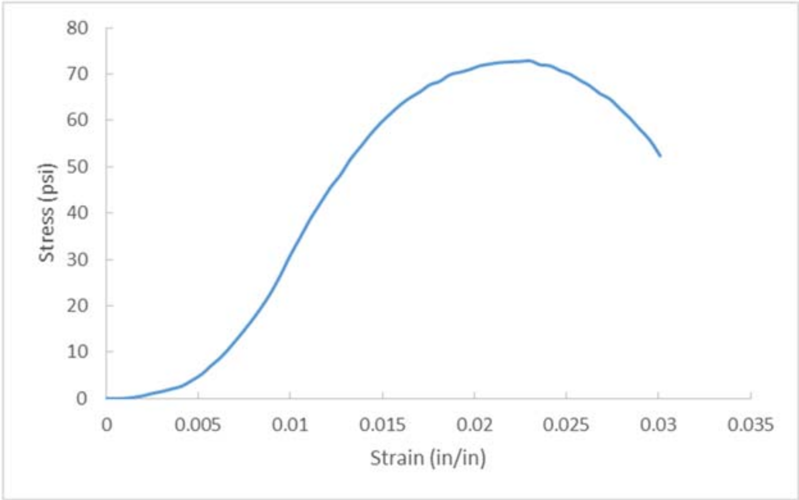

Figure A.165 D31-5, OC= 11.8%, CF= 400 pcf, T=28 days.

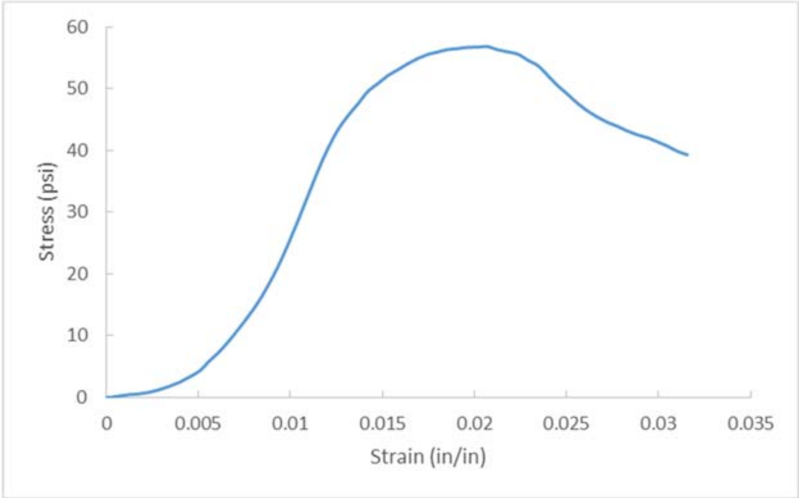

Figure A.166 D31-6, OC= 11.8%, CF= 400 pcf, T=28 days.

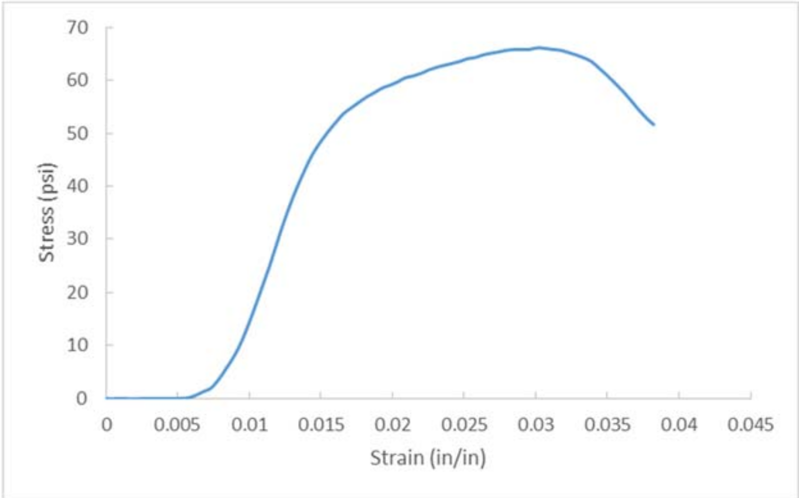

Figure A.167 D32-4, OC= 17.2%, CF= 400 pcf, T=28 days.

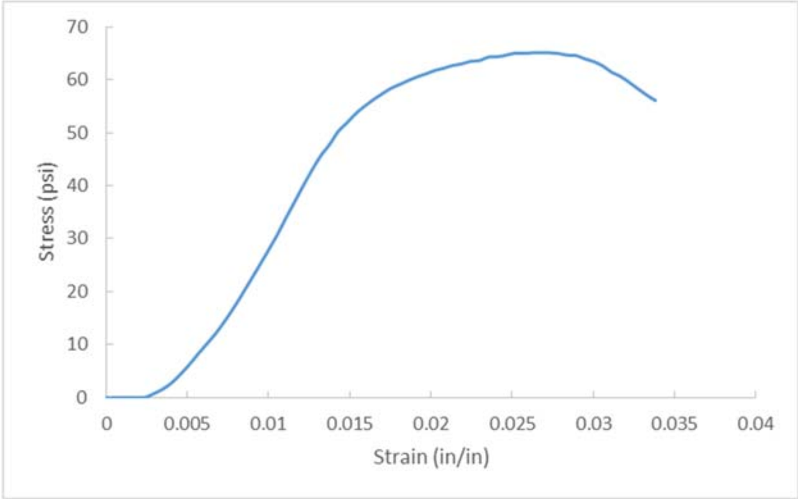


Figure A.168 D32-5, OC= 17.2%, CF= 400 pcf, T=28 days.

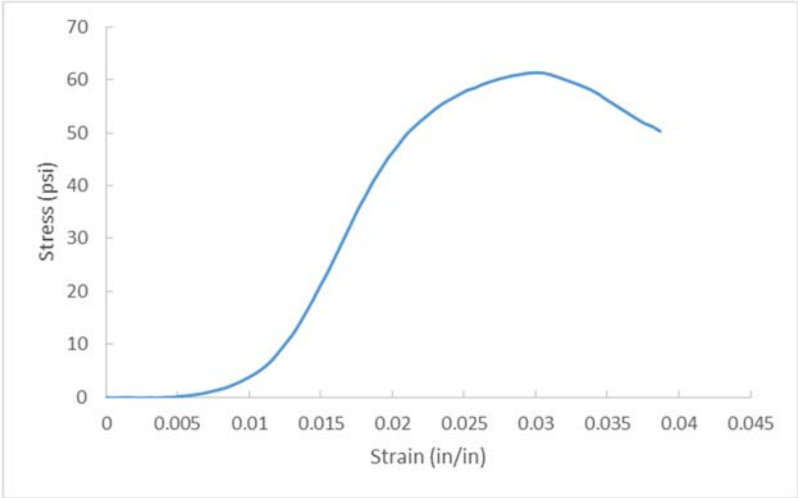


Figure A.169 D32-6, OC= 17.2%, CF= 400 pcf, T=28 days.

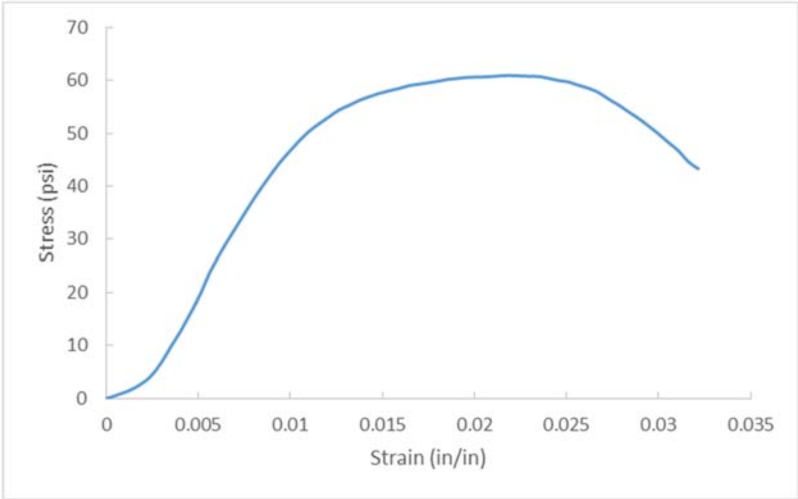


Figure A.170 D33-4, OC= 25.1%, CF= 400 pcf, T=28 days.

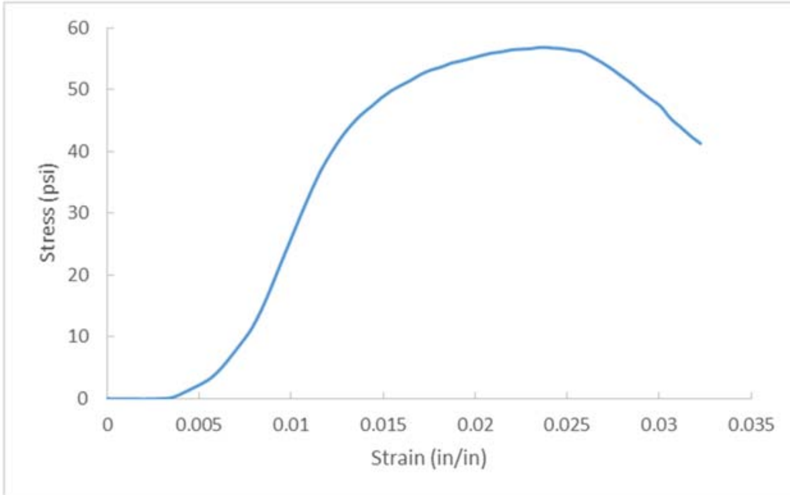

Figure A.171 D33-5, OC= 25.1%, CF= 400 pcf, T=28 days.

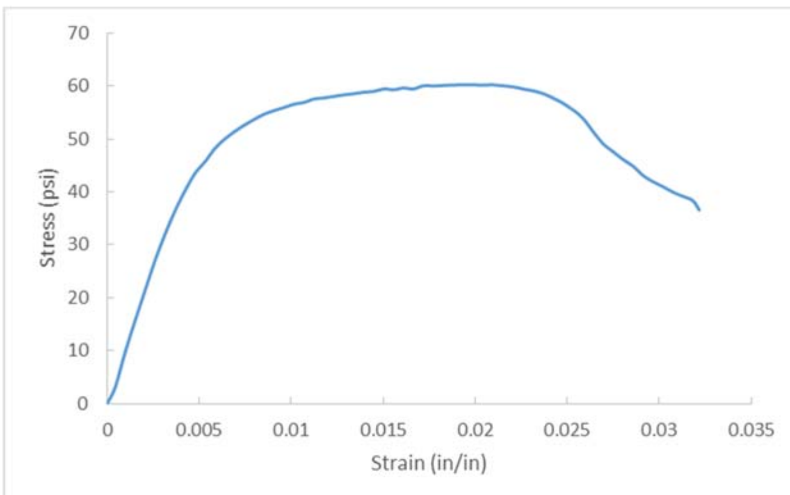

Figure A.172 D33-6, OC= 25.1%, CF= 400 pcf, T=28 days.

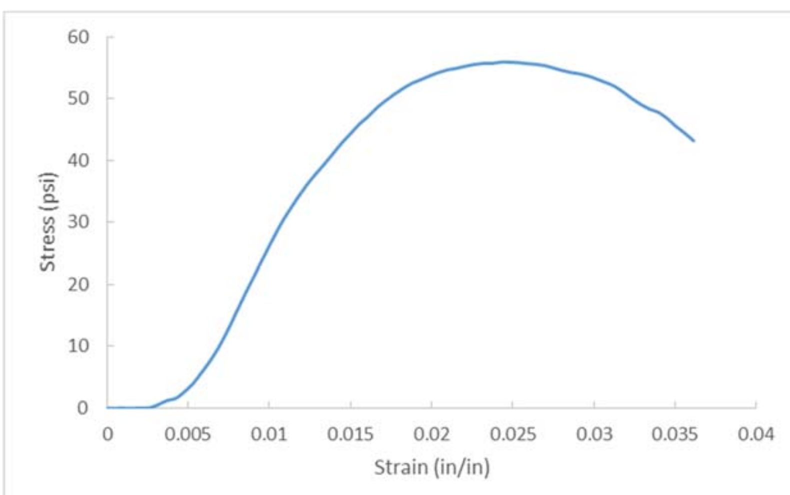

Figure A.173 D34-5, OC= 40.9%, CF= 400 pcf, T=28 days.

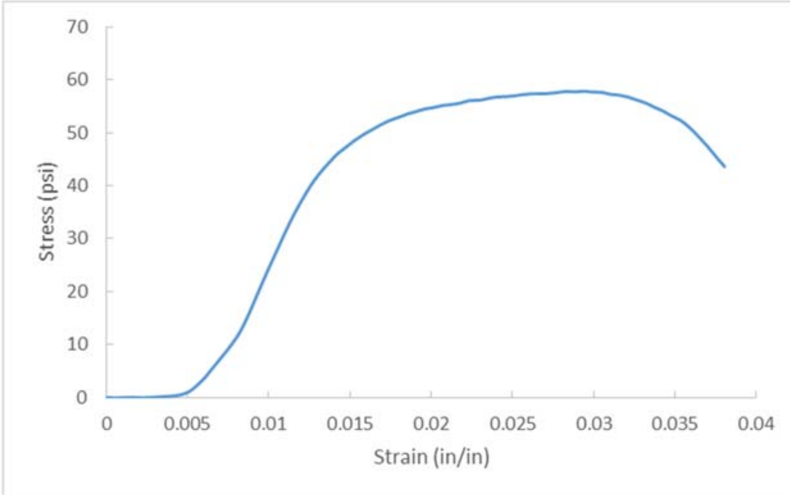

Figure A.174 D34-6, OC= 40.9%, CF= 400 pcf, T=28 days.

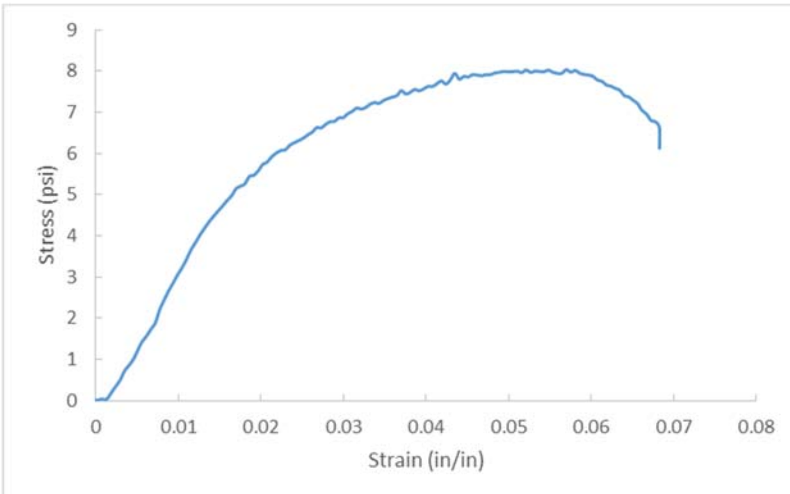

Figure A.175 D35-6, OC= 39.6%, CF= 200 pcf, T=28 days.

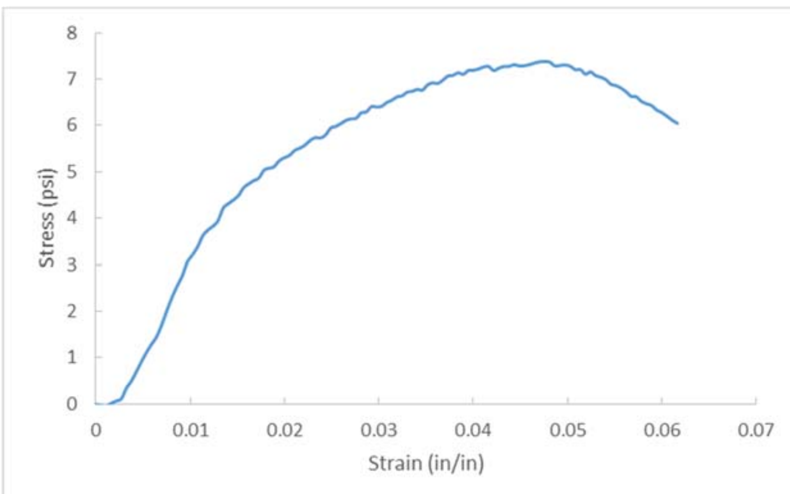

Figure A.176 D35-7, OC= 39.6%, CF= 200 pcf, T=28 days.

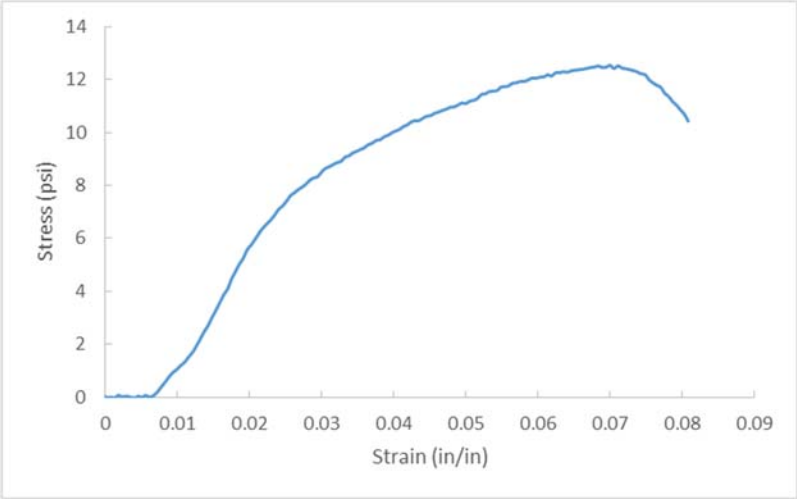

Figure A.177 D36.4, OC= 25.6%, CF= 200 pcf, T=28 days.

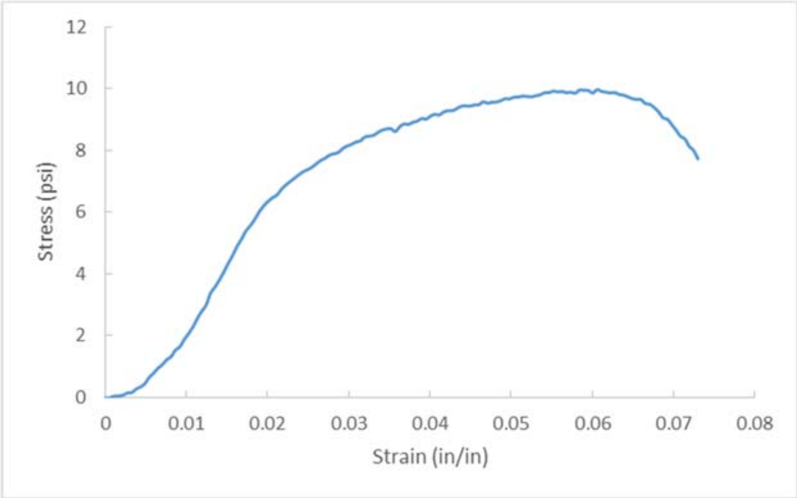

Figure A.178 D36.5, OC= 25.6%, CF= 200 pcf, T=28 days.

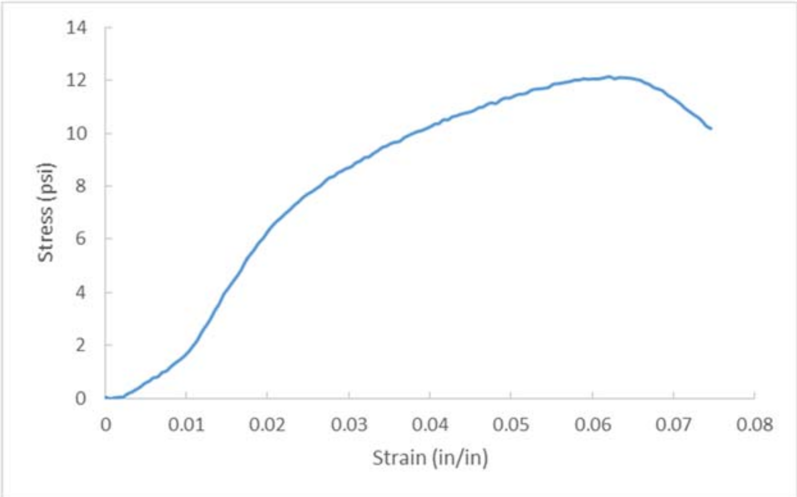

Figure A.179 D36.6, OC= 25.6%, CF= 200 pcf, T=28 days.

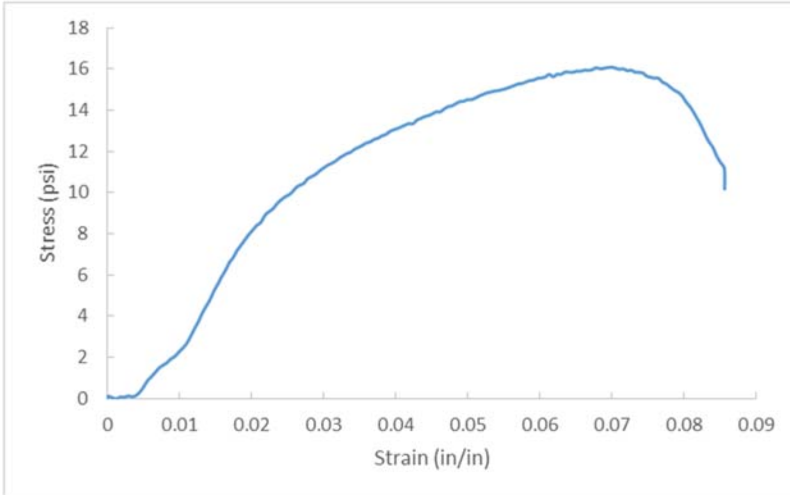

Figure A.180 D37-4, OC= 18.9%, CF= 200 pcf, T=28 days.

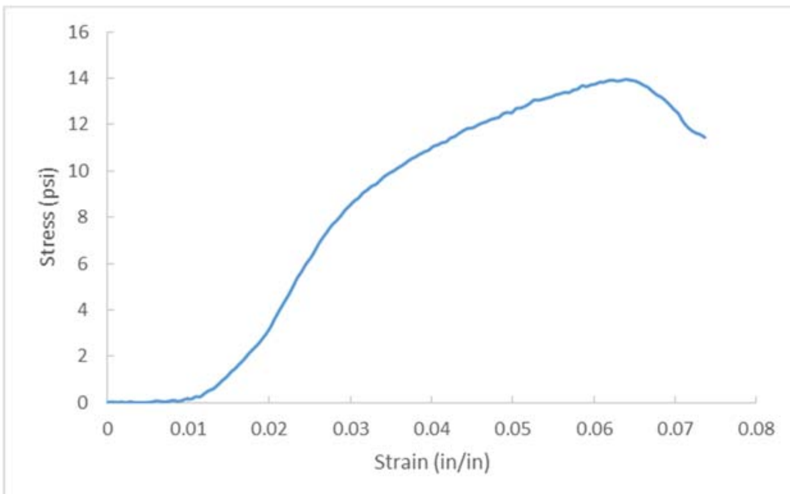

Figure A.181 D37-5, OC= 18.9%, CF= 200 pcf, T=28 days.

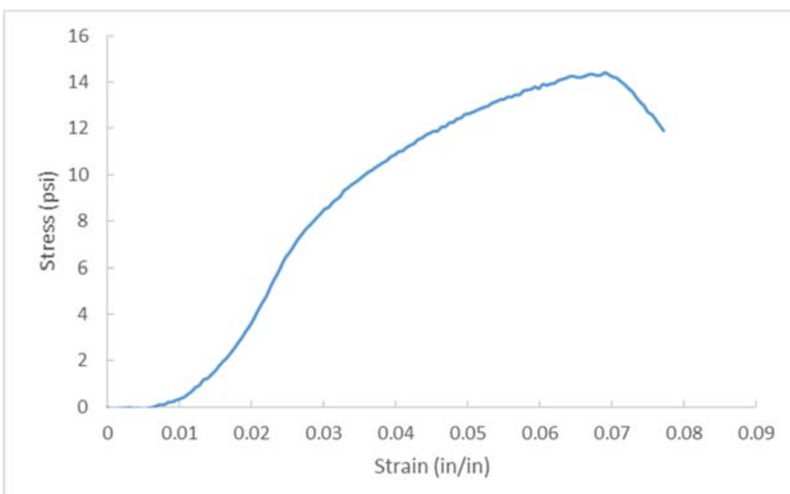

Figure A.182 D37-6, OC= 18.9%, CF= 200 pcf, T=28 days.

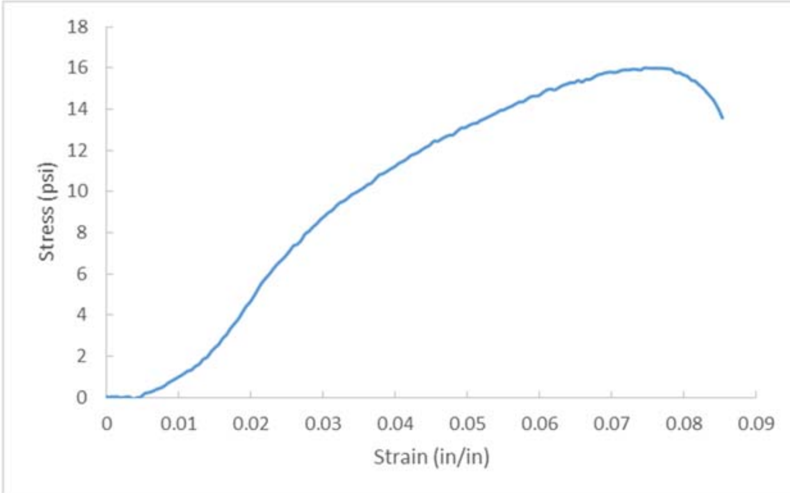


Figure A.183 D38-4, OC= 13.9%, CF= 200 pcf, T=28 days.

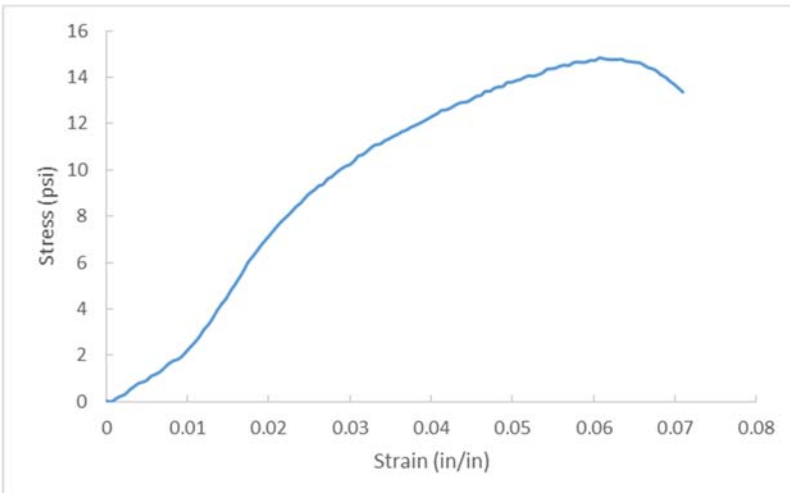


Figure A.184 D38-5, OC= 13.9%, CF= 200 pcf, T=28 days.

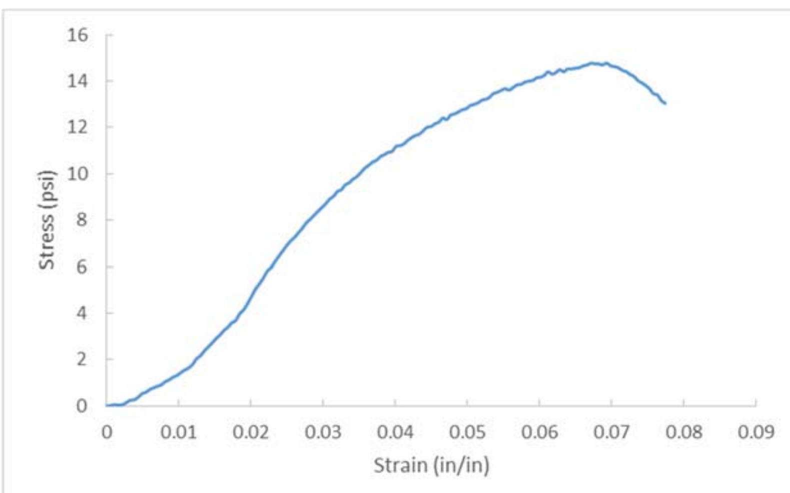


Figure A.185 D38-6, OC= 13.9%, CF= 200 pcf, T=28 days.

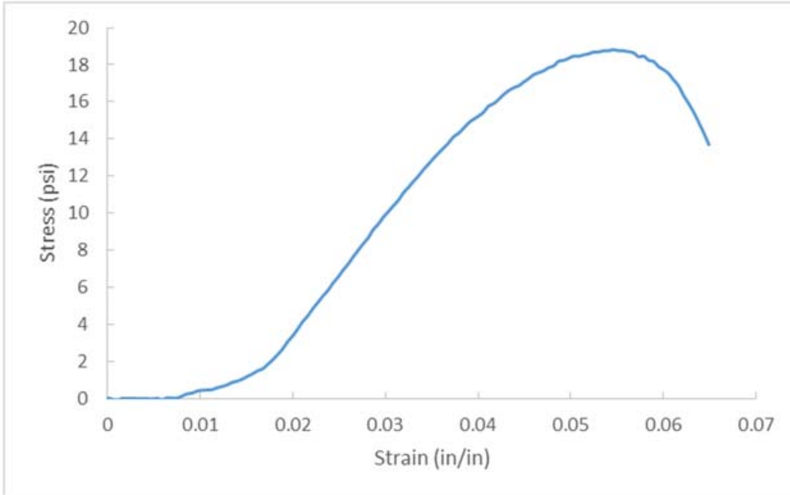


Figure A.186 D39-4, OC= 3.9%, CF= 200 pcf, T=28 days.

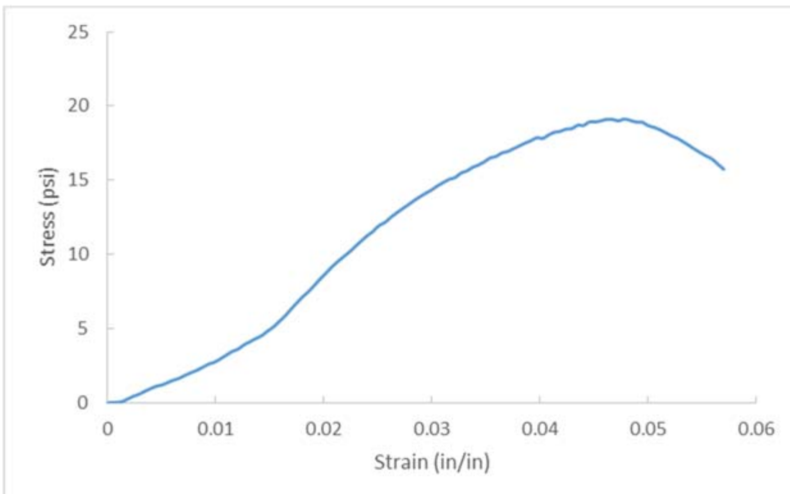


Figure A.187 D39-6, OC= 3.9%, CF= 200 pcf, T=28 days.

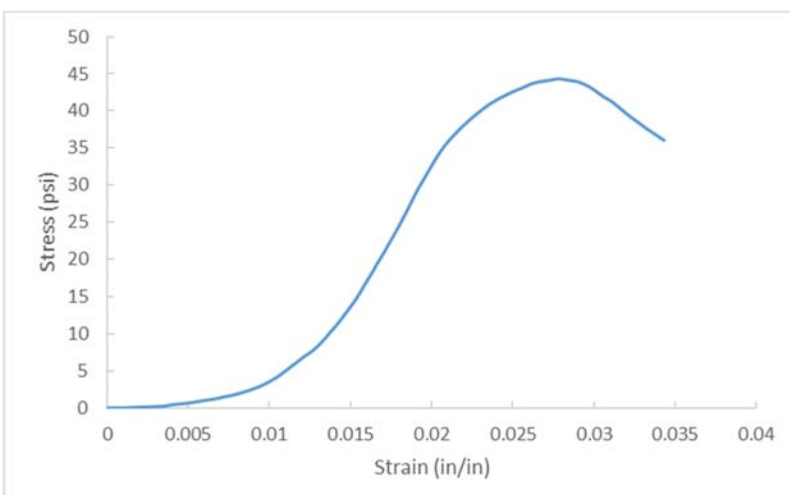


Figure A.188 D44-1, OC= 4.1%, CF= 200 pcf, T=28 days.

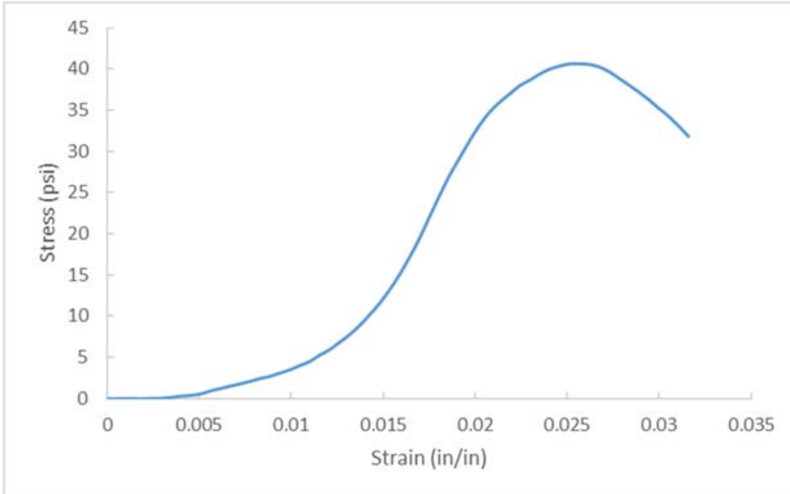


Figure A.189 D44-2, OC= 4.1%, CF= 200 pcf, T=28 days.

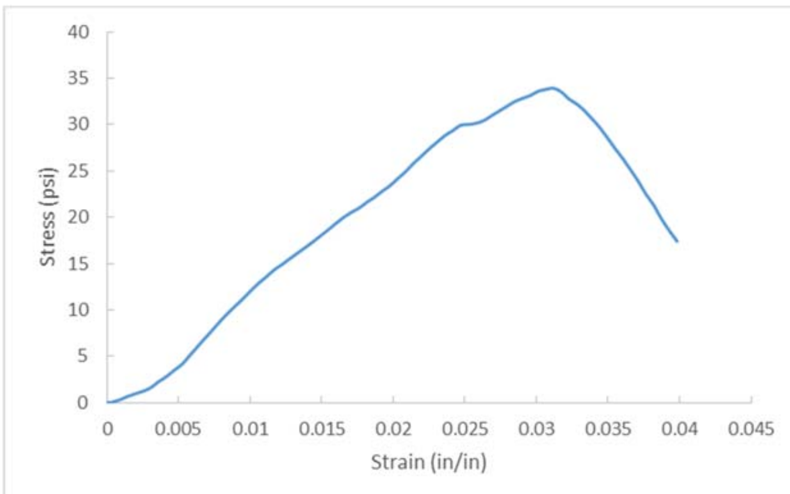


Figure A.190 D44-3, OC= 4.1%, CF= 200 pcf, T=28 days.

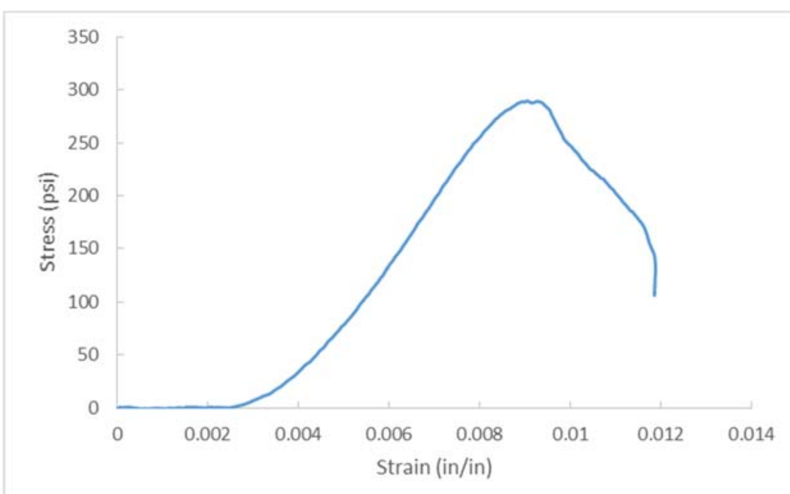


Figure A.191 D45-4, OC= 0.0%, CF= 400 pcf, T=28 days.

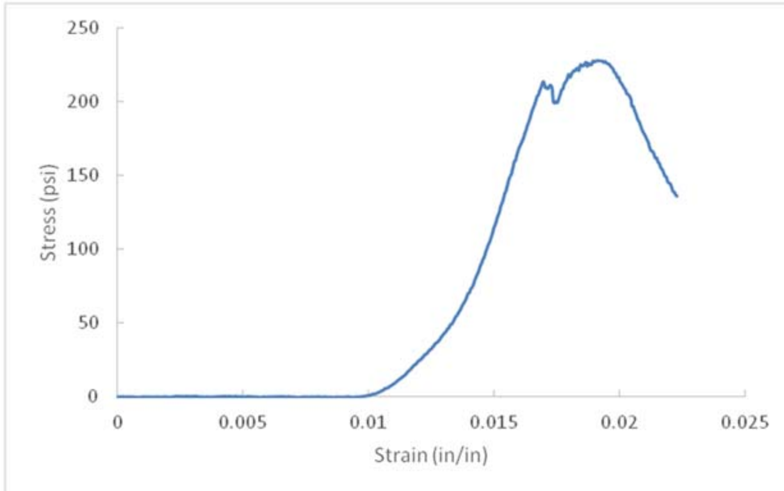

Figure A.192 D45-5, OC= 0.0%, CF= 400 pcf, T=28 days.

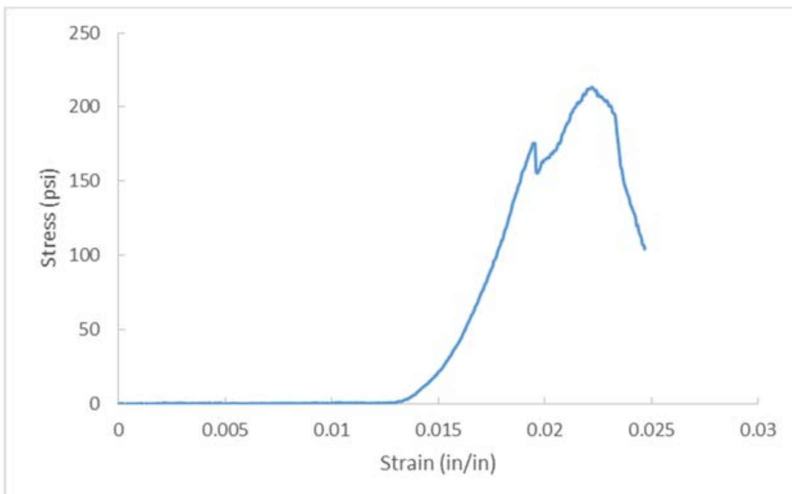

Figure A.193 D45-6, OC= 0.0%, CF= 400 pcf, T=28 days.

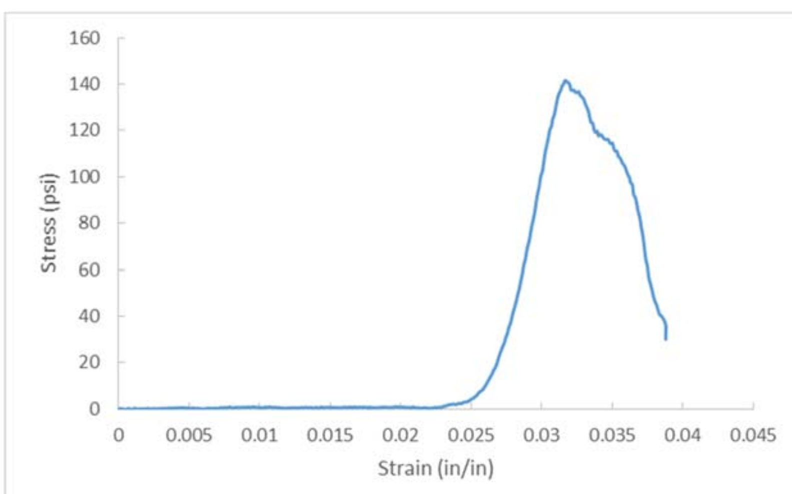

Figure A.194 D46-5, OC= 0.0%, CF= 300 pcf, T=28 days.

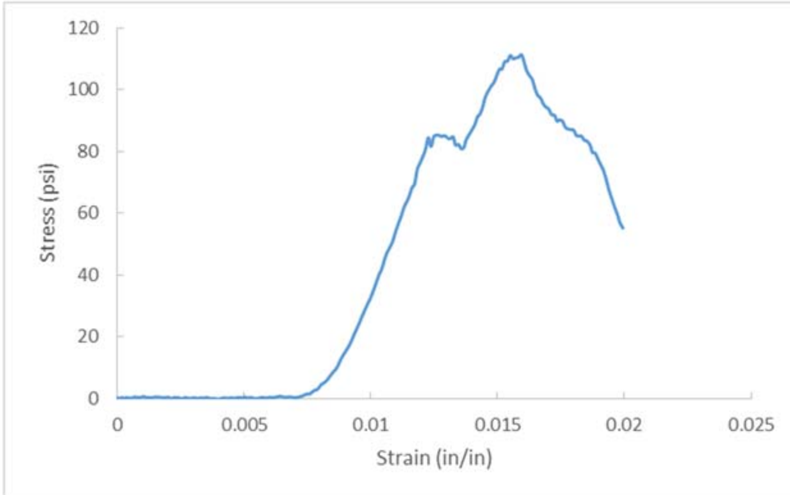

Figure A.195 D46-6, OC= 0.0%, CF= 300 pcf, T=28 days.

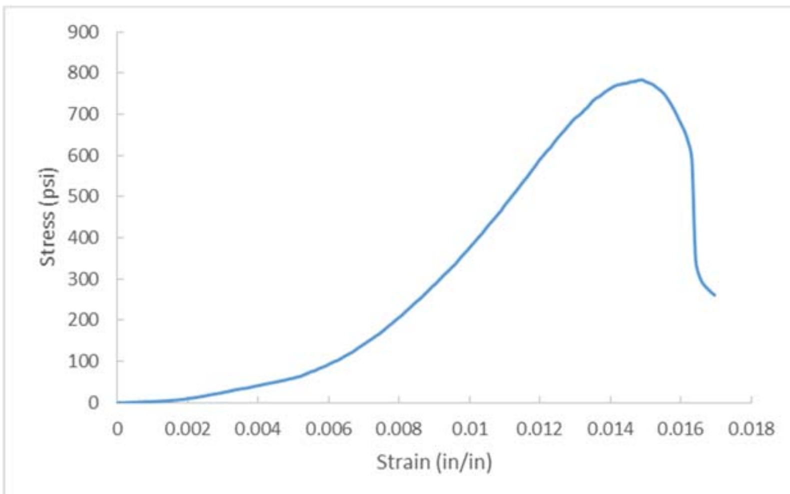

Figure A.196 D47-4, OC= 0.0%, CF= 400 pcf, T=28 days.

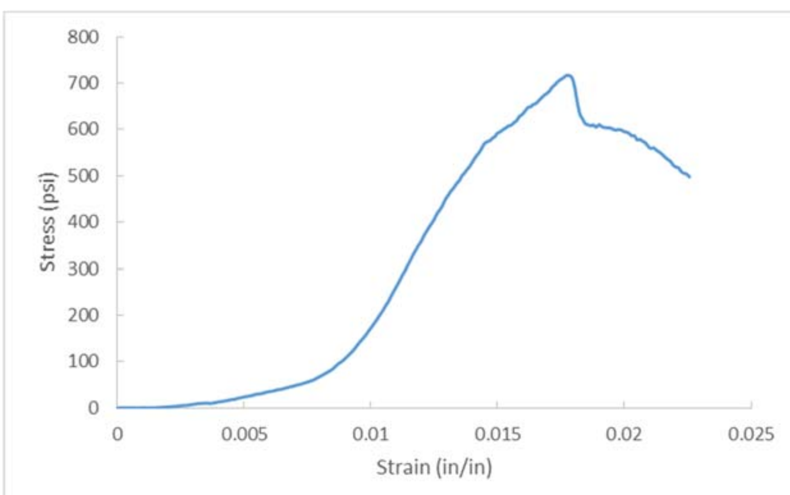

Figure A.197 D47-5, OC= 0.0%, CF= 400 pcf, T=28 days.

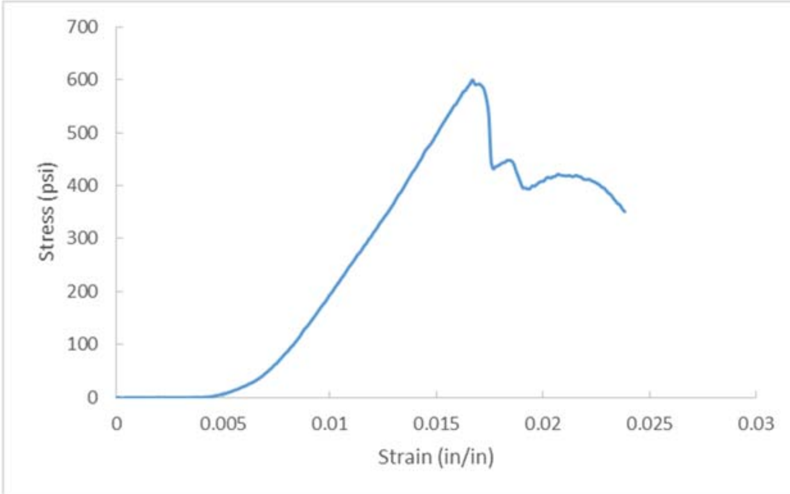


Figure A.198 D47-6, OC= 0.0%, CF= 400 pcf, T=28 days.

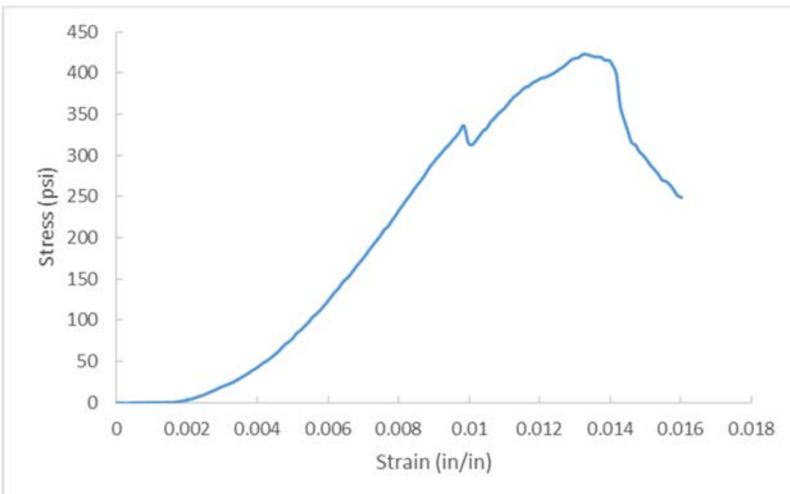


Figure A.199 D48-4, OC= 0.0%, CF= 300 pcf, T=28 days.

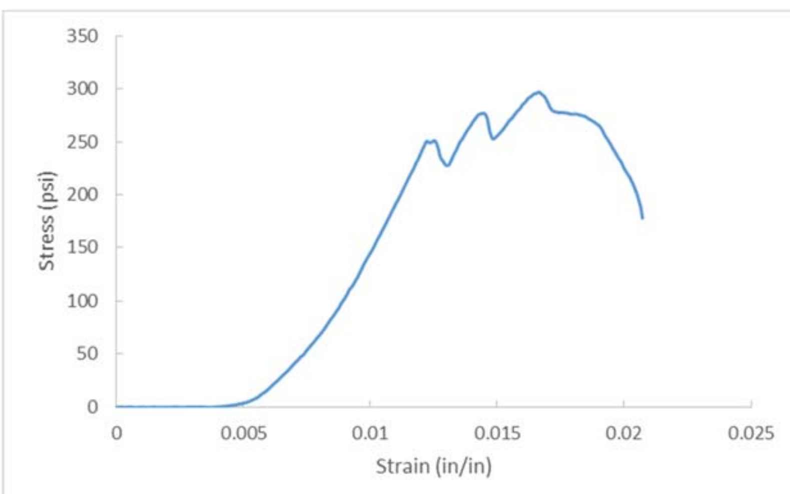


Figure A.200 D48-5, OC= 0.0%, CF= 300 pcf, T=28 days.

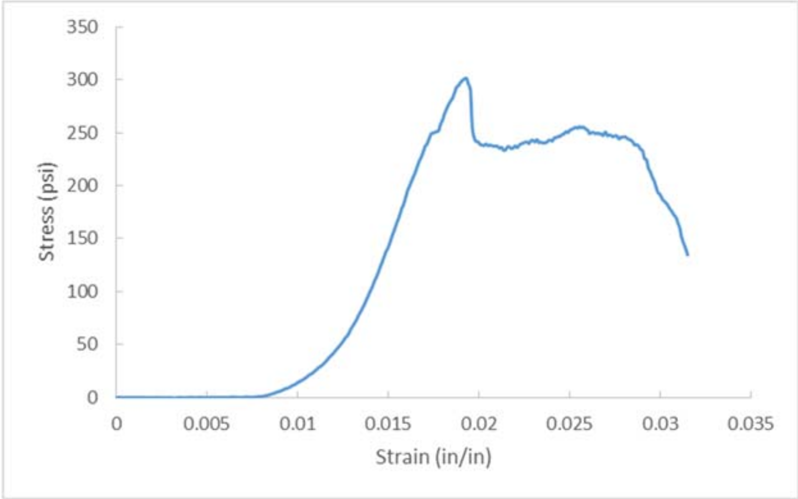


Figure A.201 D48-6, OC= 0.0%, CF= 300 pcf, T=28 days.

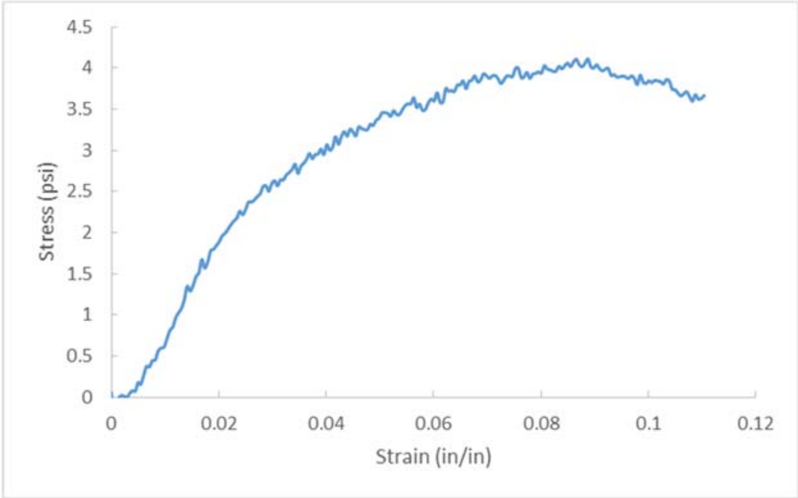


Figure A.202 W49-4, OC= 43.8%, CF= 300 pcf, T=28 days.

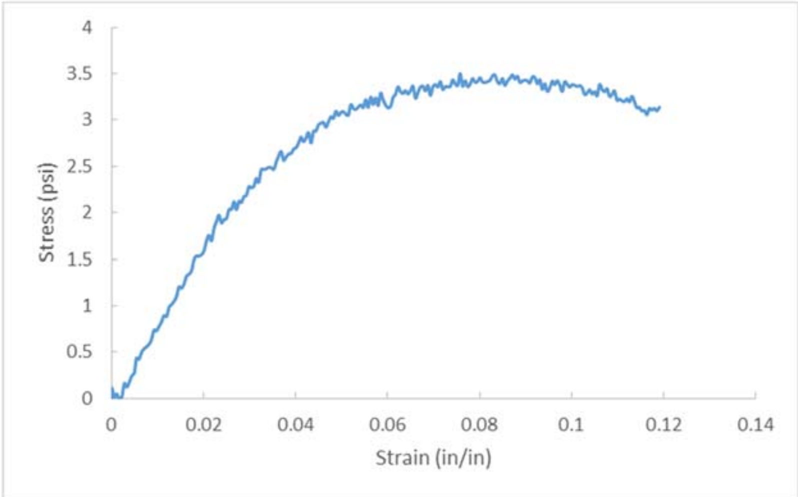


Figure A.203 W49-5, OC= 43.8%, CF= 300 pcf, T=28 days.

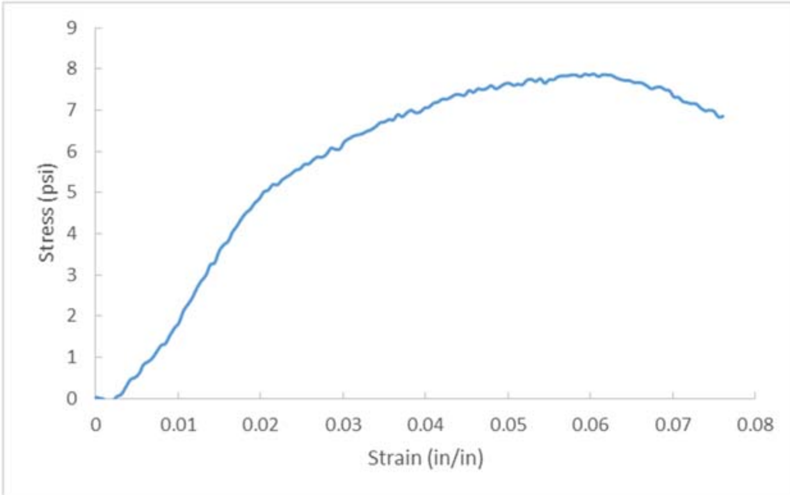

Figure A.204 W50-4, OC= 43.8%, CF= 400 pcf, T=28 days.

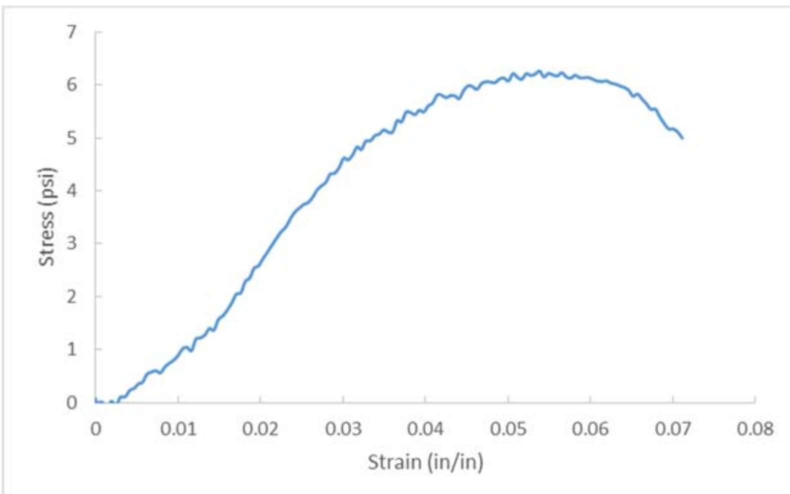

Figure A.205 W50-5, OC= 43.8%, CF= 400 pcf, T=28 days.

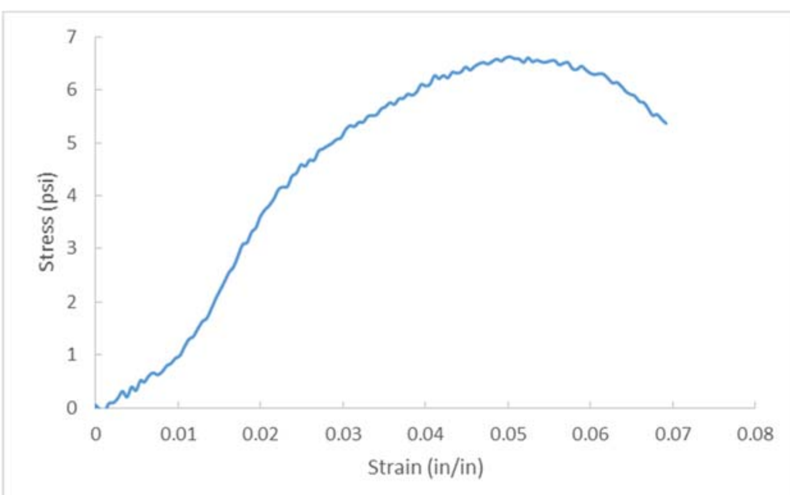

Figure A.206 W50-6, OC= 43.8%, CF= 400 pcf, T=28 days.

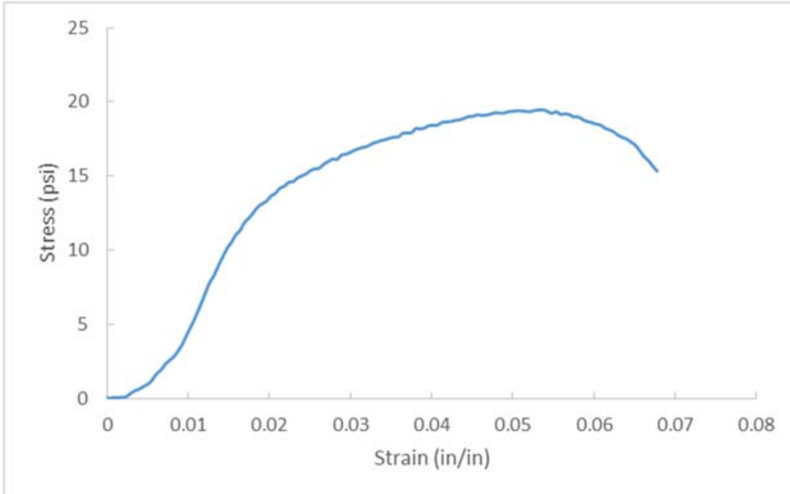

Figure A.207 W51.4, OC= 43.8%, CF= 500 pcf, T=28 days.

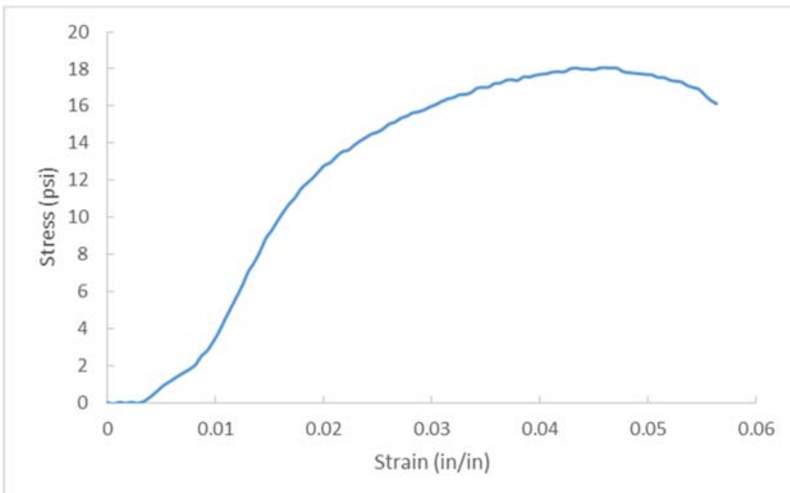

Figure A.208 W51.5, OC= 43.8%, CF= 500 pcf, T=28 days.

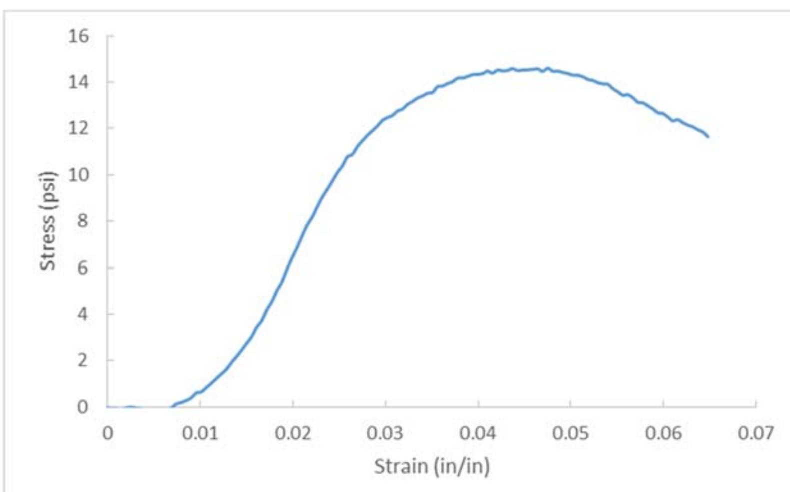

Figure A.209 W51.6, OC= 43.8%, CF= 500 pcf, T=28 days.

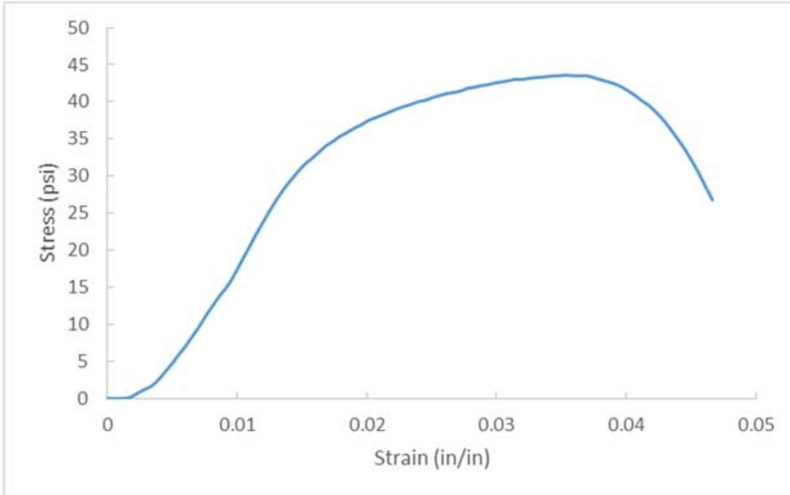

Figure A.210 D55.1, OC= 42.1%, CF= 500 pcf, T=28 days.

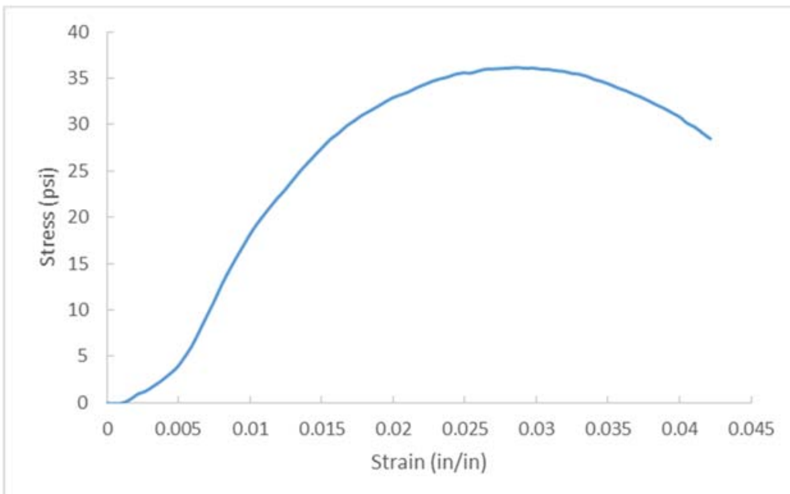

Figure A.211 D55.2, OC= 42.1%, CF= 500 pcf, T=28 days.

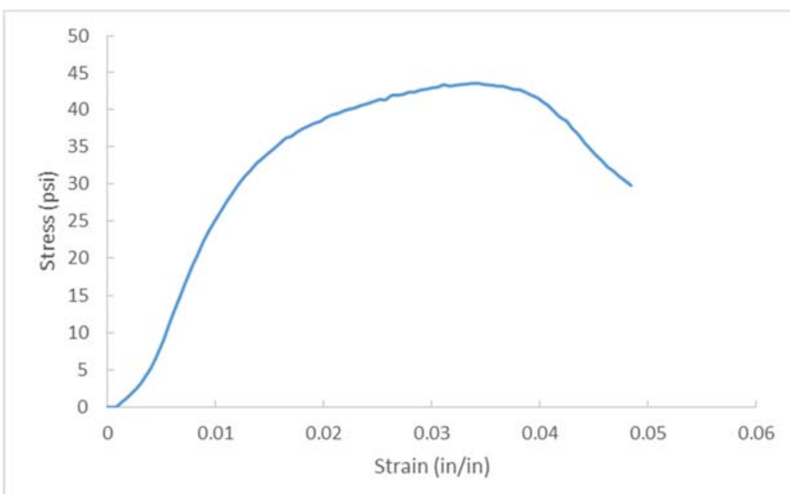

Figure A.212 D55.3, OC= 42.1%, CF= 500 pcf, T=28 days.

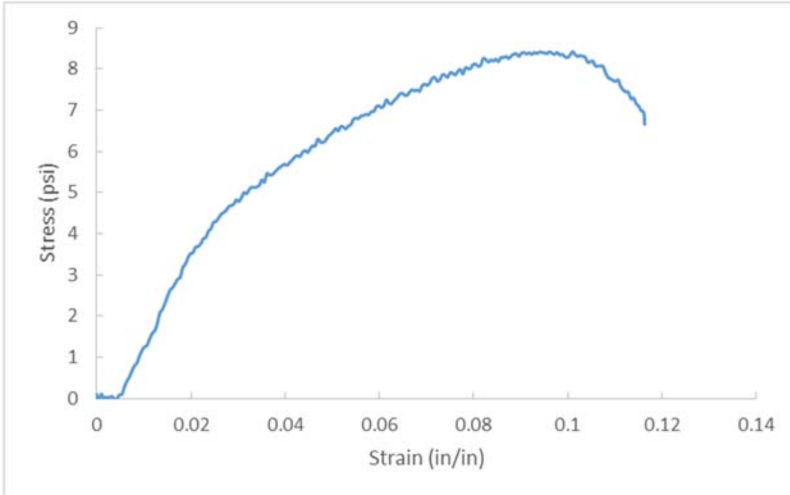


Figure A.213 D57.1, OC= 42.1%, CF= 500 pcf, T=28 days.

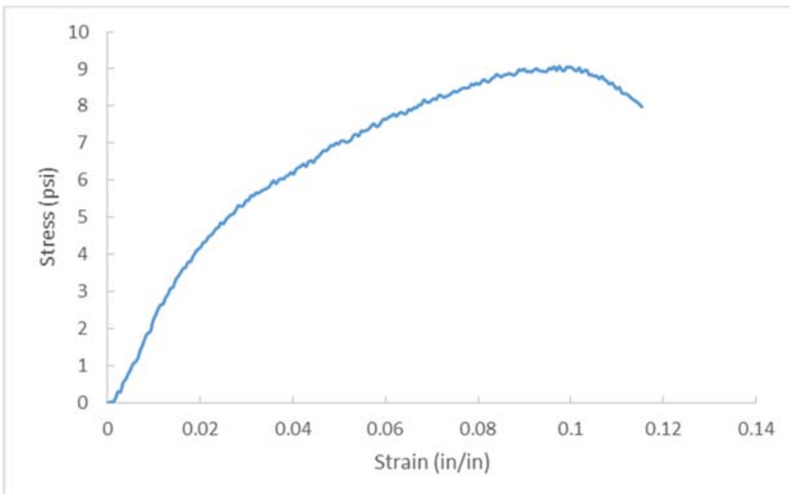


Figure A.214 D57.2, OC= 42.1%, CF= 500 pcf, T=28 days.

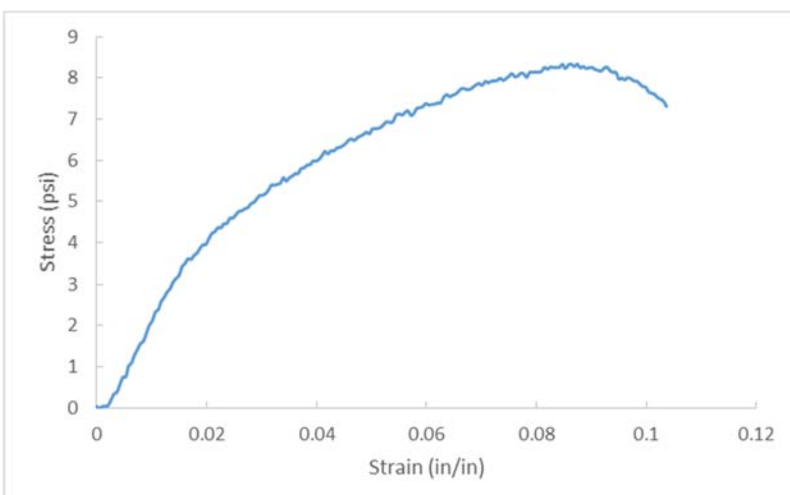


Figure A.215 D57.3, OC= 42.1%, CF= 500 pcf, T=28 days.

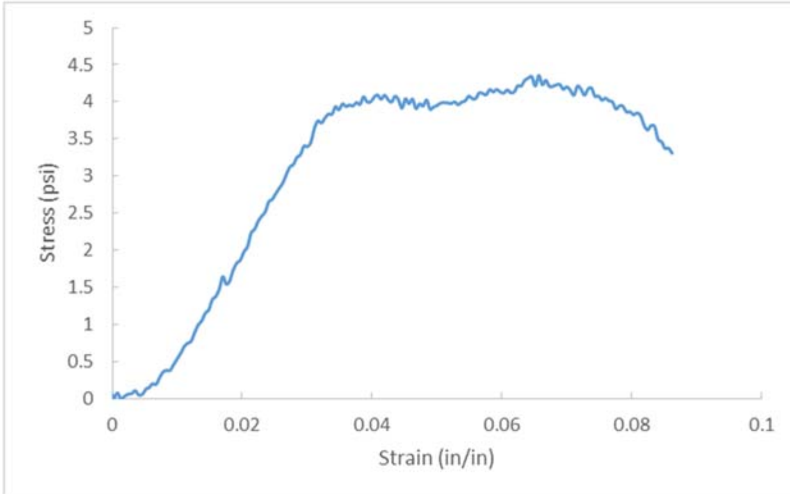

Figure A.216 D3-7, OC= 66.4%, CF= 400 pcf, T=56 days.

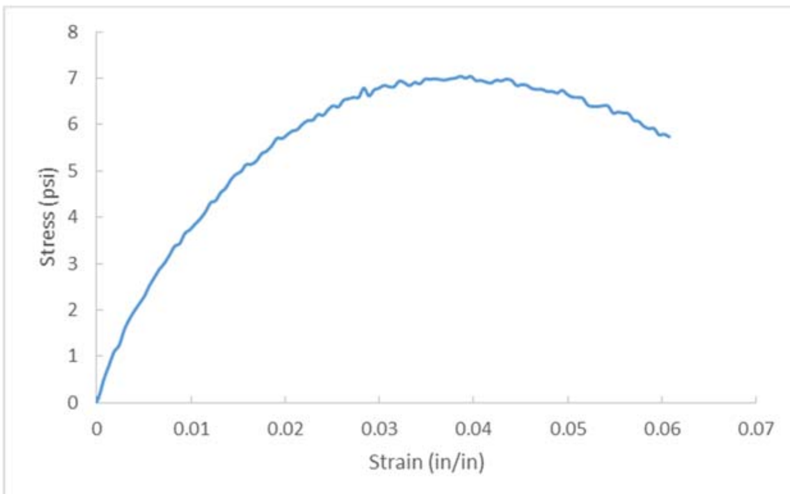

Figure A.217 D3-8, OC= 66.4%, CF= 400 pcf, T=56 days.

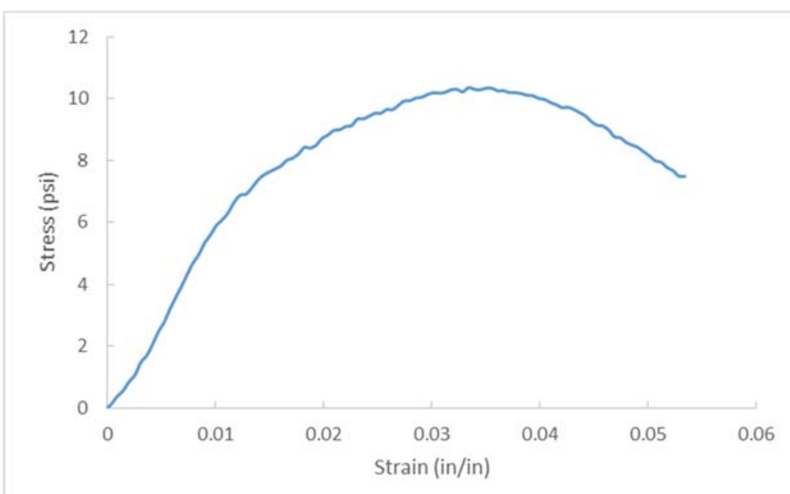

Figure A.218 D3-9, OC= 66.4%, CF= 400 pcf, T=56 days.

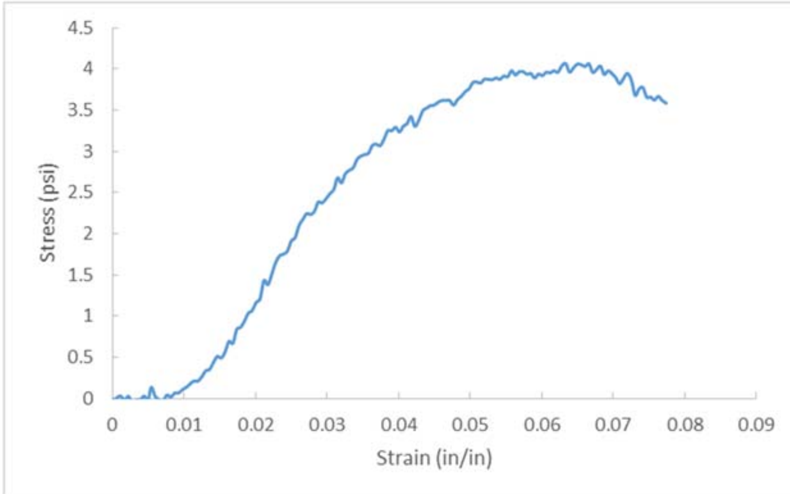

Figure A.219 D4-7, OC= 66.4%, CF= 200 pcf, T=56 days.

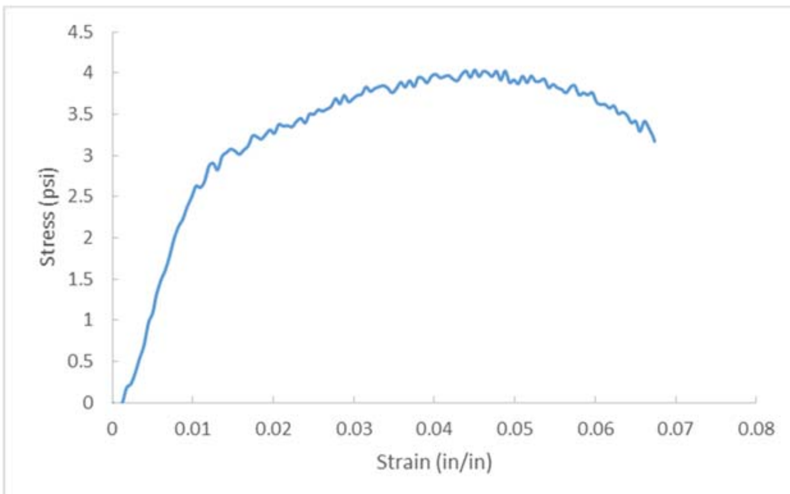

Figure A.220 D4-9, OC= 66.4%, CF= 200 pcf, T=56 days.

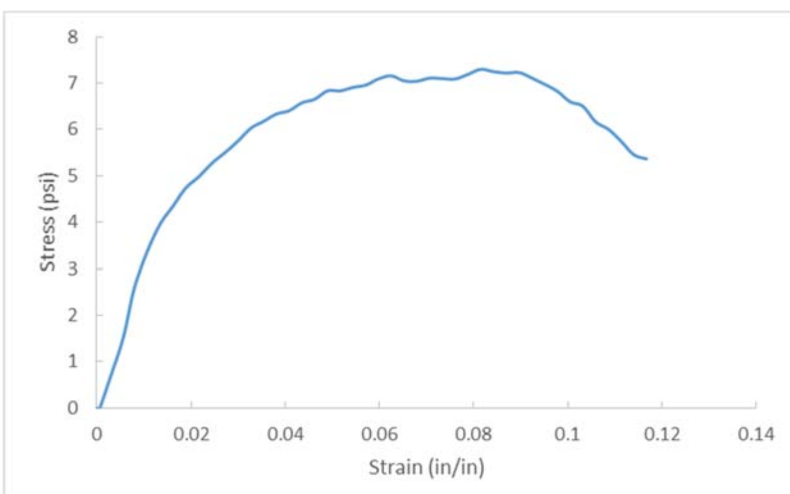

Figure A.221 D8-7, OC= 65.9%, CF= 300 pcf, T=56 days.

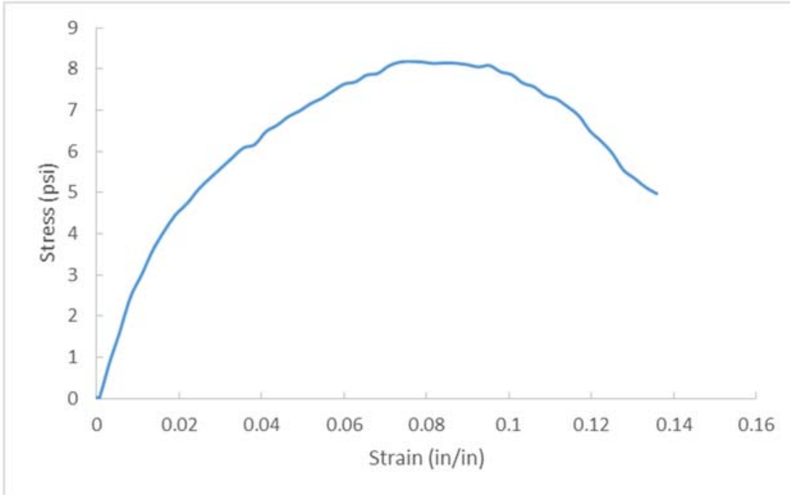


Figure A.222 D8-8, OC= 65.9%, CF= 300 pcf, T=56 days.

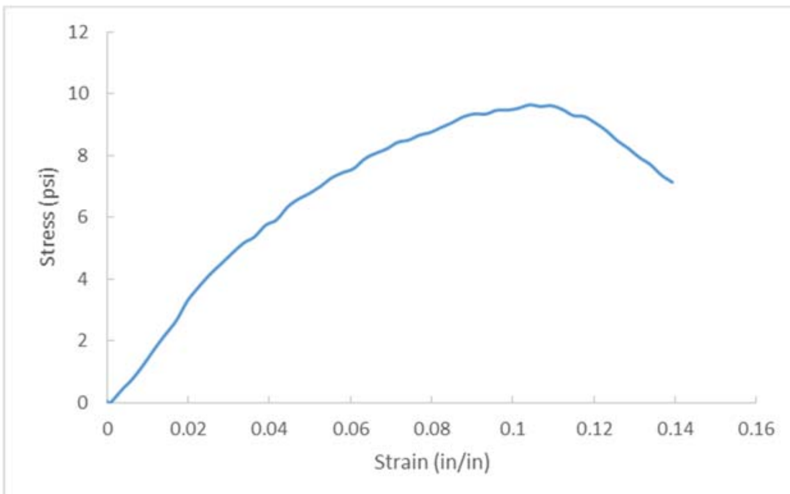


Figure A.223 D8-9, OC= 65.9%, CF= 300 pcf, T=56 days.

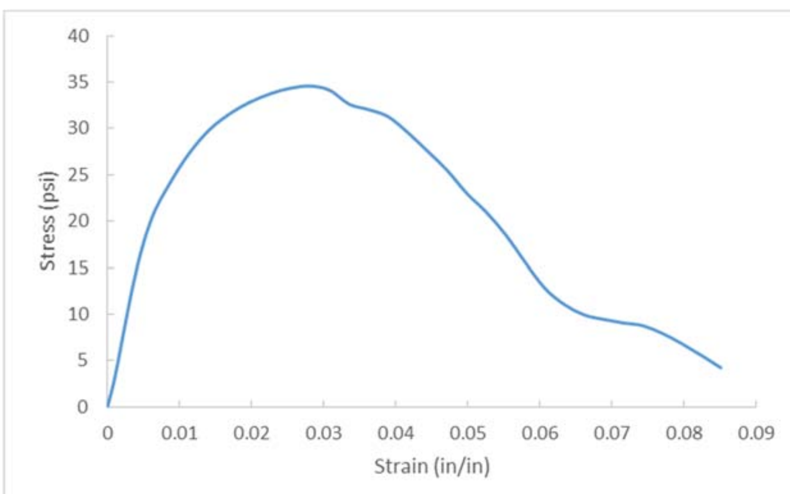


Figure A.224 D9-7, OC= 65.9%, CF= 400 pcf, T=56 days.

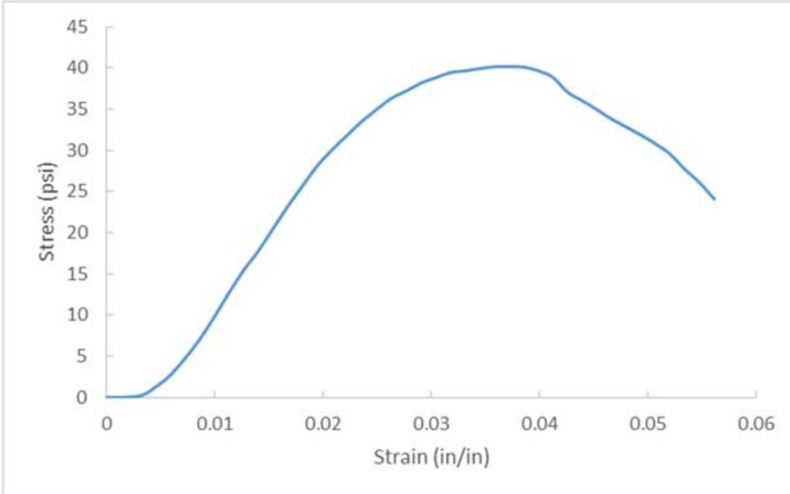


Figure A.225 D9-8, OC= 65.9%, CF= 400 pcf, T=56 days.

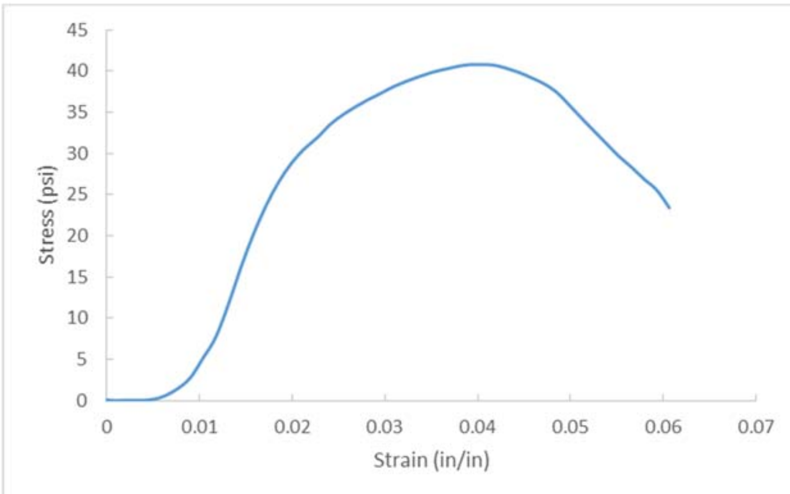


Figure A.226 D9-9, OC= 65.9%, CF= 400 pcf, T=56 days.

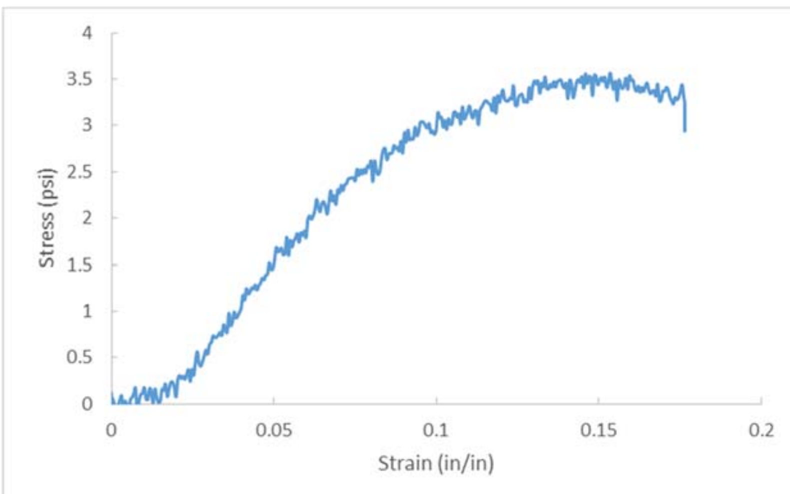


Figure A.227 D10-7, OC= 41.3%, CF= 300 pcf, T=56 days.

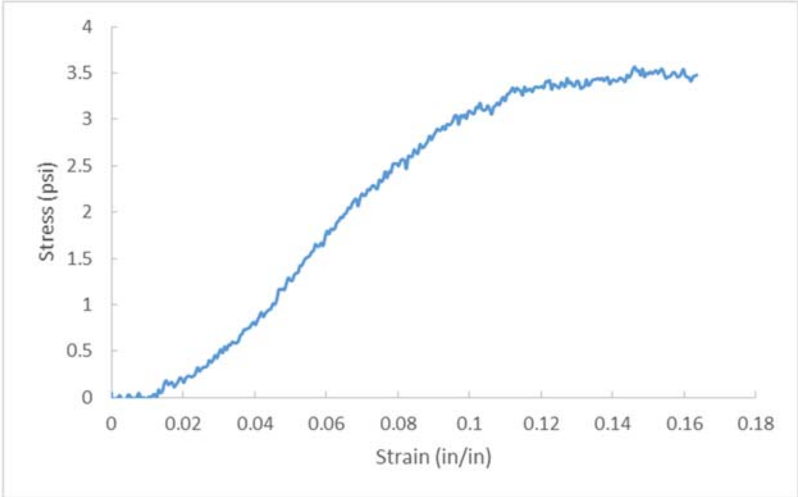

Figure A.228 D10-8, OC= 41.3%, CF= 300 pcf, T=56 days.

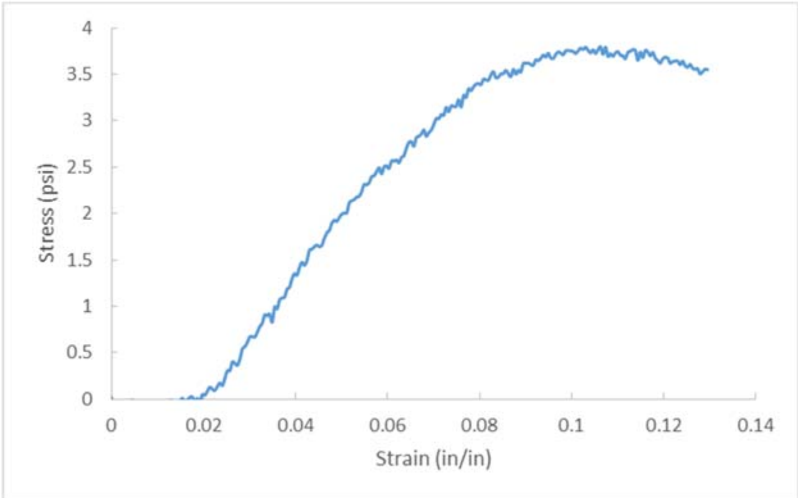

Figure A.229 D11-7, OC= 27.8%, CF= 300 pcf, T=56 days.

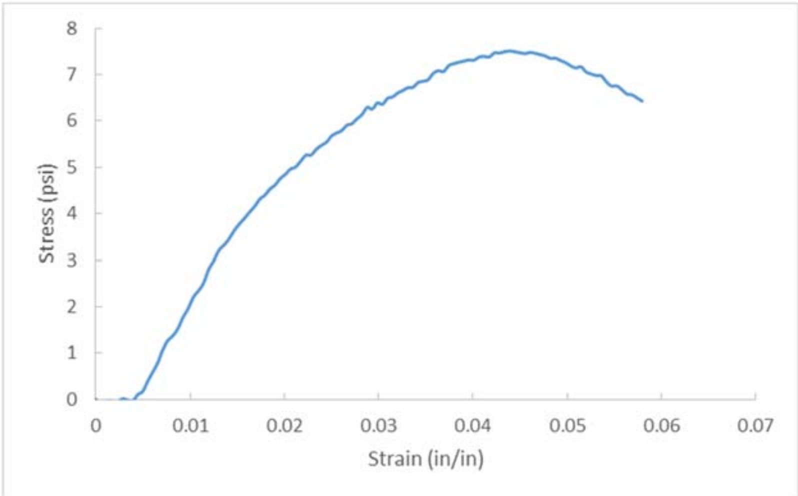

Figure A.230 D12-7, OC= 24.1%, CF= 300 pcf, T=56 days.

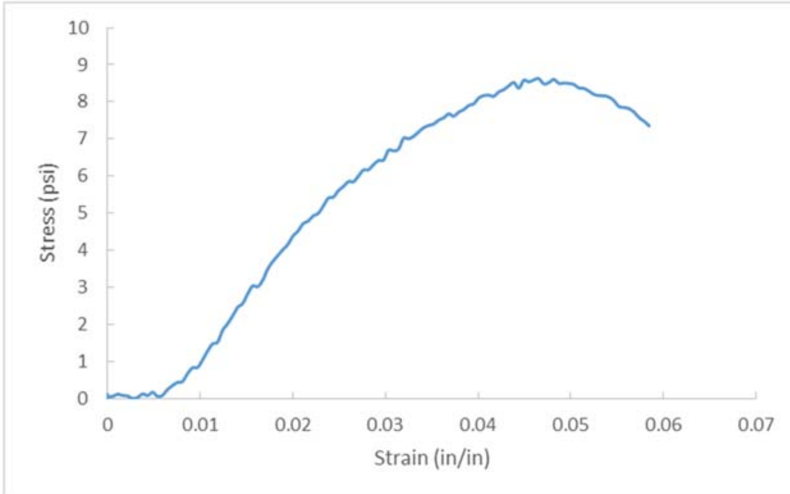

Figure A.231 D12-8, OC= 24.1%, CF= 300 pcf, T=56 days.

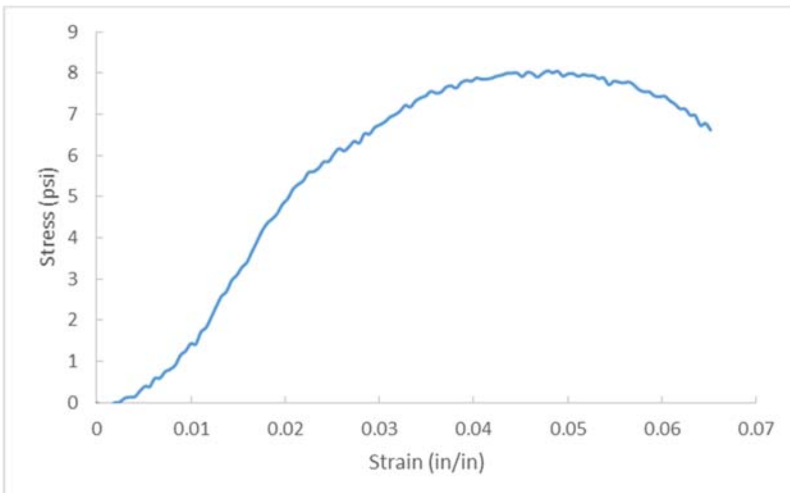

Figure A.232 D12-9, OC= 24.1%, CF= 300 pcf, T=56 days.

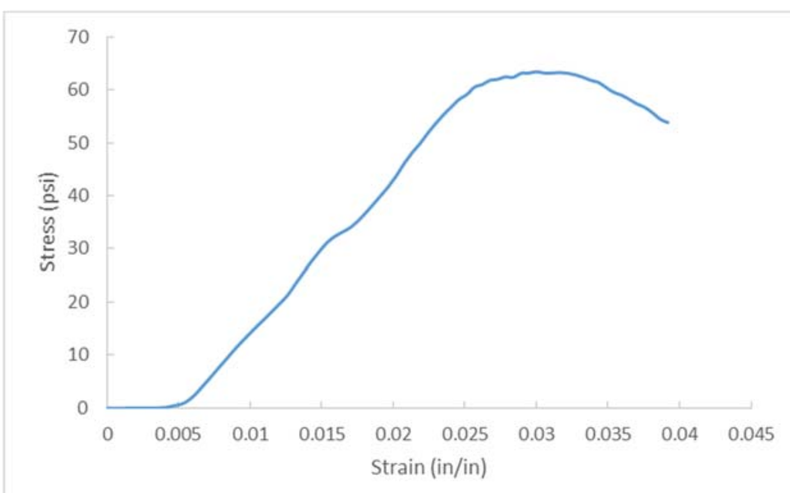

Figure A.233 D13-7, OC= 11.2%, CF= 300 pcf, T=56 days.

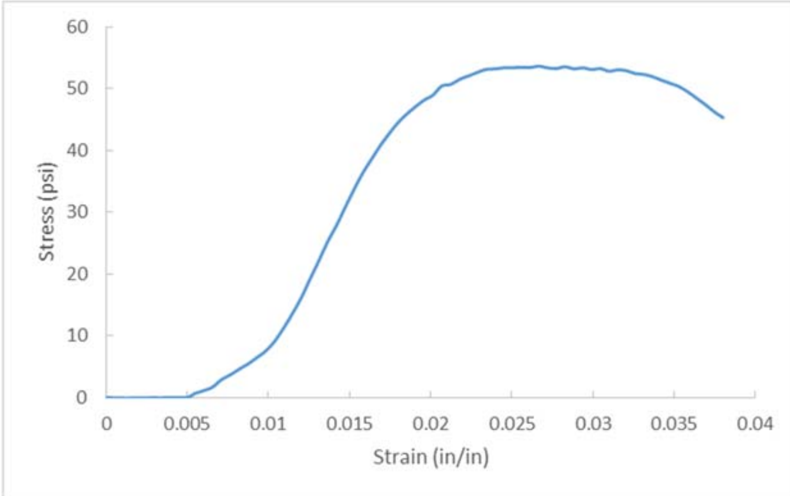

Figure A.234 D13-8, OC= 11.2%, CF= 300 pcf, T=56 days.

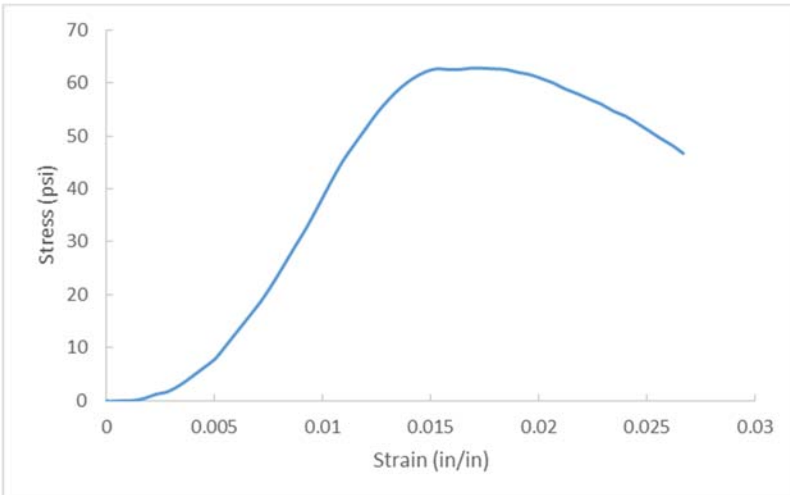

Figure A.235 D13-9, OC= 11.2%, CF= 300 pcf, T=56 days.

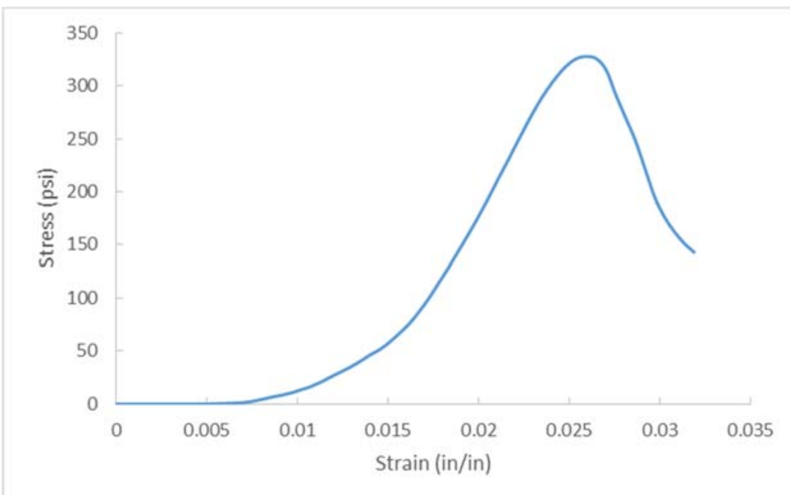

Figure A.236 D14-7, OC= 4.6%, CF= 300 pcf, T=56 days.

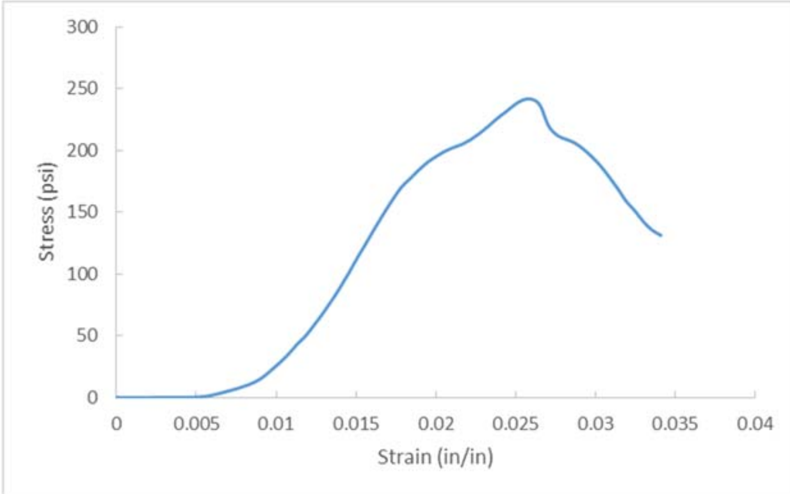

Figure A.237 D14-8, OC= 4.6%, CF= 300 pcf, T=56 days.

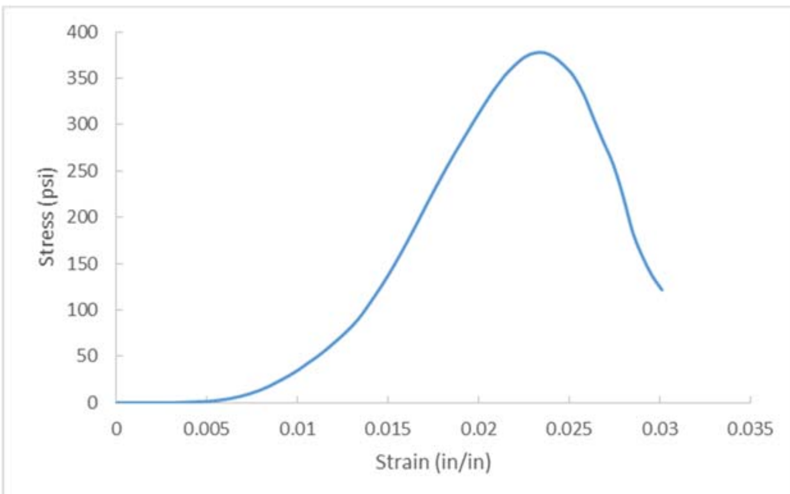

Figure A.238 D14-9, OC= 4.6%, CF= 300 pcf, T=56 days.

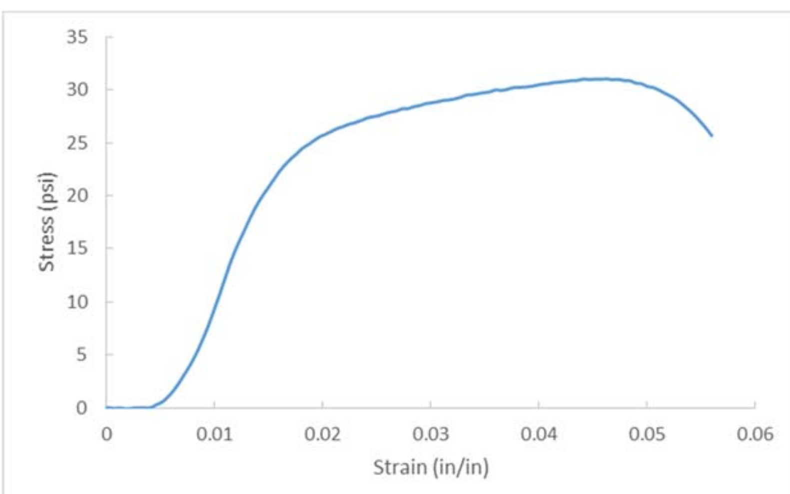

Figure A.239 D15-7, OC= 40.5%, CF= 300 pcf, T=56 days.

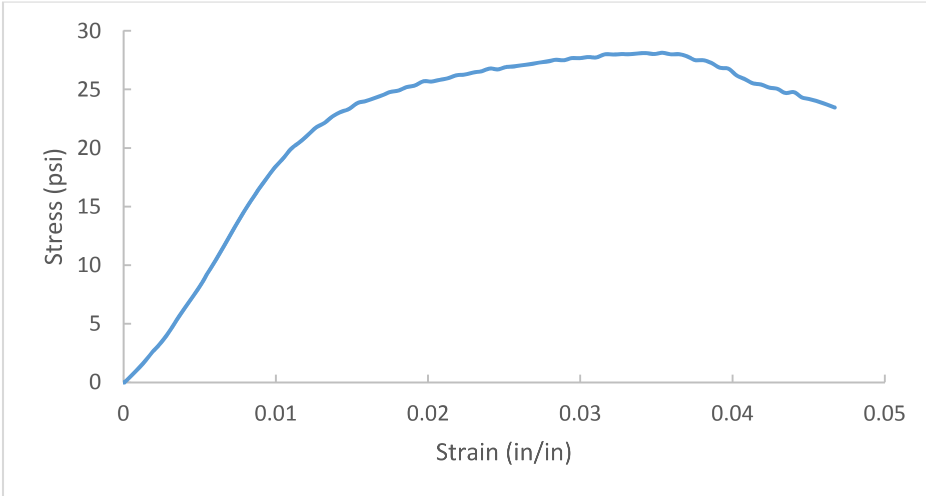


Figure A.240 D15-8, OC= 40.5%, CF= 300 pcf, T=56 days.

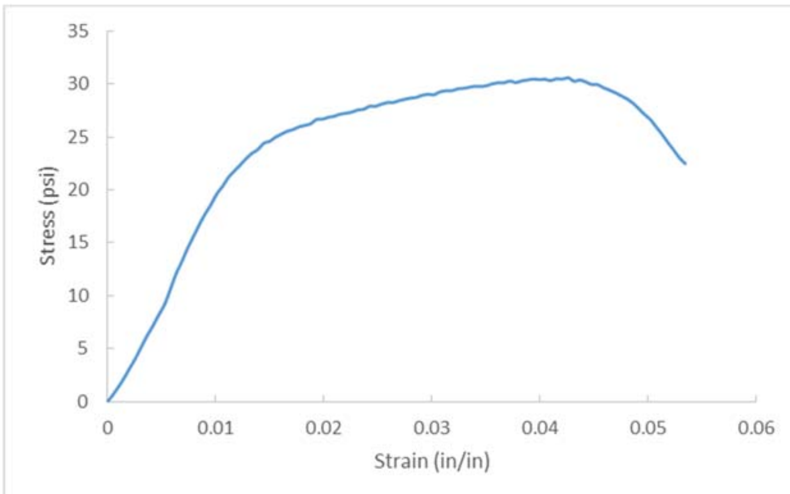


Figure A.241 D15-9, OC= 40.5%, CF= 300 pcf, T=56 days.

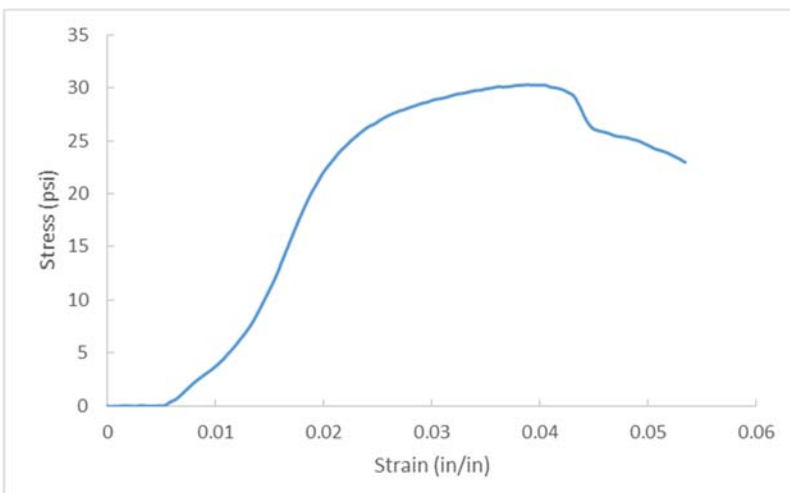


Figure A.242 D16-7, OC= 34.7%, CF= 300 pcf, T=56 days.

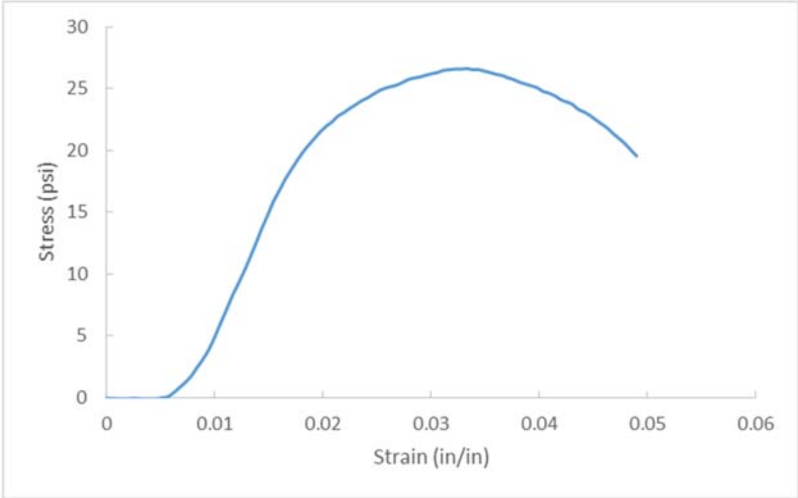

Figure A.243 D16-8, OC= 34.7%, CF= 300 pcf, T=56 days.

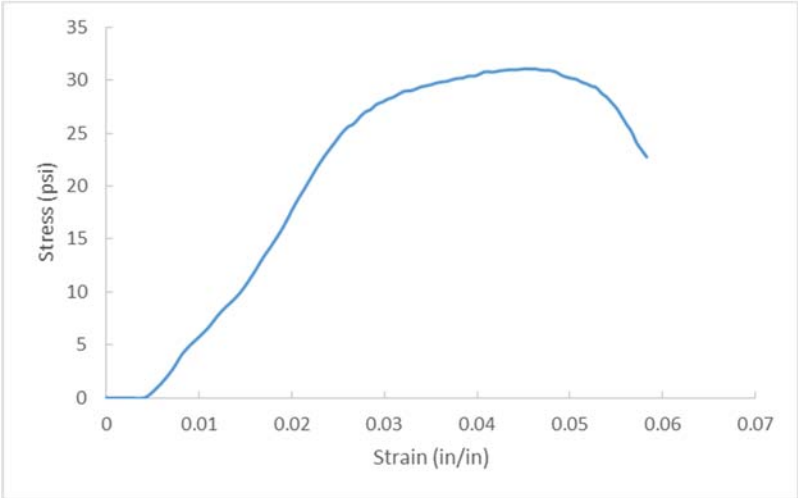

Figure A.244 D16-9, OC= 34.7%, CF= 300 pcf, T=56 days.

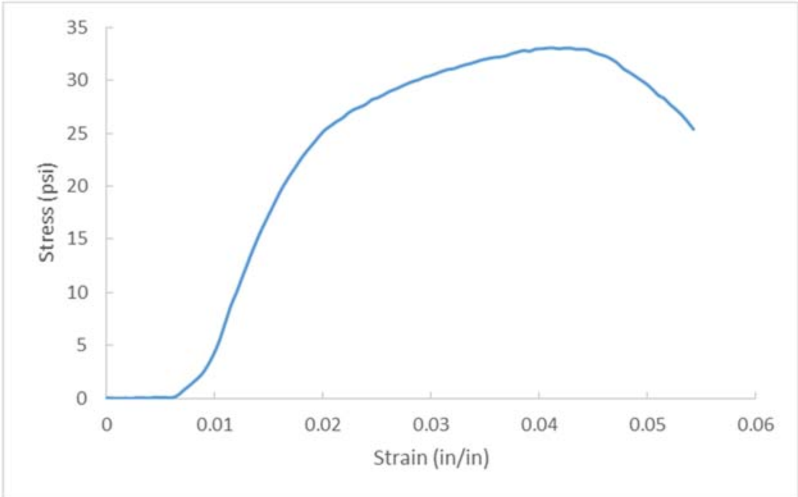

Figure A.245 D17-7, OC= 19.2%, CF= 300 pcf, T=56 days.

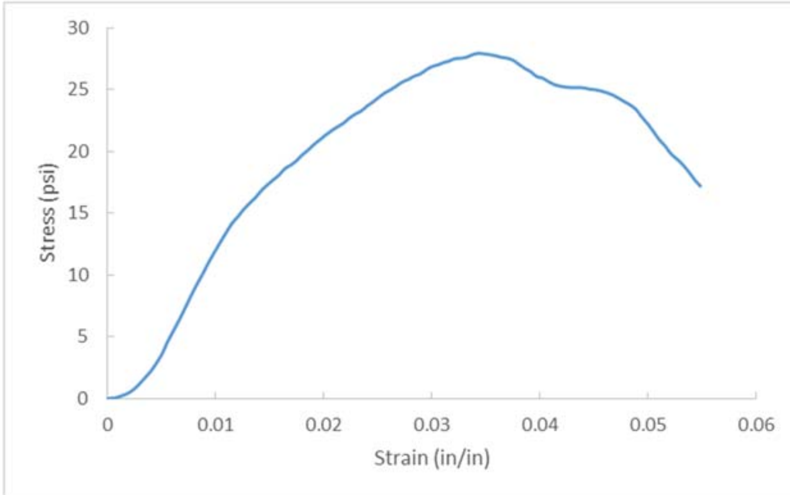

Figure A.246 D17-8, OC= 19.2%, CF= 300 pcf, T=56 days.

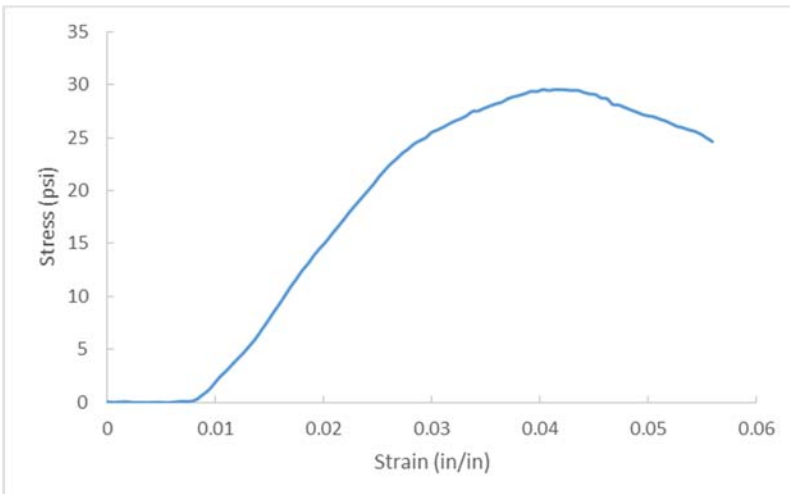

Figure A.247 D17-9, OC= 19.2%, CF= 300 pcf, T=56 days.

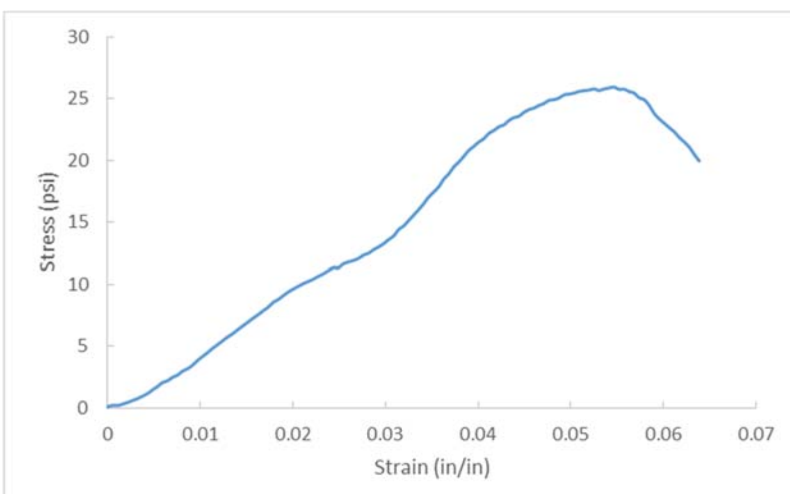

Figure A.248 D18-7, OC= 18.9%, CF= 300 pcf, T=56 days.

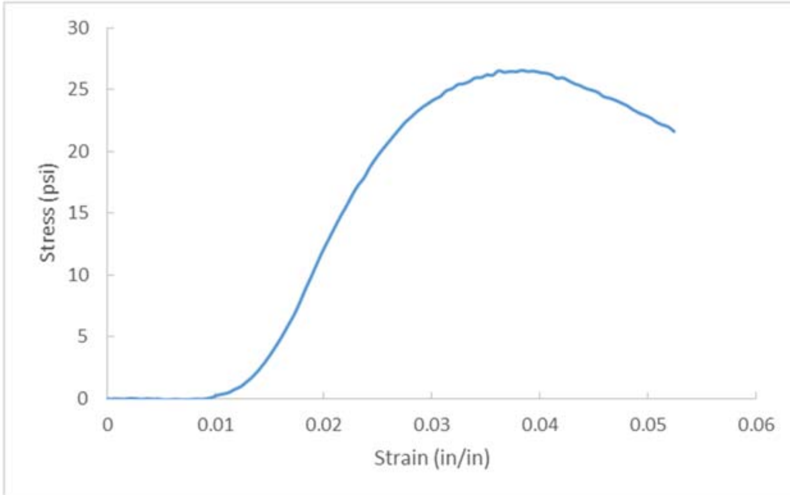

Figure A.249 D18-8, OC= 18.9%, CF= 300 pcf, T=56 days.

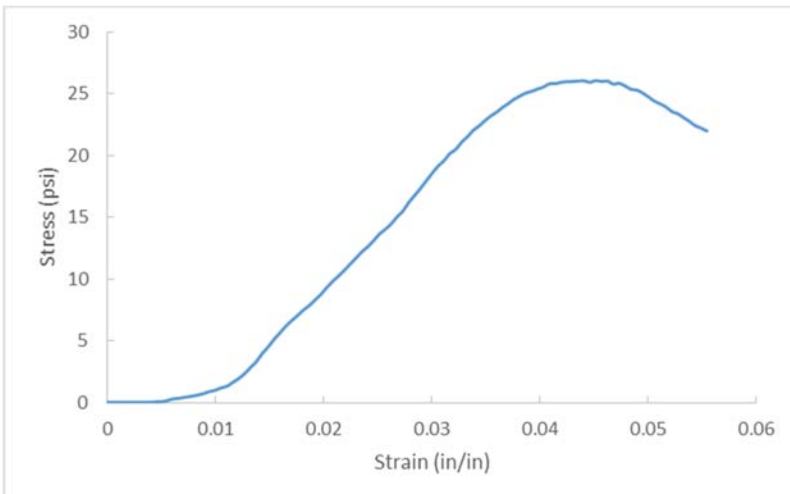

Figure A.250 D18-9, OC= 18.9%, CF= 300 pcf, T=56 days.

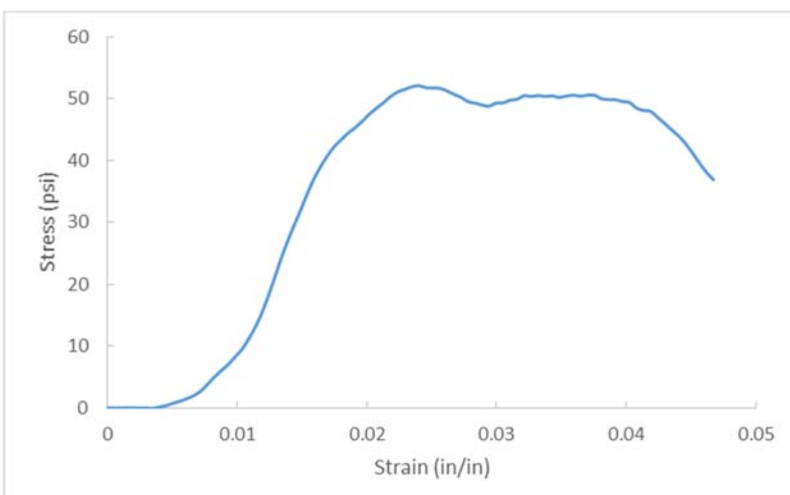

Figure A.251 D19-7, OC= 8.5%, CF= 300 pcf, T=56 days.

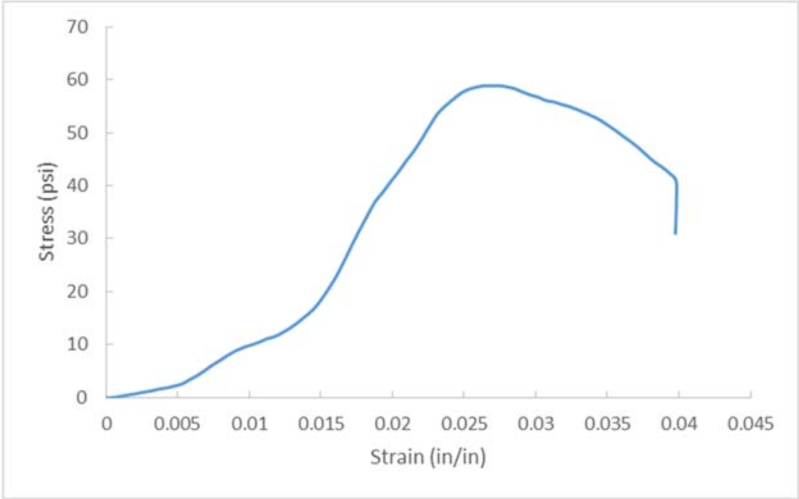

Figure A.252 D19-8, OC= 8.5%, CF= 300 pcf, T=56 days.

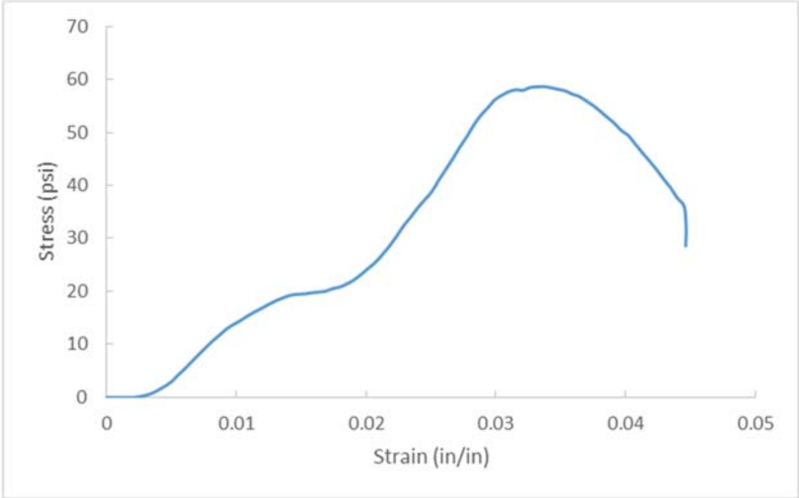

Figure A.253 D19-9, OC= 8.5%, CF= 300 pcf, T=56 days.

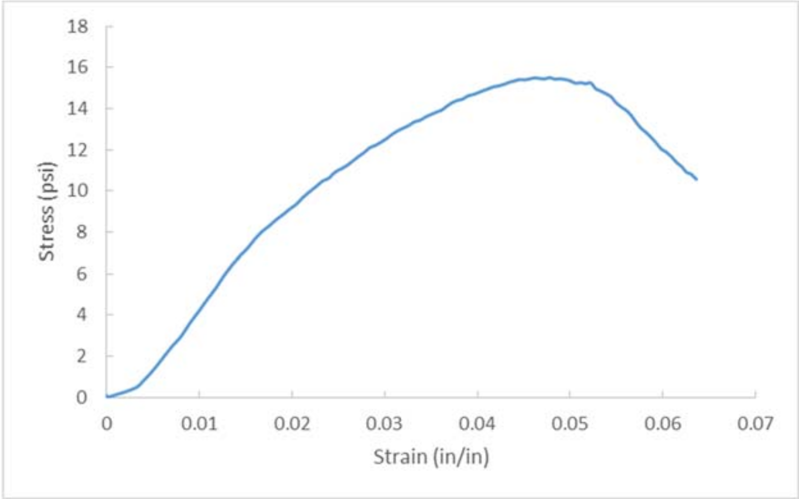

Figure A.254 D25-8, OC= 41.2%, CF= 400 pcf, T=56 days.

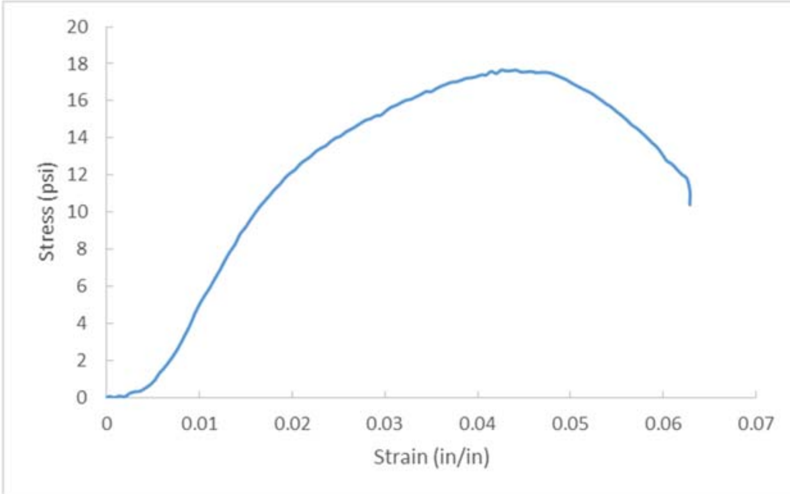


Figure A.255 D25-9, OC= 41.2%, CF= 400 pcf, T=56 days.

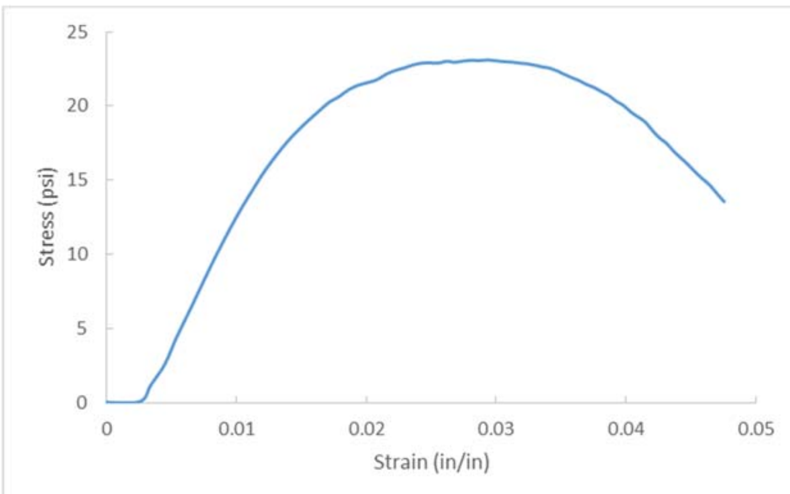


Figure A.256 D26-7, OC= 29.8%, CF= 400 pcf, T=56 days.

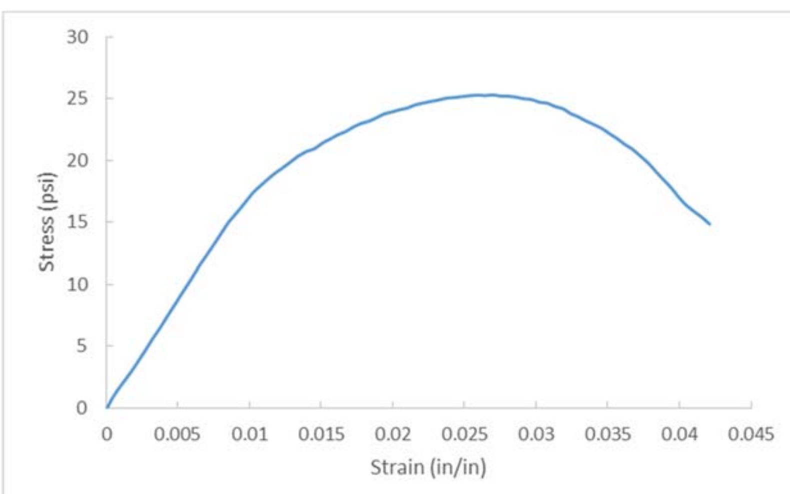


Figure A.257 D26-8, OC= 29.8%, CF= 400 pcf, T=56 days.

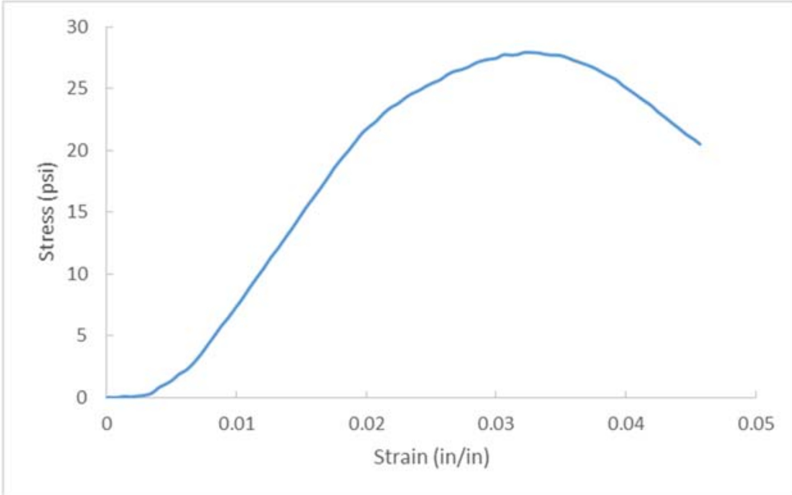

Figure A.258 D26-9, OC= 29.8%, CF= 400 pcf, T=56 days.

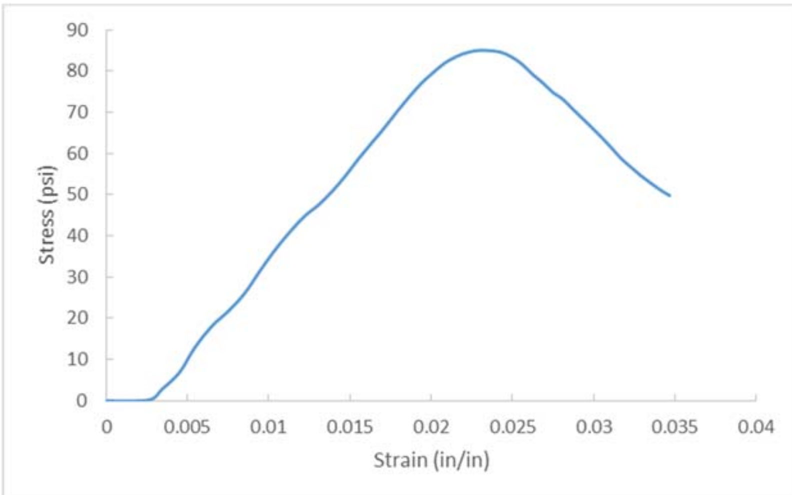

Figure A.259 D27-7, OC= 21.1%, CF= 400 pcf, T=56 days.

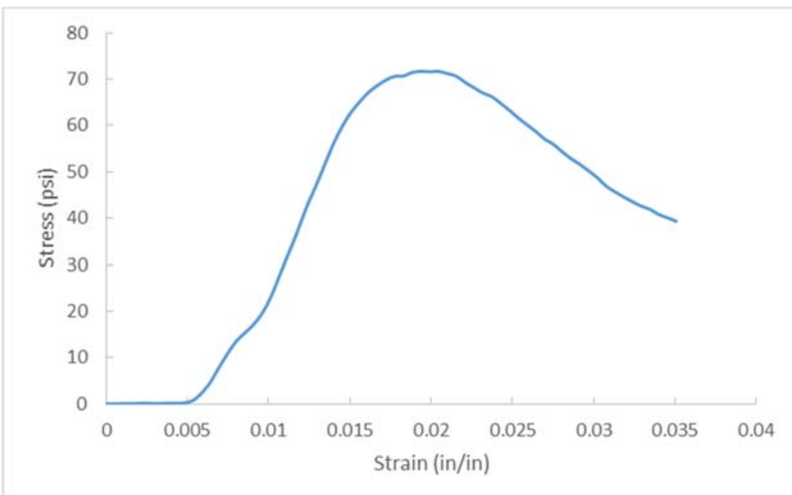

Figure A.260 D27-8, OC= 21.1%, CF= 400 pcf, T=56 days.

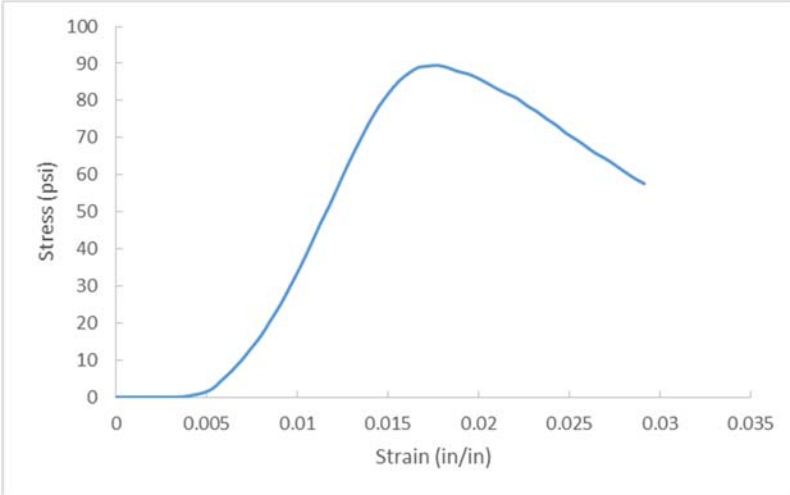

Figure A.261 D27-9, OC= 21.1%, CF= 400 pcf, T=56 days.

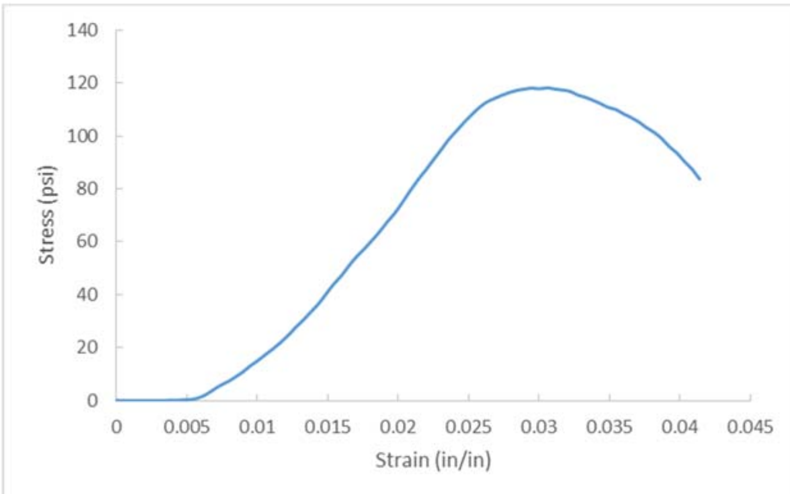

Figure A.262 D28-7, OC= 12.6%, CF= 400 pcf, T=56 days.

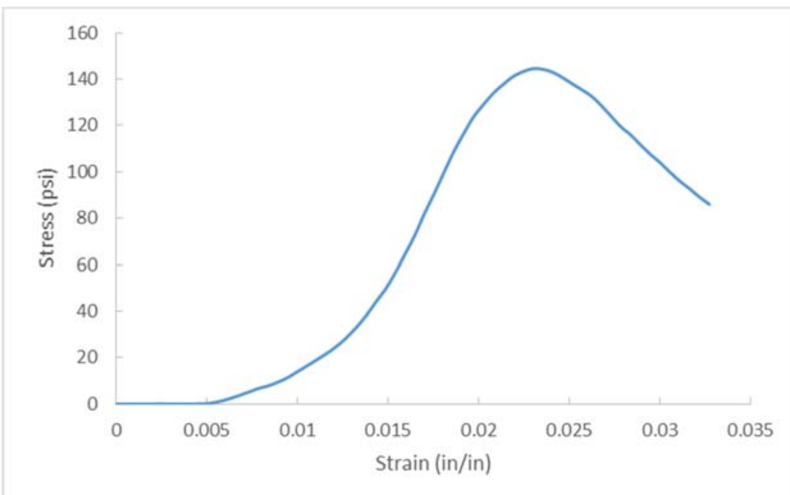

Figure A.263 D28-8, OC= 12.6%, CF= 400 pcf, T=56 days.

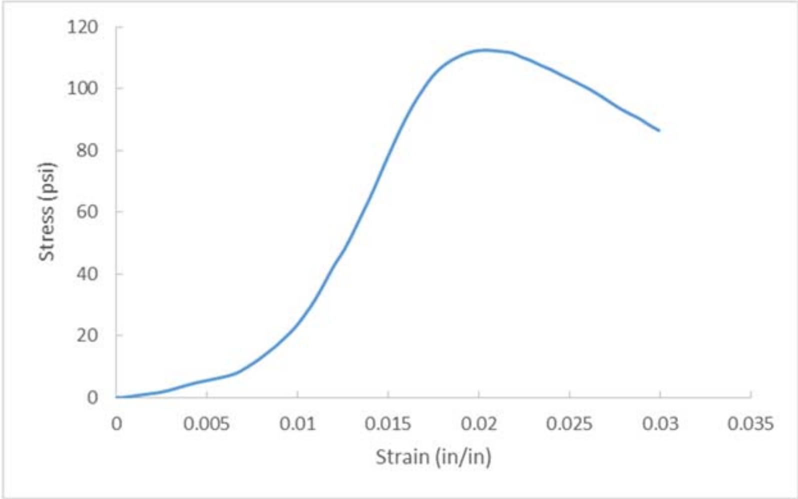

Figure A.264 D28-9, OC= 12.6%, CF= 400 pcf, T=56 days.

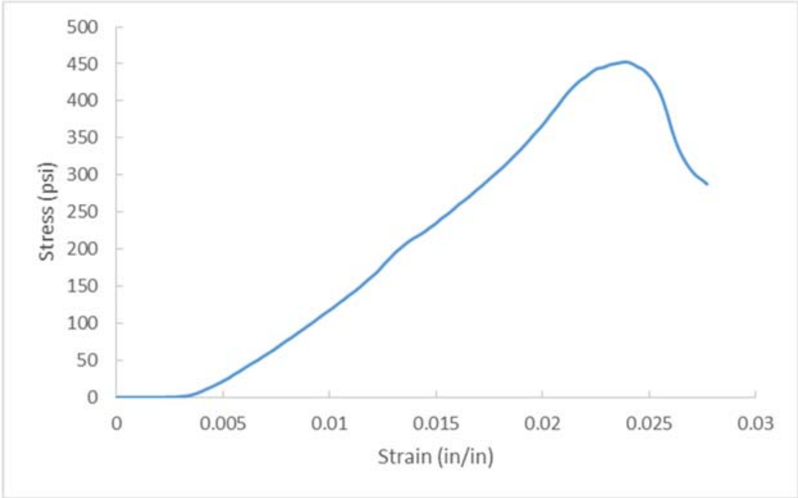

Figure A.265 D29-7, OC= 4.2%, CF= 400 pcf, T=56 days.

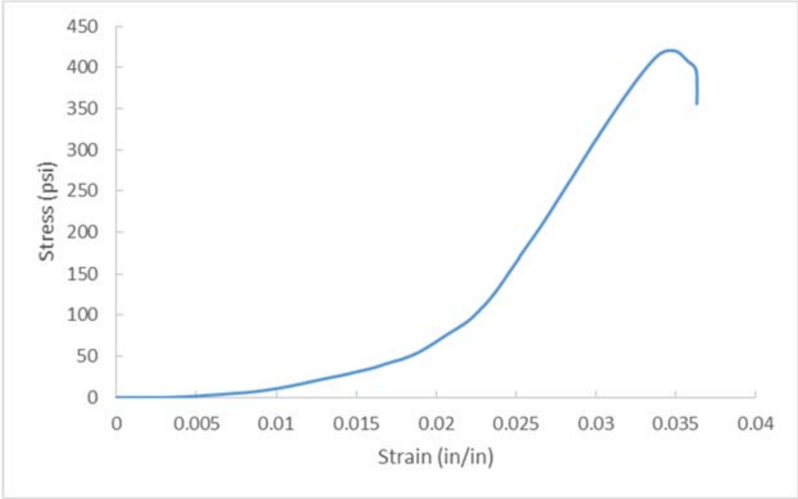

Figure A.266 D29-8, OC= 4.2%, CF= 400 pcf, T=56 days.

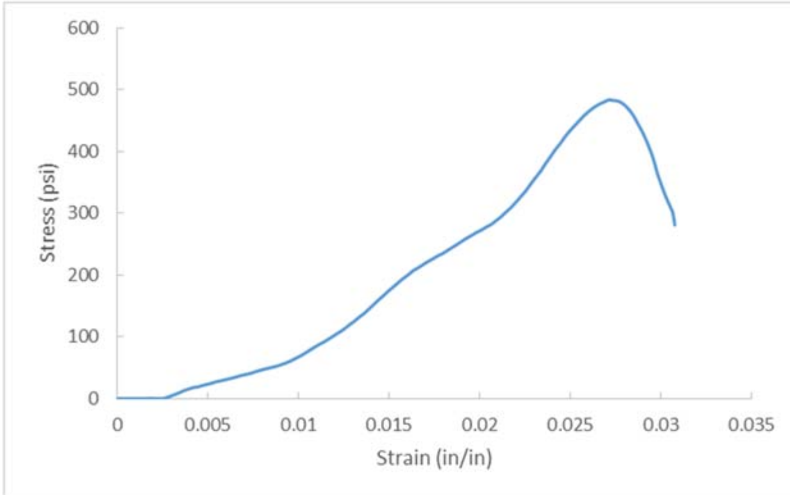


Figure A.267 D29-9, OC= 4.2%, CF= 400 pcf, T=56 days.

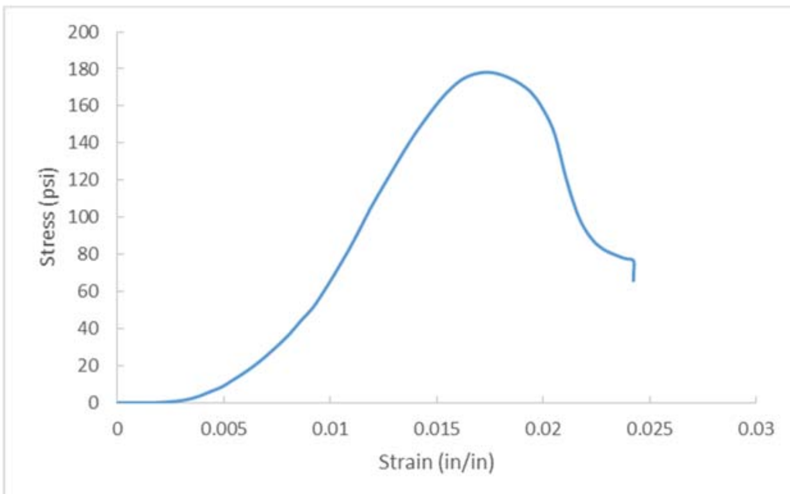


Figure A.268 D30-7, OC= 4.9%, CF= 400 pcf, T=56 days.

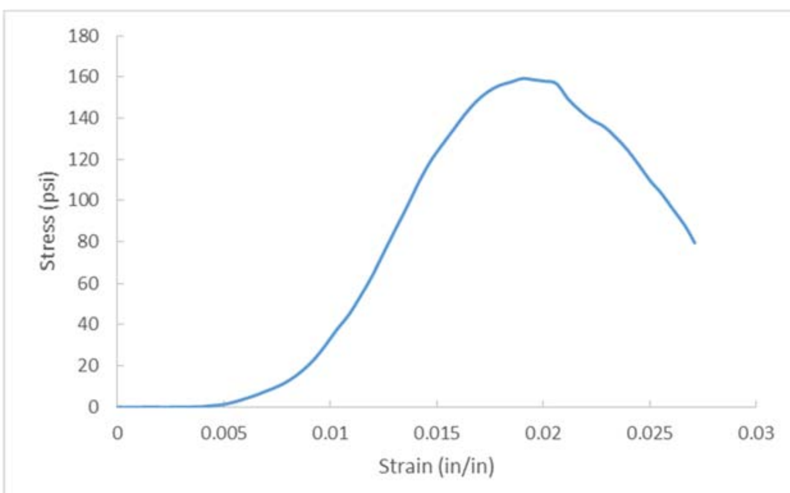


Figure A.269 D30-8, OC= 4.9%, CF= 400 pcf, T=56 days.

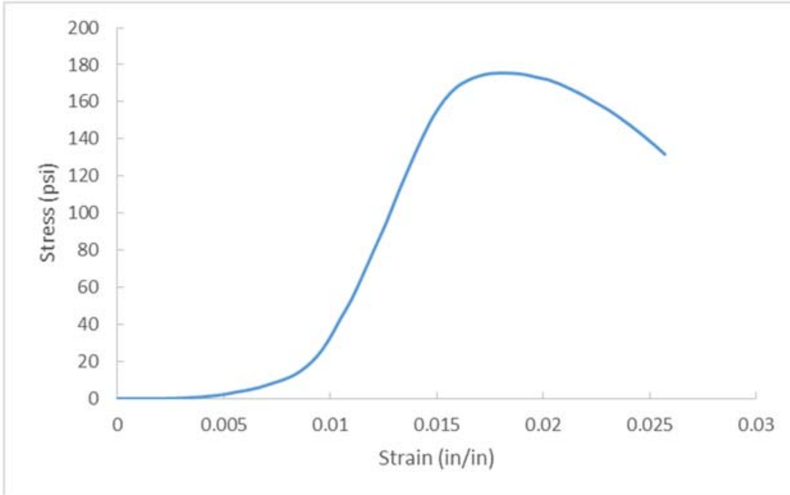


Figure A.270 D30-9, OC= 4.9%, CF= 400 pcf, T=56 days.

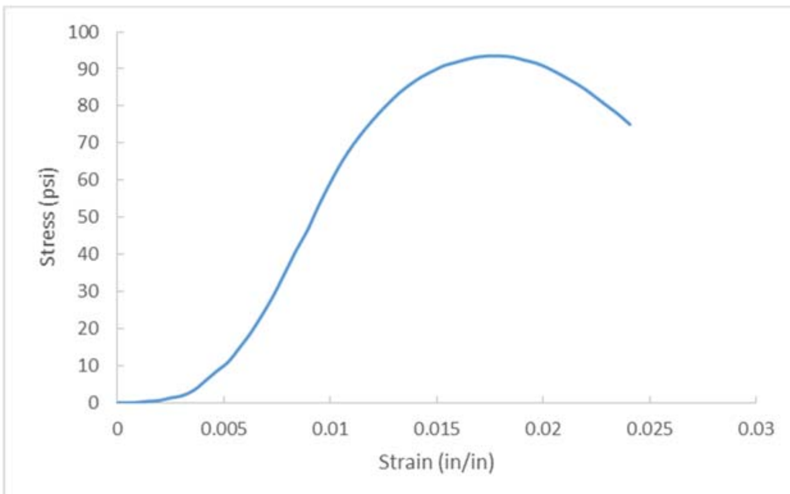


Figure A.271 D31-7, OC= 11.8%, CF= 400 pcf, T=56 days.

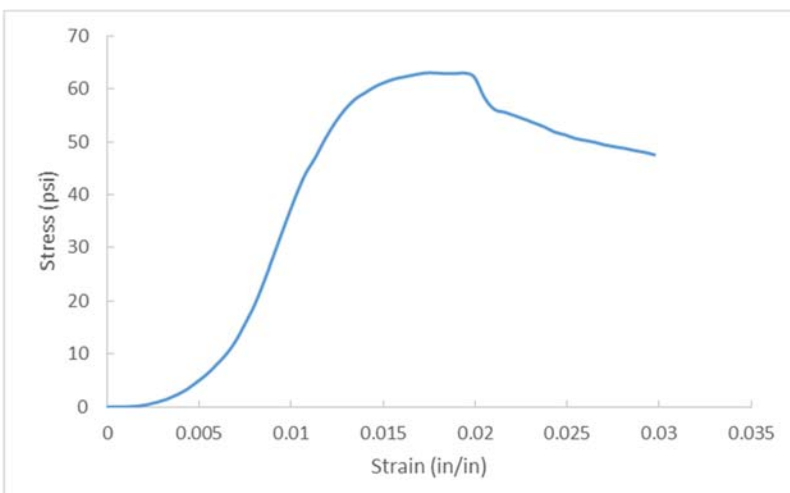


Figure A.272 D31-8, OC= 11.8%, CF= 400 pcf, T=56 days.

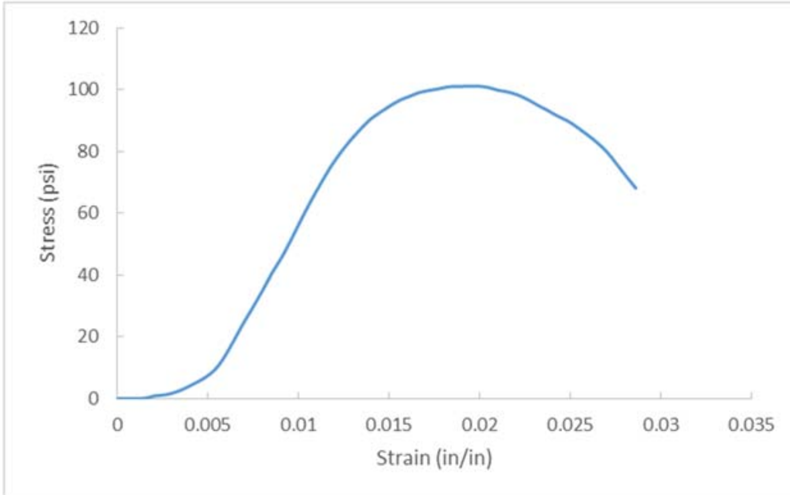


Figure A.273 D31-9, OC= 11.8%, CF= 400 pcf, T=56 days.

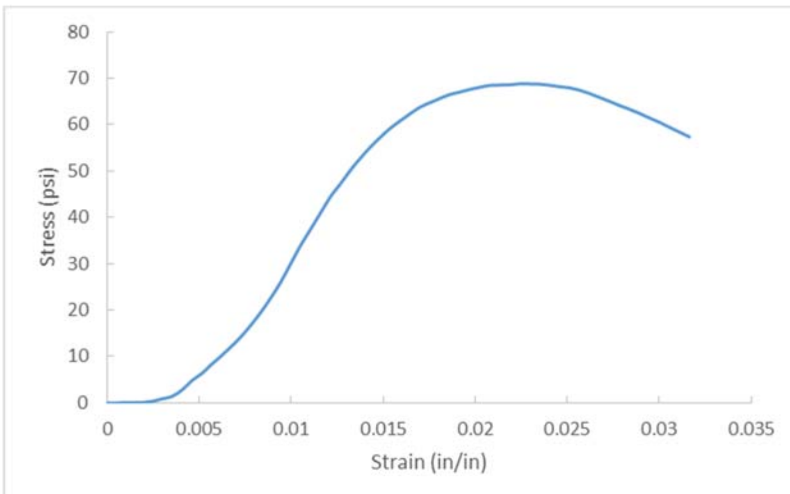


Figure A.274 D32-7, OC= 17.2%, CF= 400 pcf, T=56 days.

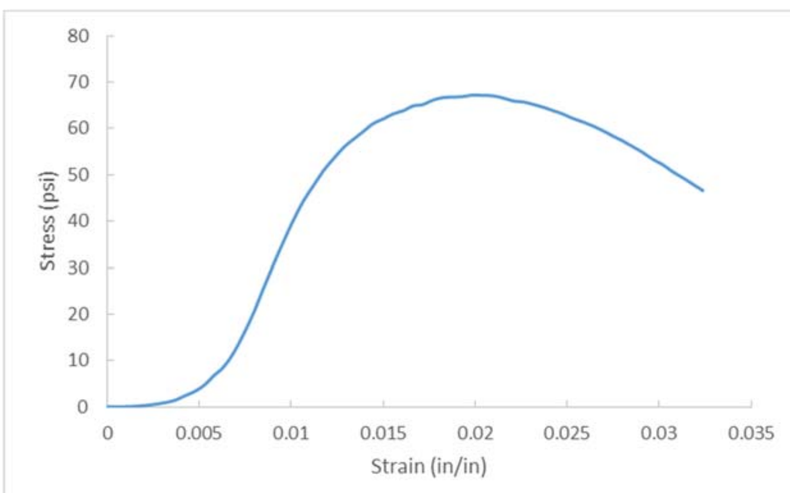


Figure A.275 D32-8, OC= 17.2%, CF= 400 pcf, T=56 days.

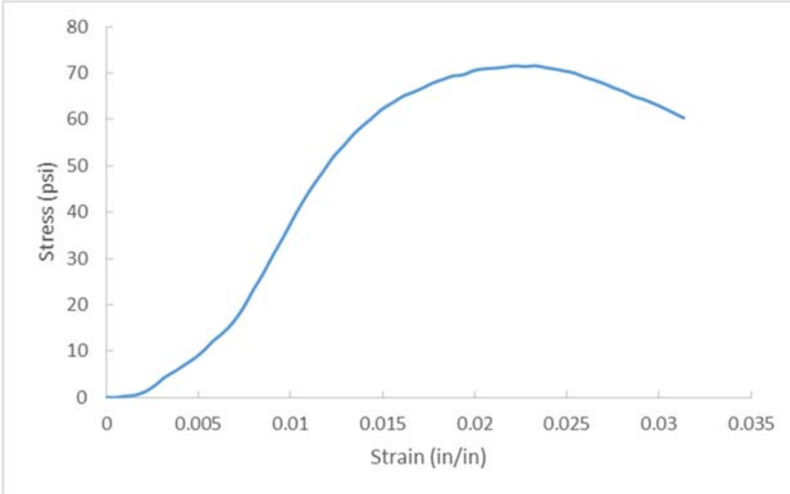

Figure A.276 D32-9, OC= 17.2%, CF= 400 pcf, T=56 days.

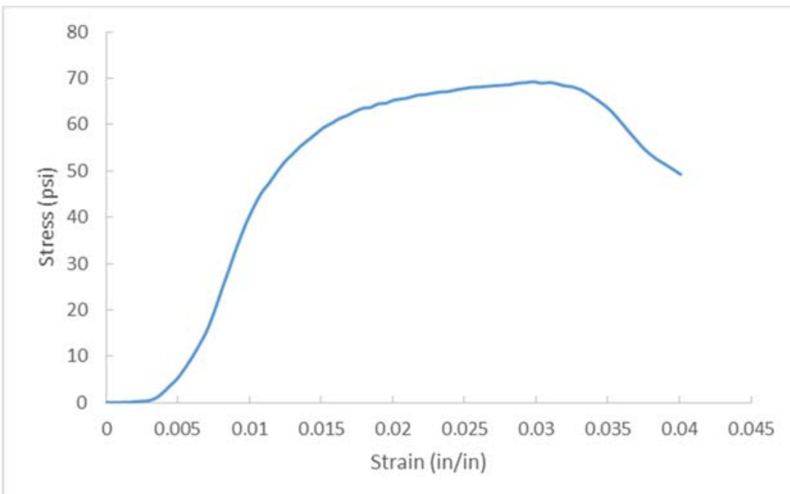

Figure A.277 D33-7, OC= 25.1%, CF= 400 pcf, T=56 days.

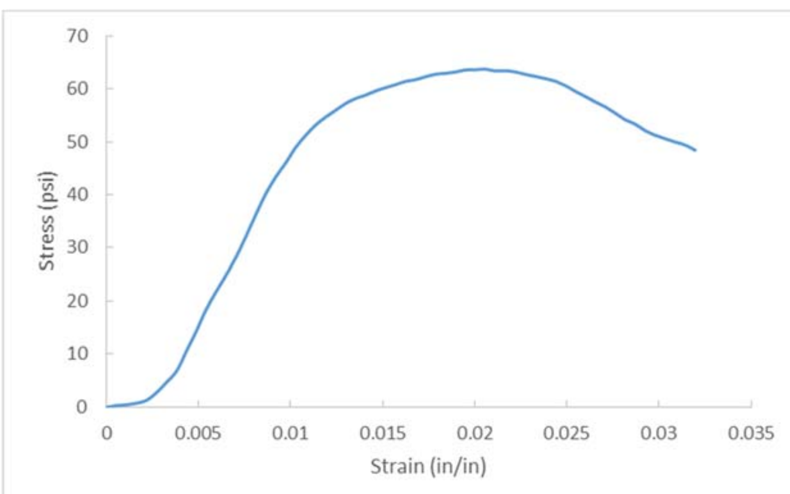

Figure A.278 D33-8, OC= 25.1%, CF= 400 pcf, T=56 days.

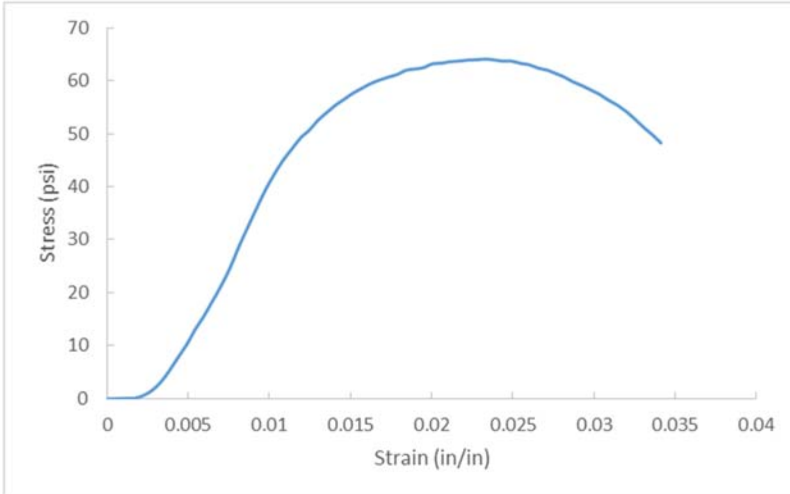

Figure A.279 D33-9, OC= 25.1%, CF= 400 pcf, T=56 days.

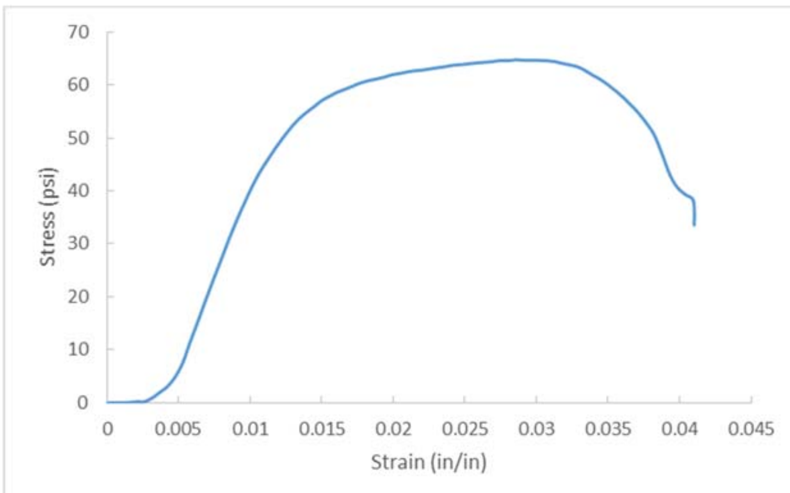

Figure A.280 D34-7, OC= 40.9%, CF= 400 pcf, T=56 days.

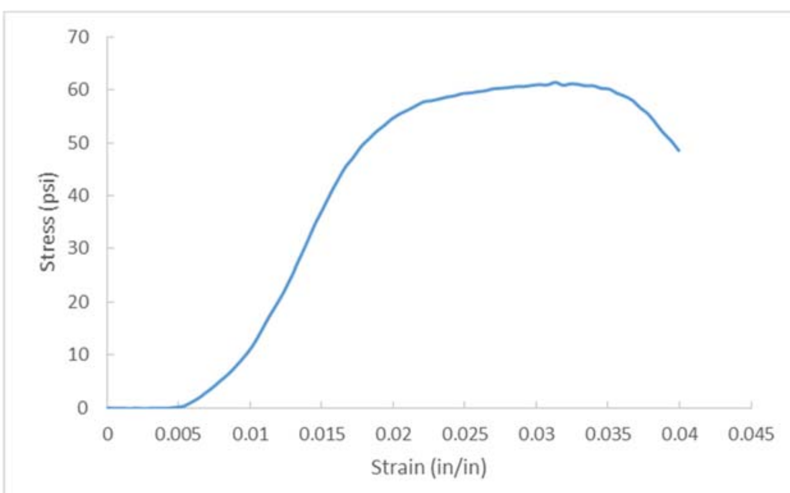

Figure A.281 D34-8, OC= 40.9%, CF= 400 pcf, T=56 days.

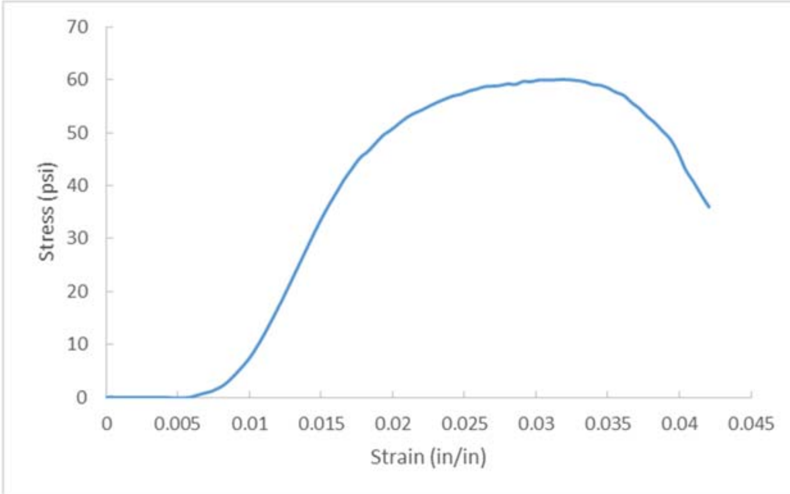

Figure A.282 D34-9, OC= 40.9%, CF= 400 pcf, T=56 days.

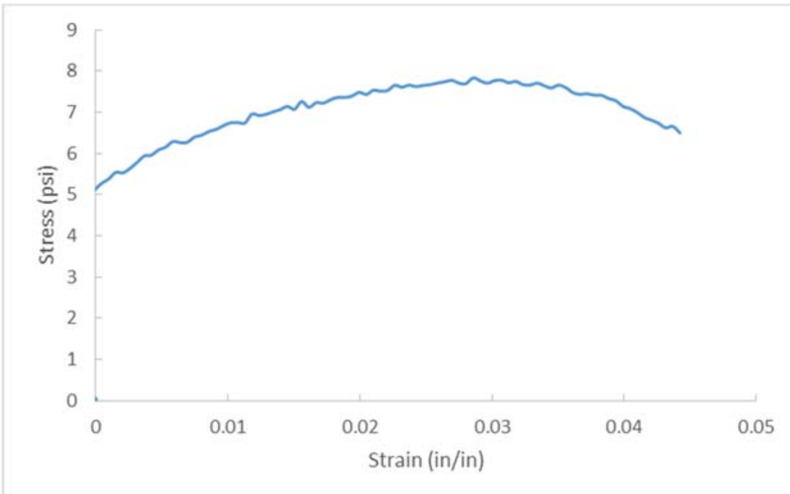

Figure A.283 D35-8, OC= 39.6%, CF= 200 pcf, T=56 days.

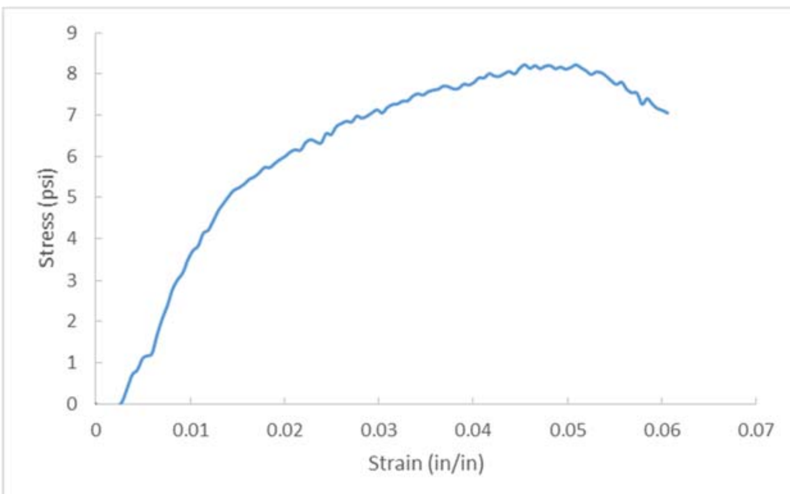

Figure A.284 D35-9, OC= 39.6%, CF= 200 pcf, T=56 days.

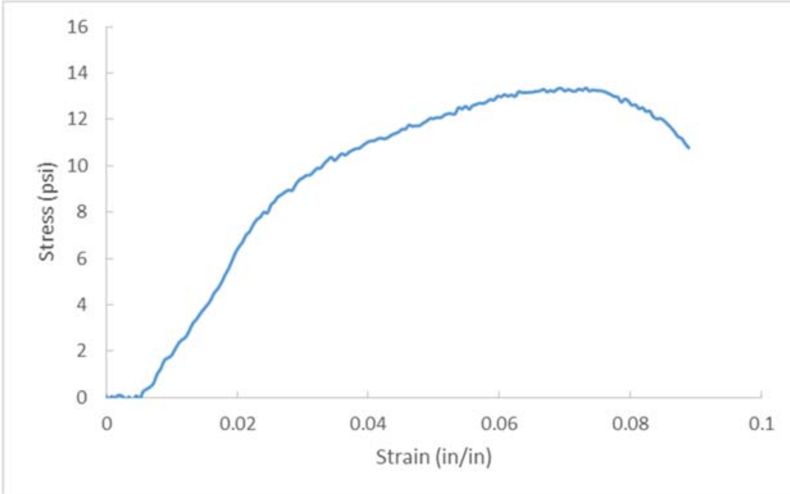

Figure A.285 D36-7, OC= 25.6%, CF= 200 pcf, T=56 days.

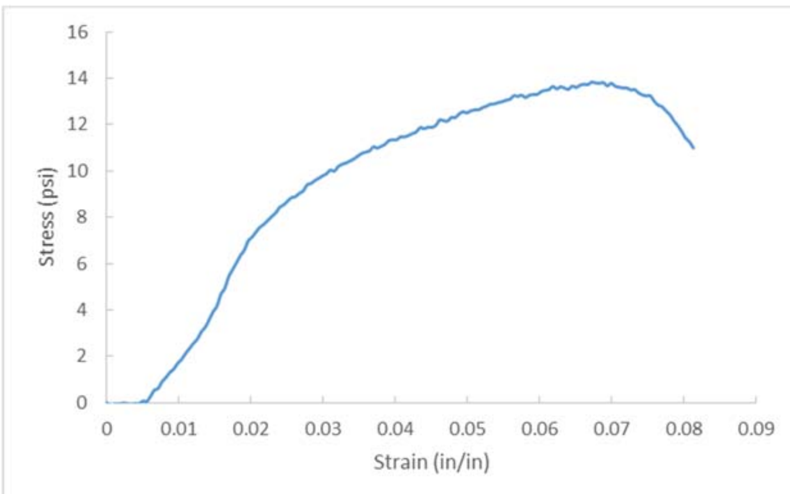

Figure A.286 D36-8, OC= 25.6%, CF= 200 pcf, T=56 days.

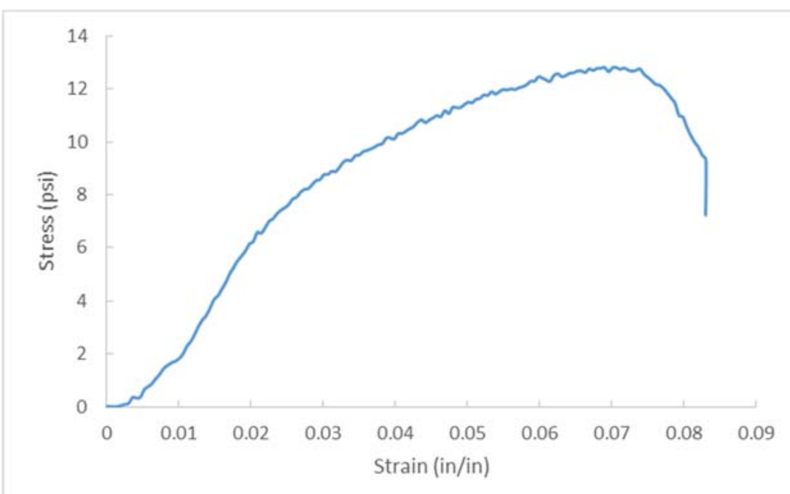

Figure A.287 D36-9, OC= 25.6%, CF= 200 pcf, T=56 days.

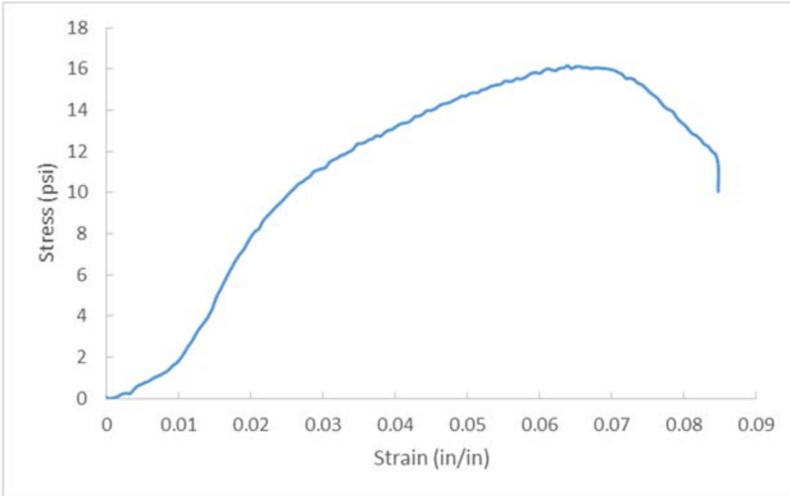

Figure A.288 D37-7, OC= 18.9%, CF= 200 pcf, T=56 days.

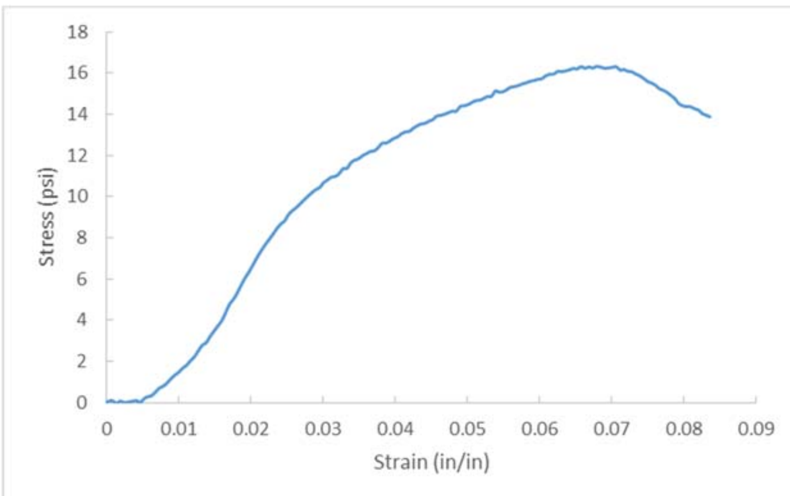

Figure A.289 D37-8, OC= 18.9%, CF= 200 pcf, T=56 days.

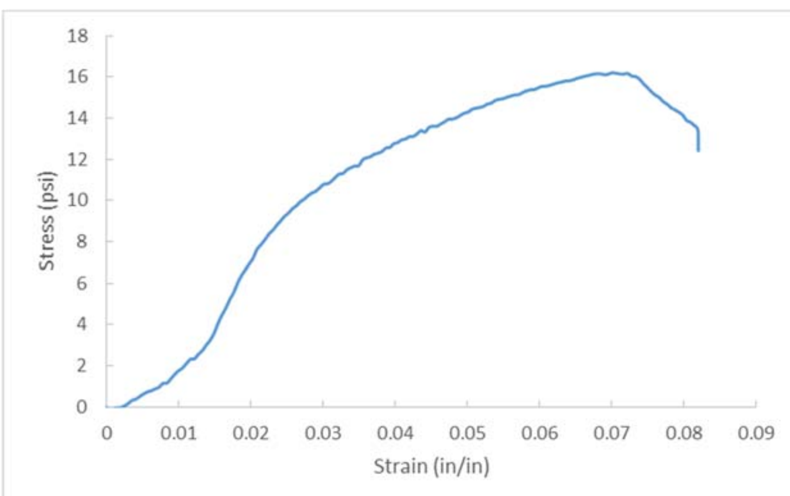

Figure A.290 D37-9, OC= 18.9%, CF= 200 pcf, T=56 days.

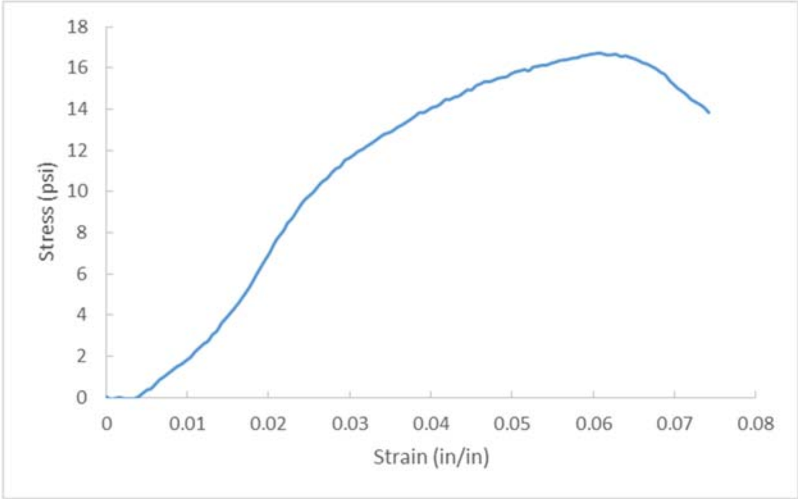

Figure A.291 D38-7, OC= 13.9%, CF= 200 pcf, T=56 days.

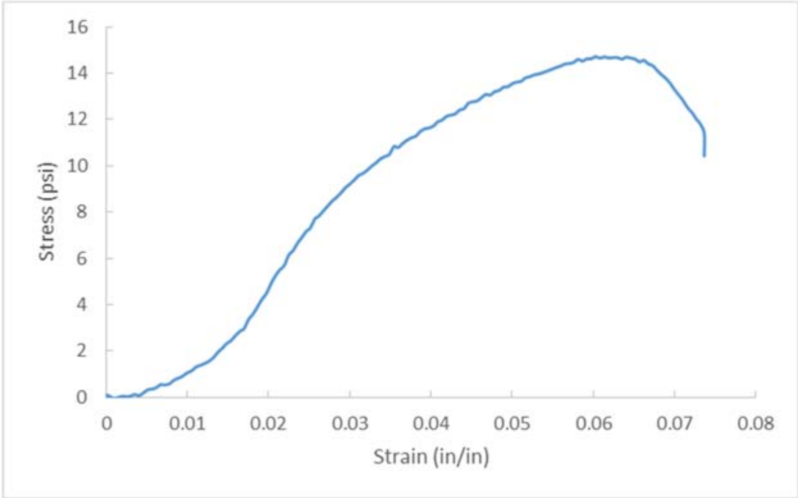

Figure A.292 D38-8, OC= 13.9%, CF= 200 pcf, T=56 days.

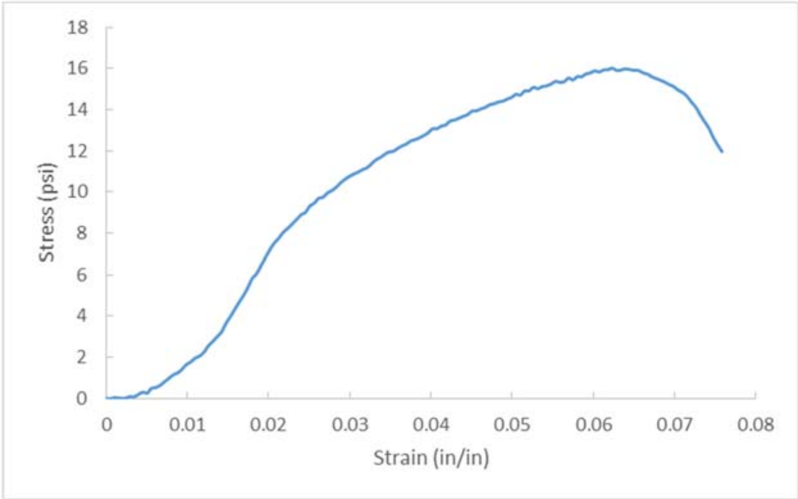

Figure A.293 D38-9, OC= 13.9%, CF= 200 pcf, T=56 days.

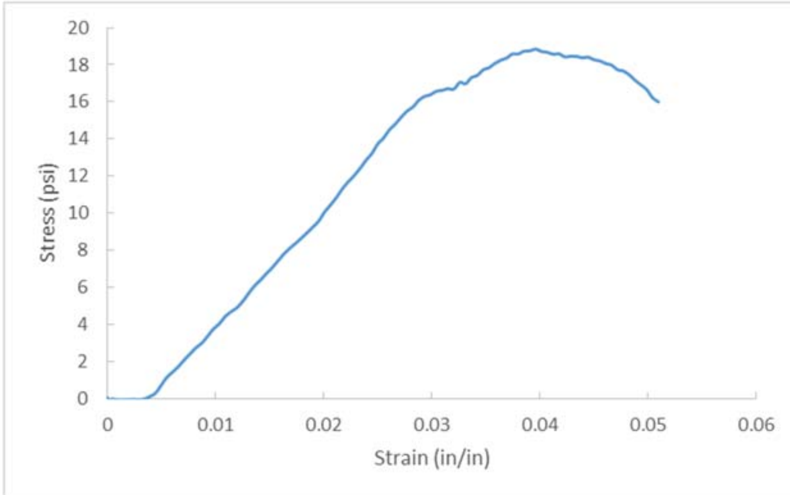

Figure A.294 D39-7, OC= 3.9%, CF= 200 pcf, T=56 days.

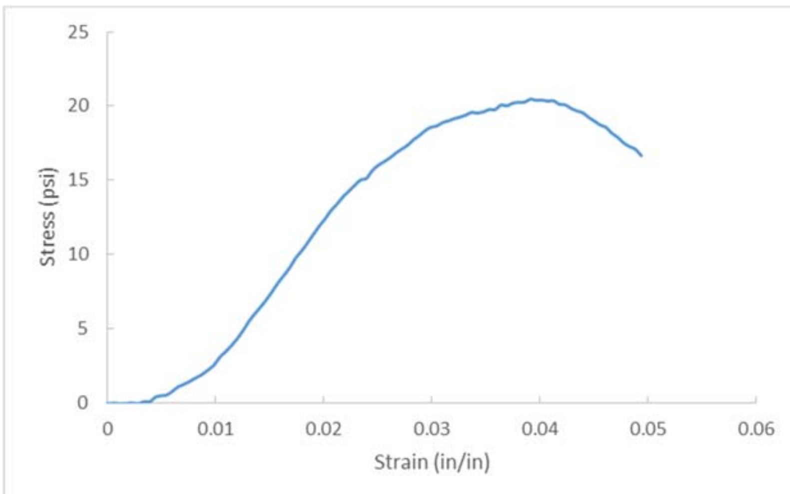

Figure A.295 D39-8, OC= 3.9%, CF= 200 pcf, T=56 days.

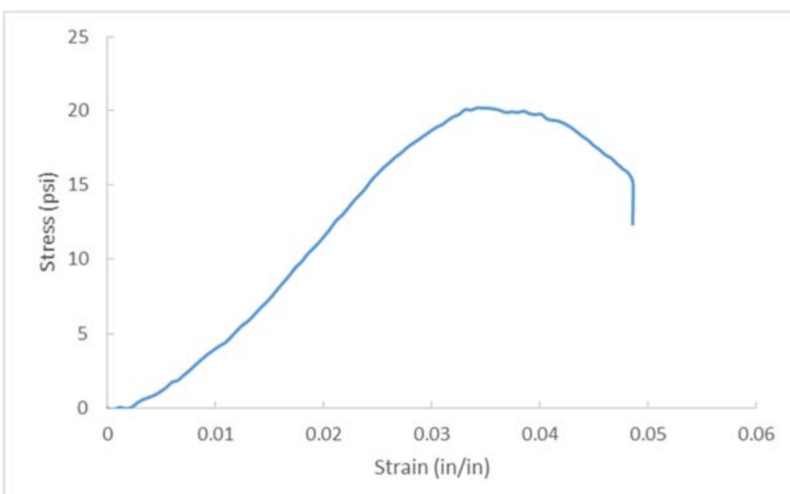

Figure A.296 D39-9, OC= 3.9%, CF= 200 pcf, T=56 days.

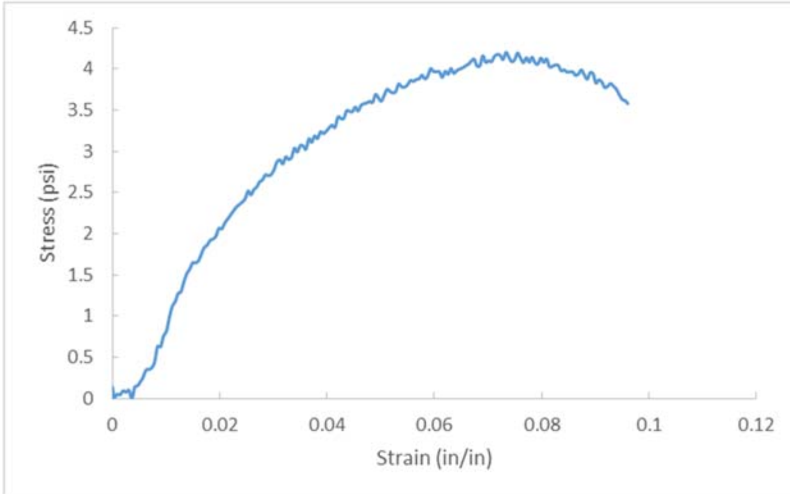

Figure A.297 D43-3, OC= 11.3%, CF= 200 pcf, T=56 days.

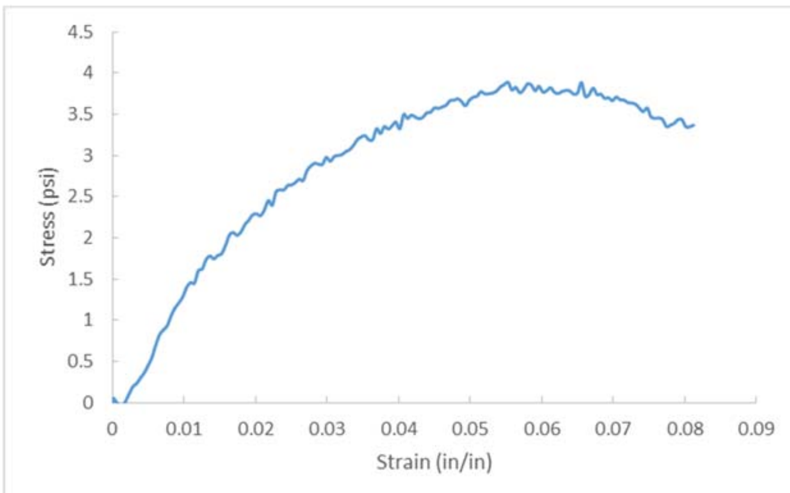

Figure A.298 D43-4, OC= 11.3%, CF= 200 pcf, T=56 days.

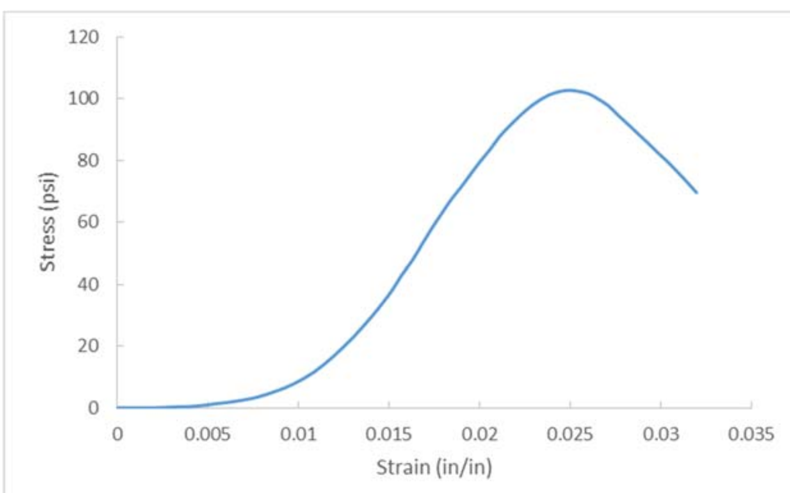

Figure A.299 D44-4, OC= 4.1%, CF= 200 pcf, T=56 days.

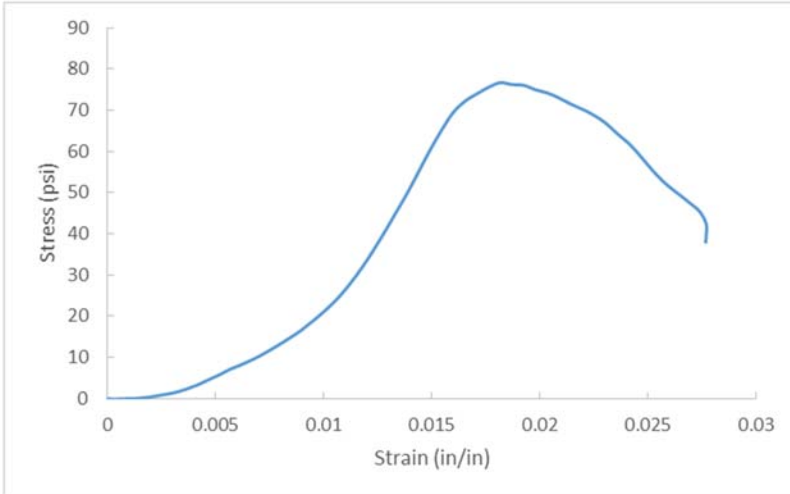

Figure A.300 D44-5, OC= 4.1%, CF= 200 pcf, T=56 days.

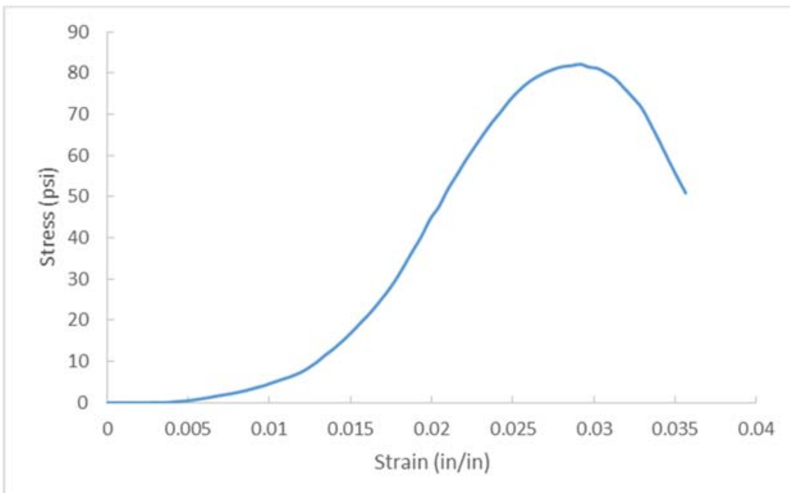

Figure A.301 D44-6, OC= 4.1%, CF= 200 pcf, T=56 days.

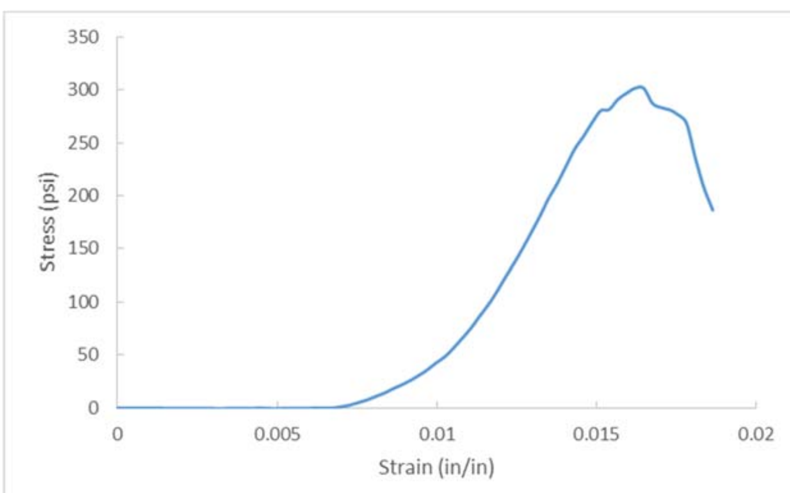

Figure A.302 D45-7, OC= 0.0%, CF= 400 pcf, T=56 days.

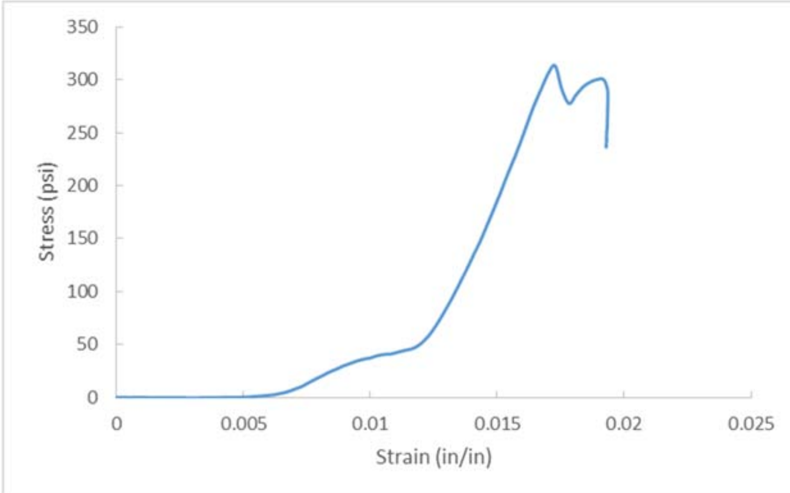

Figure A.303 D45-8, OC= 0.0%, CF= 400 pcf, T=56 days.

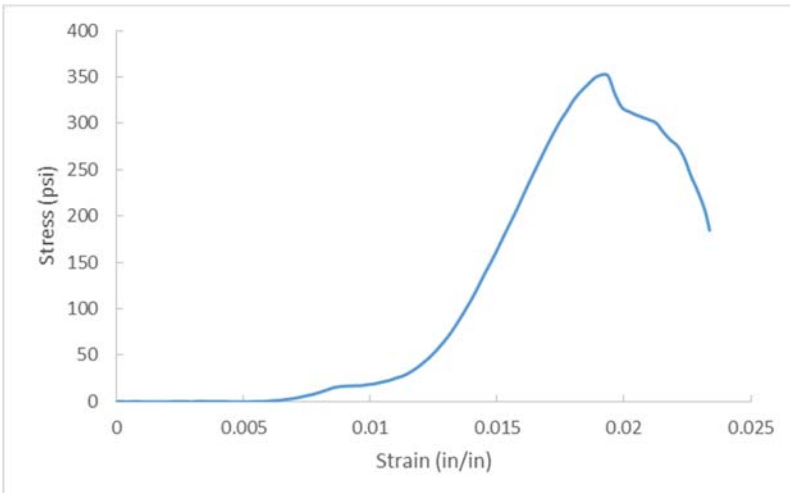

Figure A.304 D45-9, OC= 0.0%, CF= 400 pcf, T=56 days.

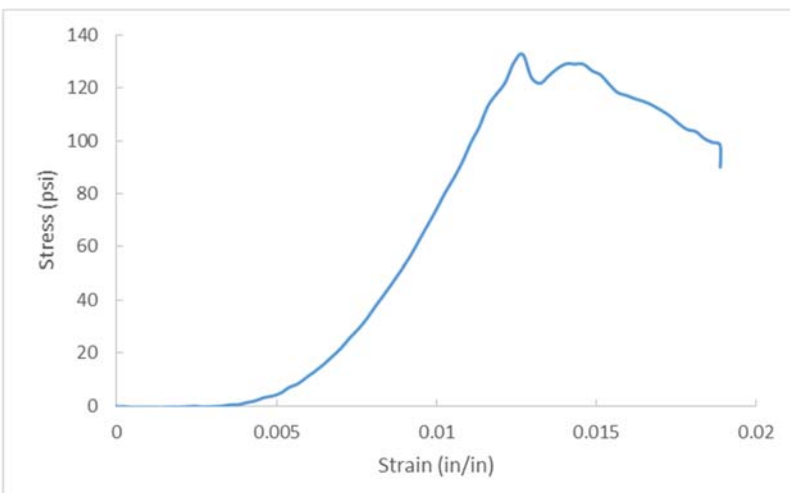

Figure A.305 D46-7, OC= 0.0%, CF= 300 pcf, T=56 days.

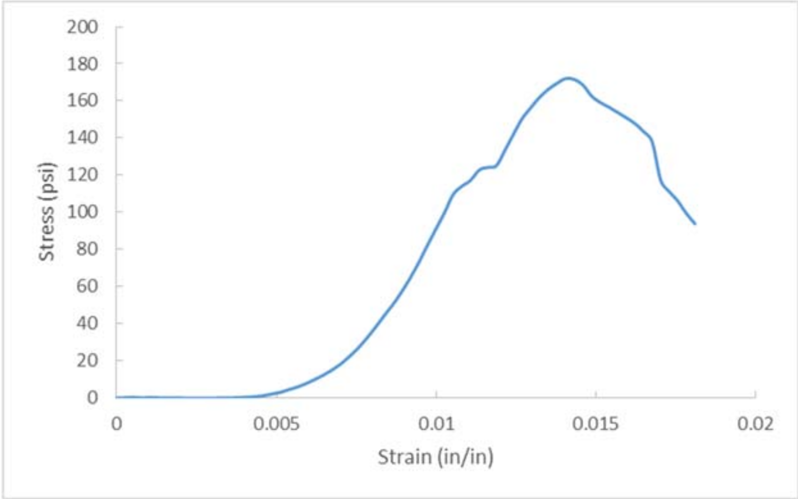

Figure A.306 D46-8, OC= 0.0%, CF= 300 pcf, T=56 days.

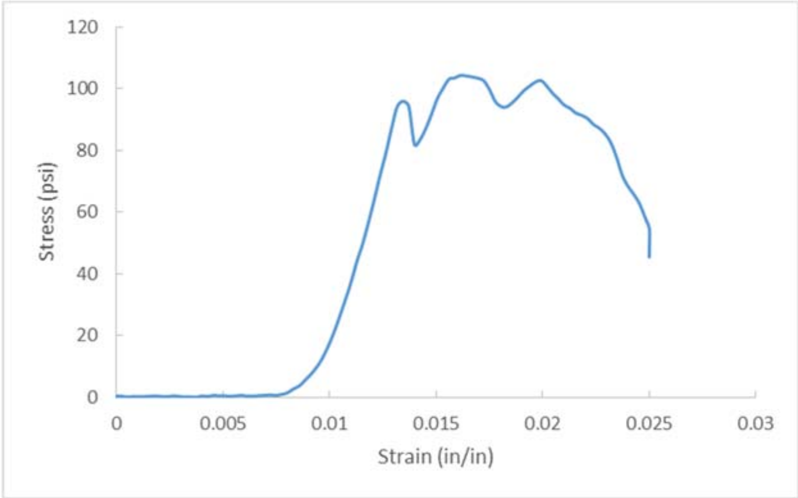

Figure A.307 D46-9, OC= 0.0%, CF= 300 pcf, T=56 days.

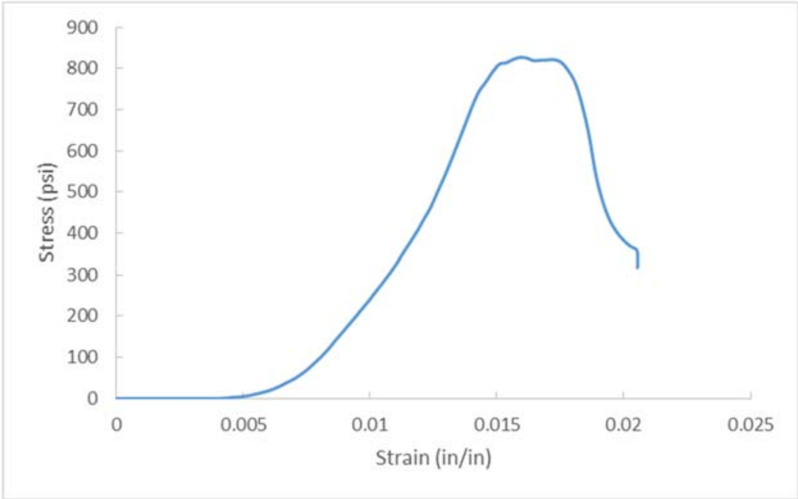

Figure A.308 D47-7, OC= 0.0%, CF= 400 pcf, T=56 days.

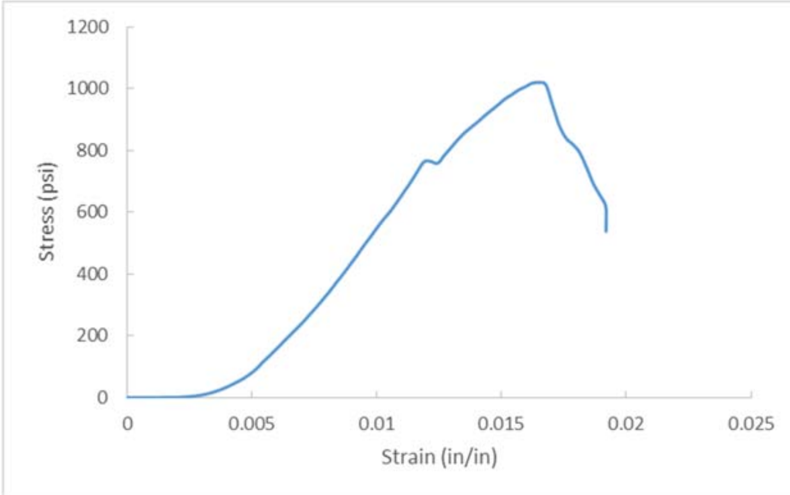

Figure A.309 D47-8, OC= 0.0%, CF= 400 pcf, T=56 days.

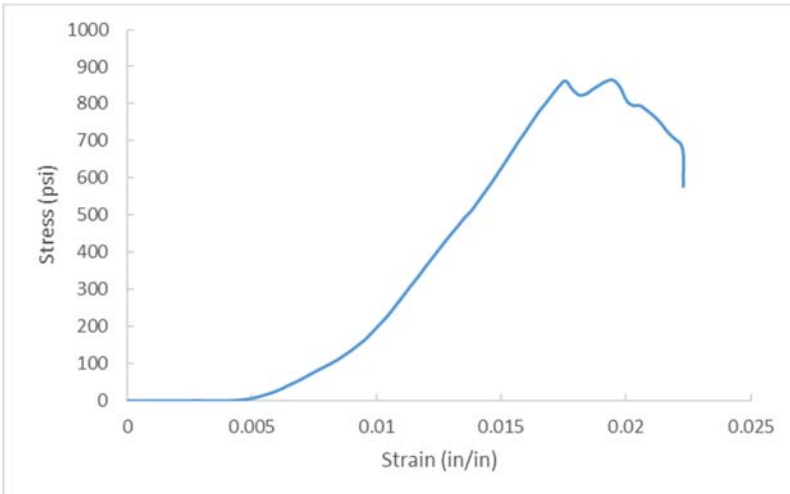

Figure A.310 D47-9, OC= 0.0%, CF= 400 pcf, T=56 days.

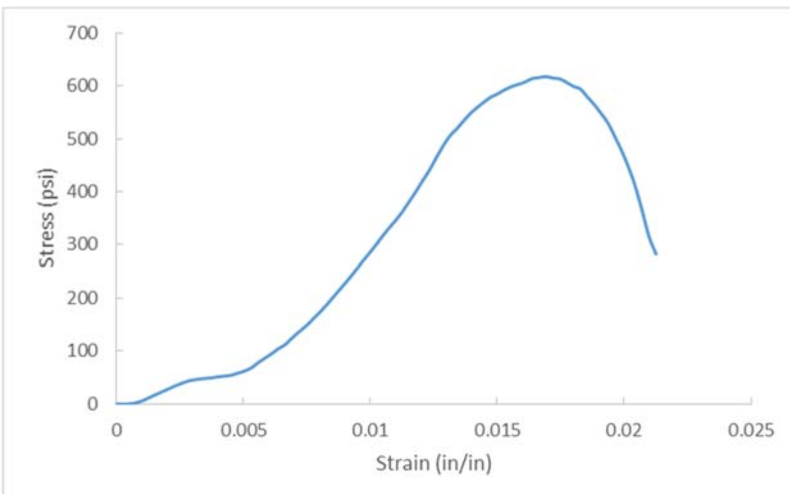

Figure A.311 D48-7, OC= 0.0%, CF= 300 pcf, T=56 days.

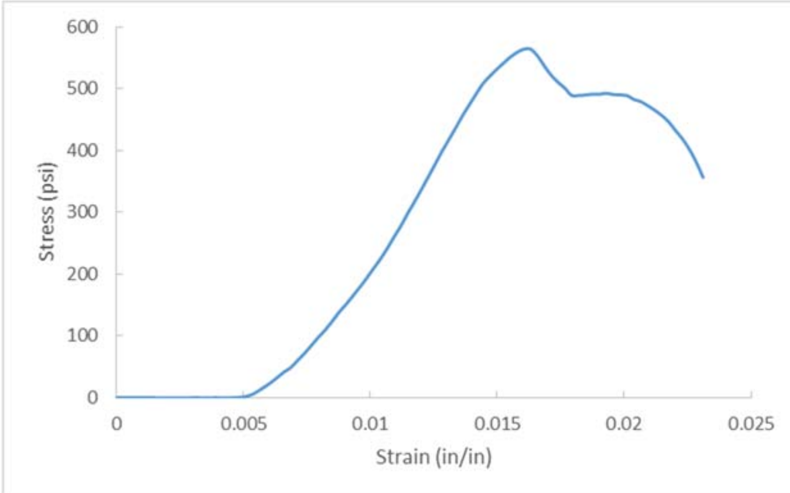

Figure A.312 D48-8, OC= 0.0%, CF= 300 pcf, T=56 days.

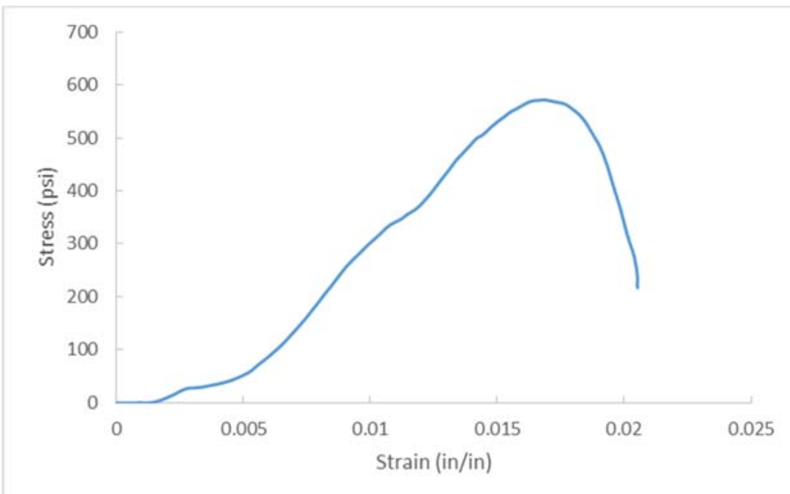

Figure A.313 D48-9, OC= 0.0%, CF= 300 pcf, T=56 days.

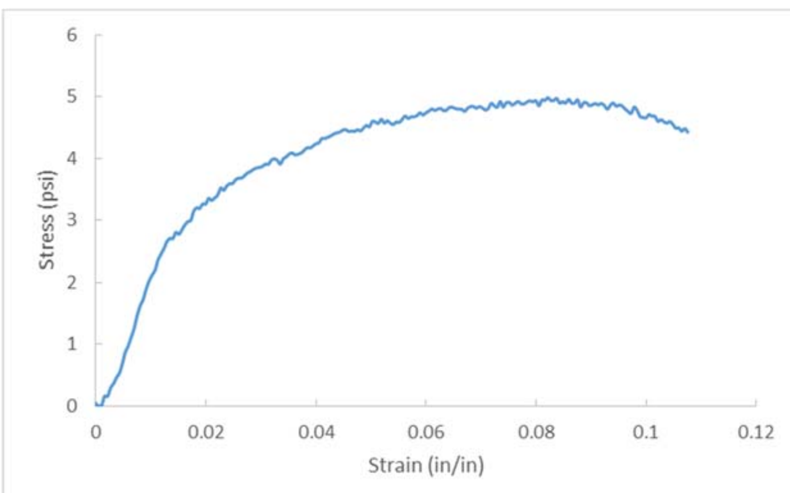

Figure A.314 W49-7, OC= 43.8%, CF= 300 pcf, T=56 days.

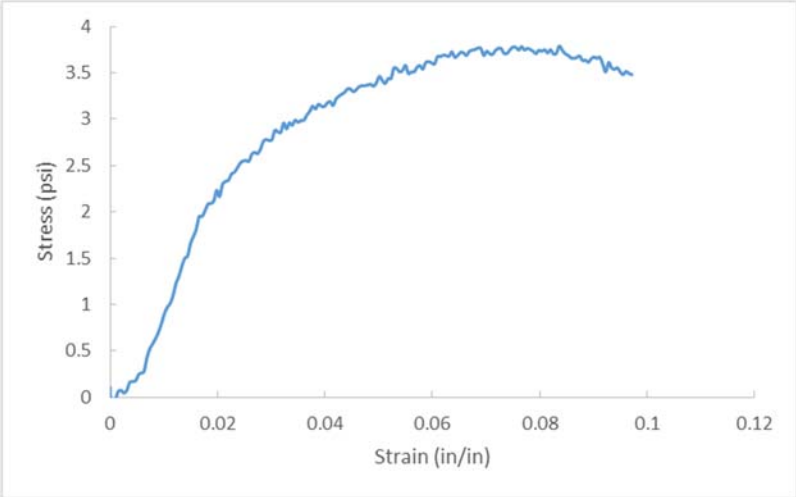

Figure A.315 W49-9, OC= 43.8%, CF= 300 pcf, T=56 days.

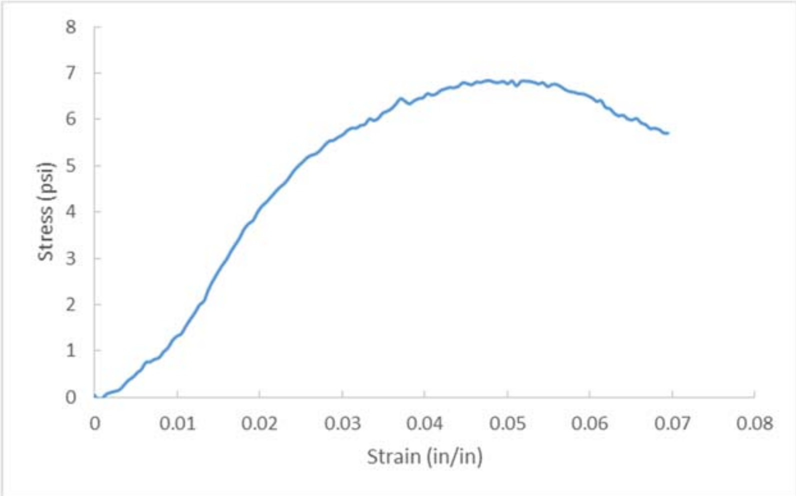

Figure A.316 W50-7, OC= 43.8%, CF= 400 pcf, T=56 days.

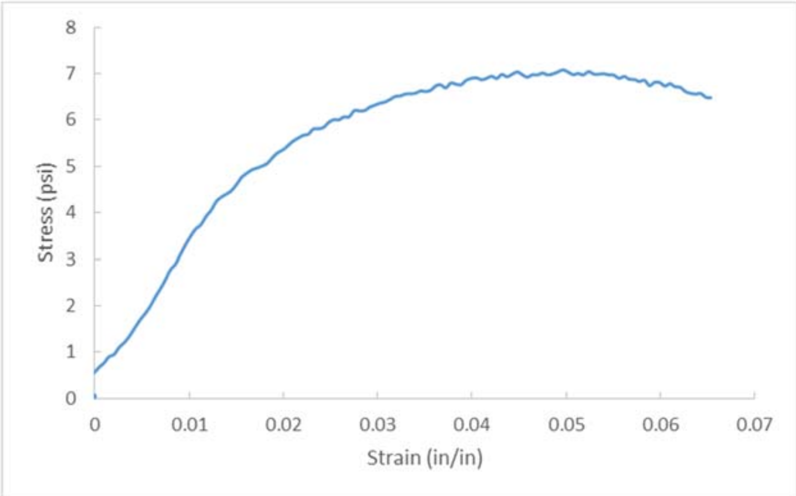

Figure A.317 W50-8, OC= 43.8%, CF= 400 pcf, T=56 days.

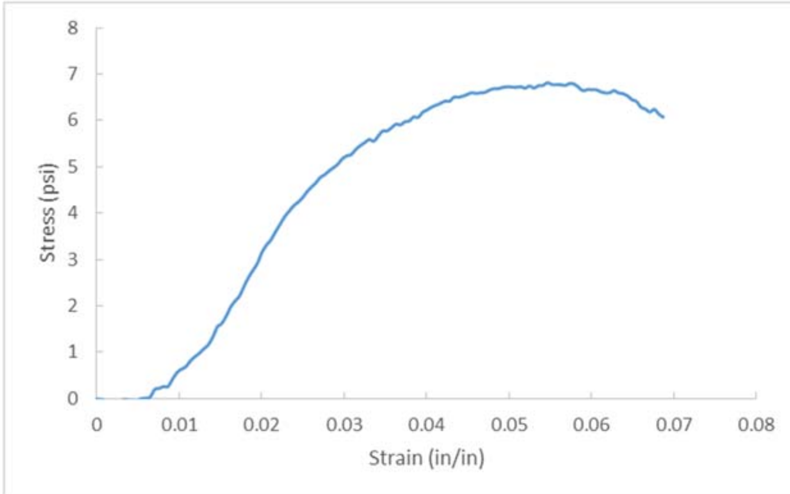


Figure A.318 W50-9, OC= 43.8%, CF= 400 pcf, T=56 days.

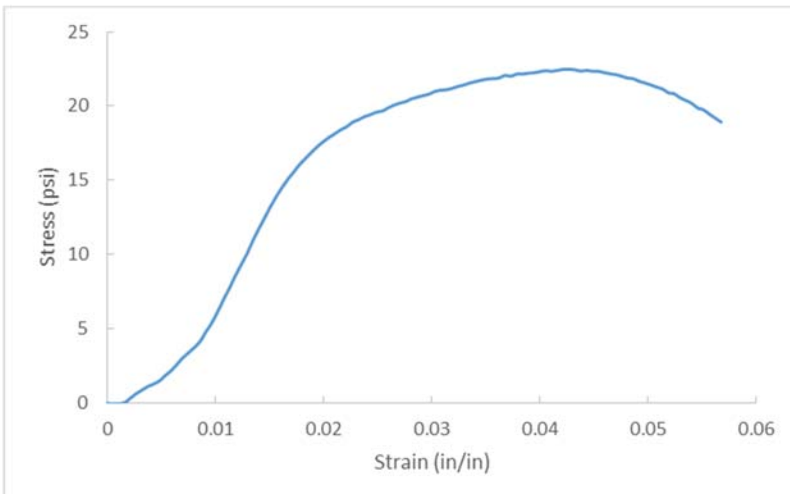


Figure A.319 W51-7, OC= 43.8%, CF= 500 pcf, T=56 days.

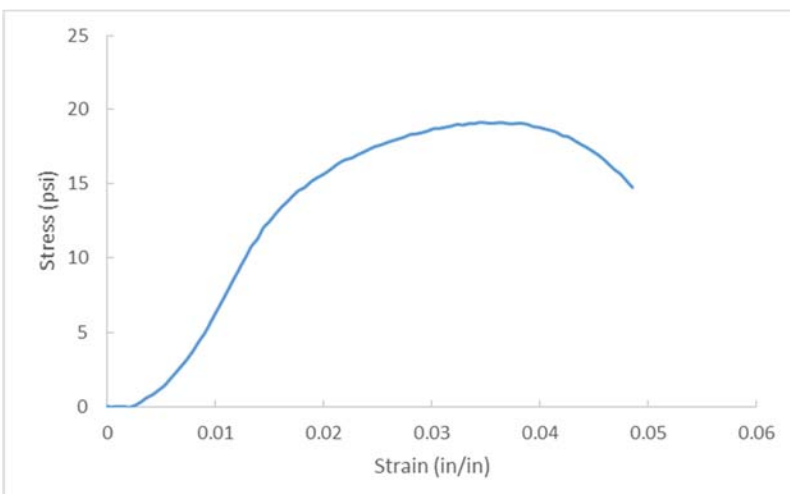


Figure A.320 W51-9, OC= 43.8%, CF= 500 pcf, T=56 days.

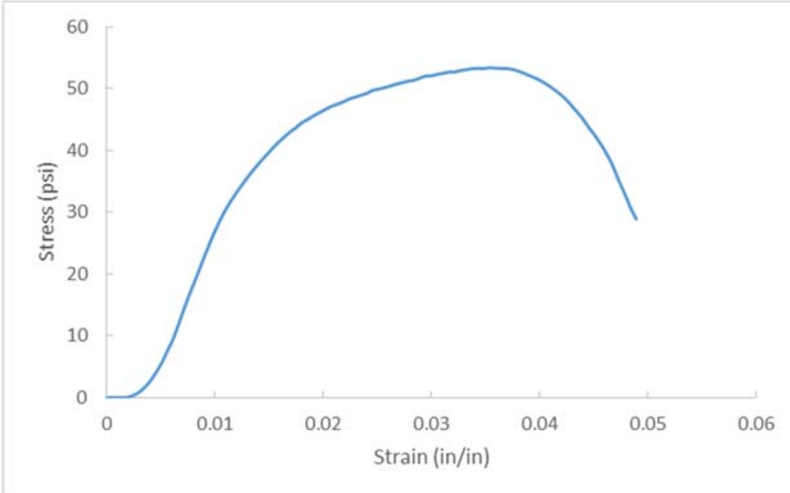

Figure A.321 D55-4, OC= 42.1%, CF= 500 pcf, T=56 days.

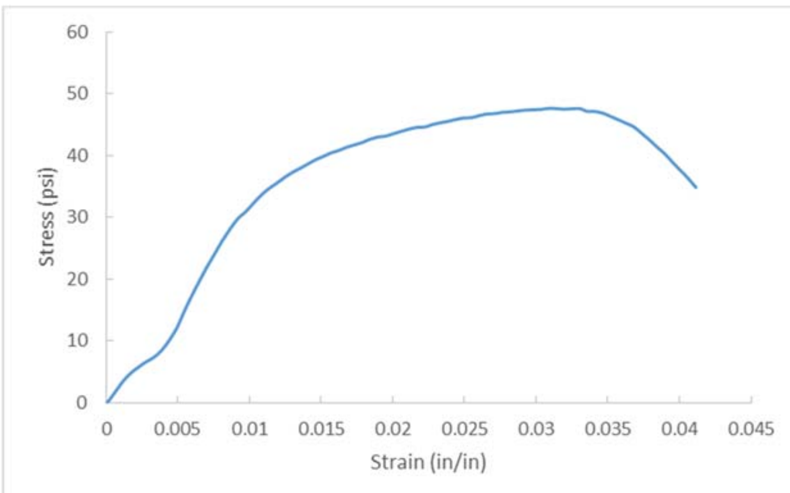

Figure A.322 D55-5, OC= 42.1%, CF= 500 pcf, T=56 days.

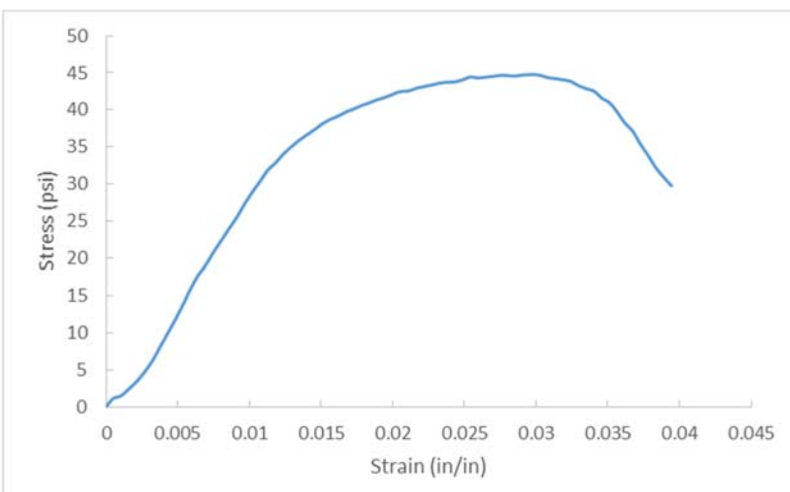

Figure A.323 D55-6, OC= 42.1%, CF= 500 pcf, T=56 days.

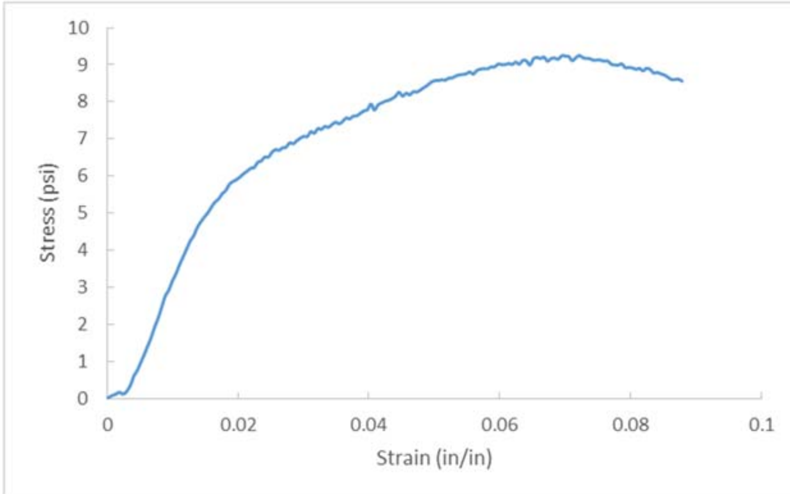


Figure A.324 D57-4, OC= 42.1%, CF= 500 pcf, T=56 days.

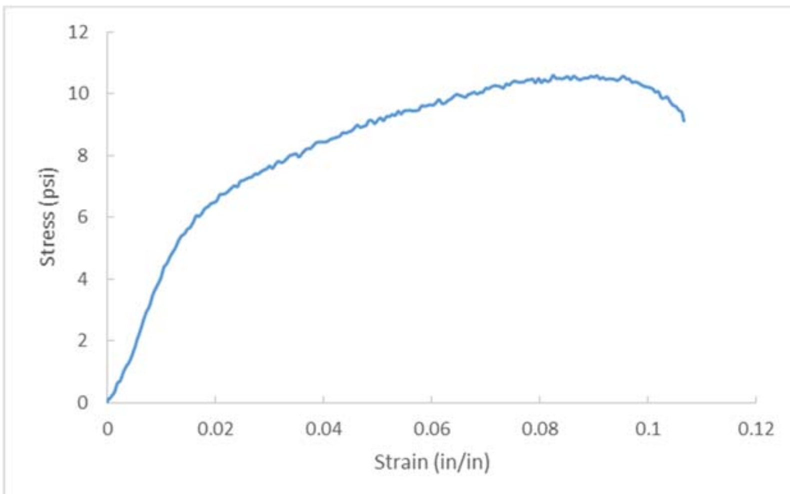


Figure A.325 D57-5, OC= 42.1%, CF= 500 pcf, T=56 days.

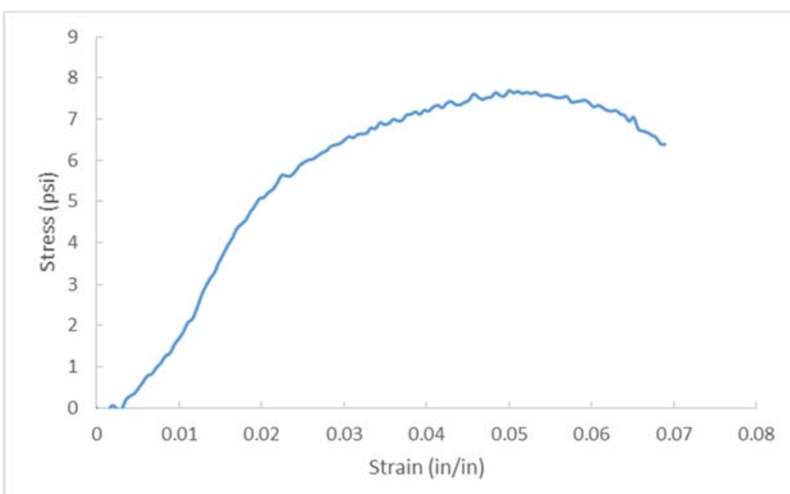


Figure A.326 D57-6, OC= 42.1%, CF= 500 pcf, T=56 days.