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Mechanical Properties Of Neat Cement Paste: Investigation Of Correlation To Degree Of Hydration And Water-To-Cement Ratios

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Mechanical Properties of Neat Cement Paste: Investigation of Correlation to Degree of Hydration and Water-to-Cement Ratios

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Biographical Sketch

Sean J. Walker was born on March 25, 1989. He is 25 years old. He grew up in the military town of Fayetteville, NC where majority of his peers go into the military. Sean J. Walker chose a different route instead. Coming from a rough neighborhood, he managed to make it through high school. He graduated from Seventy First High School in 2007. After graduating high school, he chose to come to North Carolina A&T State University to pursue his Bachelor's Degree in Civil Engineering. He graduated with a Bachelor's degree in 2011. He then decided to continue his path for higher education, where he got accepted into the Civil Engineering master's program at the same university. Sean J. Walker is set to graduate with a Master's degree in December 2014.

North Carolina A&T State University has meant and did a lot for him being that most of his peers do not pursue the college route. He is the only one of his grandmother's grandchildren to graduate high school, let alone college. Unfortunately, his grandmother did not make it to see him walk across the stage in high school. She passed 3 months before his graduation around the time of his 18th birthday. Therefore, Sean J. Walker's main purpose in pursuing higher education is for her and also his mom. Both of them will be happy to see their son walk across the stage.

Dedication

First off, I would like to dedicate this thesis to my beloved grandmother, Willie Mae McLean, who did not make it to see her only grandchild graduate. I would also like to dedicate this thesis to the best mother in the world, Sheena Walker who has always been there to support me through thick and thin through this college process. I would also like to thank my cousin, Coneasha Thomas who pushed me to attend college and helping me through the admission process.

Other people I would like to dedicate this thesis to, is my father, William Walker Jr., my girlfriend, Takerra Daniels, sister Keyonna McLean, my bother William Walker-El, my grandfather, Robert Mclean and my niece, Kamiya Jones. Finally I would like to dedicate this thesis to my friends and entire family on both sides, too many names to name, but I would like to thank you all for the support and let y’all know that your nephew, cousin, uncle, brother and friend has made his dream come true.

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I am also thankful for my former advisor, Dr. Wonchang Choi who I started this thesis with for his advice and the valuable learning experience that I got from him. I would also like to thank Robert Moser and Paul Allison and the rest of the people I met from the Army Corps of Engineers in Vicksburg, MS for the learning experience I received when I was interning there.

I am forever indebted to Dr. Sameer Homoush, Dr. Ram Mohan and the funding agency for financing and coming up with a research plan of study for me at North Carolina A&T State University. Thank you for your support.

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Abstract

The mechanical strength of cement paste is the property of the material that is most obviously required for structural use. The strength of mortar or concrete depends on the cohesion of the cement paste and its adhesion to the aggregate particles. Cement paste consists of two parts, cement and water. When water is added to cement, it reacts with the cement in what is known as the hydration process. The scope of this study is to determine the mechanical properties of hydrated cement paste with respect to the degree of hydration for different water-to-cement ratios, for developing a molecular macroscopic model for numerical simulations at the nano-scale. Hydration, compression, elastic modulus, flexure and direct tension tests were performed to complete this study. Vacuum-sealed dry curing was chosen for the specimens in this experiment. Results showed that with increased degree of hydration, there was an overall increase in the compressive strength. However, for the tensile strength, there was an overall decrease in both flexure and direct tensile strength. This may be the result of the phenomenon called ‘autogenous’ shrinkage from the method of vacuum-sealed dry curing. This curing method robs the interstitial water in the pores of the cement gel. The loss of pore water results in an increase of the capillary tension in the pores. This increase in the capillary tension causes autogenous shrinkage. To accommodate this shrinkage, the gel cracks or existing cracks extend, resulting in the loss of tensile strength for increasing curing time. Microscopic observations were made on the failure planes of beam A.3 to identify any cracking. The cracks observed show that they have an association with some air void present in the failure plane. Future research must be conducted for better understanding of this mechanical behavior.

CHAPTER 1

Introduction

1.1 Background

The mechanical strength of hardened cement paste is the property of the material that is perhaps most obviously required for structural use. Therefore, it is not surprising that strength tests are prescribed by all specifications for cement. The strength of mortar or concrete depends on the cohesion of the cement paste, on its adhesion to the aggregate particles, and to a certain extent on the strength of aggregates itself.

Cement paste is a material based on only two parts, which are water and cement. The properties of cement paste are relatively well known, particularly the compressive strength, which depends on the water/cement ratio. The water content in the cement paste is equally as important for the compressive strength. When increasing the amount of water in the cement paste, it allows increases of the degree of hydration of the cement paste.

Concretes creep, construction behavior, are important material properties of cement paste for mathematical simulations. Modulus of elasticity and compressive strength are parameters used for modeling of construction. Other properties used are temperature, humidity, creep and shrinkage. The strength of cement paste is defined by a maximal resisted stress in compression. Because cement paste is the basic part of concrete, the knowledge of the paste properties is important. The cement paste creates the binding material for connection of aggregates. Cement paste is the product of chemical reactions between the cement and water. When cement reacts with water, it creates a porous and crystalline structure. For determination of its quality, the density of the cement paste is one basic parameter. The length of rise time of hardened structures is usually determined at twenty-eight days after mixing cement with water.

Because of difficulties of molding and testing with the consequent large variability of test results, strength tests are not normally performed on specimens of neat cement paste. In practice, a mortar of sand-cement of prescribed proportions is commonly made with specified materials and under strictly controlled conditions. Specimens of this mortar are used for the purpose of evaluating the strength properties of cement. There are three main types of strength tests: compression, direct tension, and flexure. The latter determines in reality the tensile strength in bending because hydrated cement paste is considerably stronger in compression than in tension.

Generally, materials start to fail at local points and at much lower stresses than those predicted from considerations on a structural level. Concrete includes imperfections, flaws, and micro-cracks in the mass; when external loads are applied to the concrete, these features cause local stress concentrations. It is complicated to apply fracture mechanics to a heterogeneous material like concrete because there are three phase to concrete; the cement paste, the aggregate and the paste-aggregate interface. These three phases all have different properties, such as surface energy. The aggregate is usually stronger than the paste and paste-aggregate interface. Therefore, one must understand the strengths of these three phases.

The actual strength of hydrated cement paste is much lower than the theoretical strength estimated on the basis of molecular cohesion, and calculated from the surface energy of a solid assumed to be perfectly homogeneous and flawless. The discrepancy can be explained by the presence of flaws. These flaws lead to high stress concentrations in the material under load so that a very high stress is reached in very small volumes of the specimen with a consequent microscopic fracture. The average nominal stress in the whole specimen is comparatively low. The flaws vary in size but it is only the few largest ones that cause failure. Thus, the strength of hydrated cement paste is known to contain numerous discontinuities, such as voids, pores and micro-cracks. But the exact mechanism through which these affect the strength is not known. The voids themselves do not act as flaws, but the flaws may be cracks in individual crystals associated with the voids or caused by shrinkage or poor bonds.

Whenever a notched cement paste specimen is subjected to an increasing tensile load whether it is by flexure or direct tension, the overall stress-strain curve will be linear up to a point when it departs from linearity. Once this happens, it marks the onset of micro- cracking near the crack tip. The main crack starts to propagate once the surface energy required for the main crack and the micro-cracks is balanced by the strain energy released. As the main crack propagates, the size of the micro-cracking area and the energy required for forming it increases.

1.2 Motivation of Present Study

The major reason to undertake the present research project was grounded in the need to develop results of macroscopic tests to serve as benchmarks for comparison of results of numerical simulations at molecular and multilevel sizes. The goal of this selection was the need to reduce the number of parts of the paste that would need to be incorporated in the numerical simulation. Neat cement paste has two parts, the reacted and the unreacted cement with water and the free water still present in the gel pores. If sand or aggregate were included would results in two more parts to be included in the simulation.

1.3 Project Scope and Objective

The scope of this study is to determine the mechanical properties of hydrated cement paste with respect to the degree of hydration for different water-to-cement ratios. Hydration periods of three days, seven days, fourteen days, and twenty-eight days were chosen to perform test. For each hydration period (day), a hydration rate will be determined and for that hydration rate, the mechanical properties will be associated with that rate.

In this study, Type I Portland cement is used. The chemical composition of the cement used is presented in Table 1.1. The water/cement ratios that were considered are 0.35 and 0.40. A number of tests were chosen to determine the mechanical properties of the hydrated cement paste. These tests include the compression test of nominal two-inch-side cubical specimens; flexure test of nominal 1.5 in x 1.5 in x 6 in prismatic specimens; direct tension test of nominal 1 in x l in briquette specimens; elastic modulus test of four-inch-diameter eight-inch-long cylindrical specimens.

ASTM standard test methods will be followed each test except for the degree of hydration. A total of three replicate specimens will be tested for each test method. These specimens are to be tested for the specified hydration period (number of days) from the day that the batch is prepared. The load and displacement will be recorded during all the mechanical tests.

The degree of hydration was to be determined on specimens of ten grams of cement. In this research, the hydration rate will be determined by measuring evaporable water and non-evaporable water in the cured cement paste. The evaporable water is lost when the cured paste is heated to l05°C. The evaporable water is held in both capillary and gel pores, also in some hydrate water from the calcium sulfo-aluminates. The measured amount of water combined structurally in the hydration products is the non-evaporable water. The non-evaporable water is determined by ignition of the ground paste specimen in a furnace at 1000°C.

After the degree of hydration is determined and all specimens have been tested, the mechanical properties for the same curing period will be related to the degree of hydration for the same curing days, and, thus, establish to the correlation.

Table 1.1

Cement Composition

ARGOS

Cement Mill Test Report

Month of Issue: February 2012

Plant:	Harleyville, South Carolina
Product:	Portland Cement Type I and Type I/II(MH)
Silo:	9
Manufactured:	January 2012

ASTM C150-11 and AASHTO M85-11 Standard Requirements

CHEMICAL ANALYSIS

Item	Spec limit	Test Result
Rapid Method, X-Ray *(C114)*		
SiO2 (%)	---	20.7
Al2O3 (%)	6.0 max	5.1
Fe2O3 (%)	6.0 max	3.4
CaO (%)	---	64.5
MgO (%)	6.0 max	1.0
SO3 (%)	3.0 max *	3.0
Loss on ignition (%)	3.0 max	1.0
Insoluble residue (%)	0.75 max	0.36
Adjusted Potential Phase Composition*(C150)*		
C3S (%)	---	57
C2S (%)	---	16
C3A (%)	8 max	8
C4AF (%)	---	10
C3S+4.75*C3A (%)	100 max	94
ASTM C150-11 and AASHTO M85-11 Optional Chemical Requirements:		
NaEq (%)	0.60 max	0.49

PHYSICAL ANALYSIS

Item	Spec limit	Test Result
Air content of mortar (%)*(C185)*	12 max	7
Blaine Fineness (m2/kg) *(C204)*	260 - 430	390
-325 (%) *(C430)*	---	97.6
Autoclave expansion (%)*(C151)*	0.80 max	0.02
Compressive strength (MPa, [PSI]) *(C109)*		
1 day	---	16.5 [2390]
3 days	12.0 [1740] min	25.7 [3720]
7 days	19.0 [2760] min	33.1 [4800]
28 days (Reflects previous month's data)	---	44.1 [6400]
Time of setting (minutes)		
Vicat Initial *(C191)*	45 - 375	92
Heat of Hydration (KJ/Kg, [cal/g]) *(C186)*		
7 days (for information only)**	---	277 [66.0]
Mortar Bar Expansion (%) (C1038)**	0.02 max	na

* May exceed 3.0% SO3 maximum based on our C1038 results of <0.02% expansion at 14 days.

** Current Production run not available - most recent provided. "na" = not applicable.

We certify that the above described cement, at the time of shipment, meets the chemical and physical requirements of applicable SCDOT, NCDOT, GDOT, MDOT and VDOT Specifications for Type I and Type II(MH) ; and FDOT 921 Specifications for Type I and Type II(MH);
ASTM C150-11 & AASHTO M85-11 STANDARD SPECIFICATIONS FOR TYPE I AND TYPE II(MH) CEMENT;
ASTM C150-11 & AASHTO M85-11 OPTIONAL CHEMICAL REQUIREMENTS FOR TYPES I & II(MH) LOW ALKALI CEMENT.

Certified By:

Sean J. Makens - Process & Quality Mgr
Report created: 2/10/2012

Argos USA - Harleyville Plant
483 Judge Street, Harleyville, South Carolina 29448
Phone: 843-462-7651

The degree of hydration was to be determined on specimens of ten grams of cement. In this research, the hydration rate will be determined by measuring evaporable water and non-evaporable water in the cured cement paste. The evaporable water is lost when the cured paste is heated to l05° C. The evaporable water is held in both capillary and gel pores, also in some hydrate water from the calcium sulfo-aluminates. The measured amount of water combined structurally in the hydration products is the non-evaporable water. The non-evaporable water is determined by ignition of the ground paste specimen in a furnace at 1000°C.

After the degree of hydration is determined and all specimens have been tested, the mechanical properties for the same curing period will be related to the degree of hydration for the same curing days, and, thus, establish to the correlation.

CHAPTER 2

Literature Review

2.1 Hydration and Development of Strength in Cement Paste

Hydrated cement paste is a very complex material that has many phases at the micro and nano-scales. These features complicate the development of structure-property relationships for the hydrated paste. The interactions between nano-scale C-S-H particles have key roles when determining the mechanical properties of hydrated cement paste "HCP" Calcium silicate hydrate "C-S-H" particles are non-crystalline hydration products in character with large surface areas that enhance their bonding to each other and to other particles within their reach through Van der Waals forces.

The first step in theoretical modeling implemented by Ghebrab and Soroushian (2010) is the morphology and structural arrangement of C-S-H particles, given the binding significance of C-S-H particles, in order to determine the bond strength between them. Determination of the elastic modulus of hydrated cement paste considered the effect of relative movement of neighboring C-S-H globules based on the bond force between them. The term micro-defective hydrated cement paste is used for conventional cement paste that incorporates capillary pores and micro-cracks in its microstructure. These micro defects affect the physical and mechanical properties, which should be accounted for when determining the strength, modulus of elasticity and fracture toughness. Capillary pores and micro-cracks affect the modulus of elasticity by reducing the contact area and generating stress concentrations. The capillary pores shape and size distribution greatly affect the modulus of elasticity.

The first step in modeling the elastic modulus is determining the relationship between capillary porosity and pore size. The fracture toughness of hydrated cement paste can be assumed to be linear with respect to porosity. The prediction of the tensile strength of the hydrated cement paste using Griffith's theory from linear elastic fracture mechanics where one has to determine the critical crack length. The hardening of Portland cementing materials generates micro-cracks before the application of loads. These micro-cracks result from the restraint of thermal and dry shrinkage at early age. The differential shrinkage that exists between the relatively stiff calcium hydroxide "CH" crystal and the softer C-S-H gel result in the formation of micro-cracks in the paste.

The research reported by Li and Yang (2005) observed the microstructure and property evolution in the hydration of cement paste. They established a time-dependent micro-mechanical model to investigate the microstructure development and the effective property evolution of the cement paste, while experimental data was the input parameters of the model.

The research on the hydration model of the cement and the microstructural simulation can be traced back to the mathematical model and computer modeling for the hydration of tri-calcium silicate "C3S" (Rondo & Ueda, 1968; Frohnsdorff et al., 1986; Pommersheim & Clifton, 1980). However, these researchers worked only for a medium with a single-mineral component. The attention has been extended to the hydration of media with a single-mineral component, such as cements since the 1980s. The hydration process of cement is very complex with physical and chemical interaction.

During the hydration process, as the cement and water is mixed in certain proportion, the cement particles are surrounded by the hydrated cement gel. The produced hydrated gel shells on the surfaces of cement particles grow and swell gradually. As the hydration process progresses and new hydration cement gel is produced, the adjacent shells contact each other and a continuous cement paste forms. This results in the hardened cement paste consisting of cement gels, cement particles and the pores.

The present model does not consider the physico-chemical process of cement hydration. The effective properties of the hardened cement paste are determined by the properties, volume fractions and the distribution of the components. In addition, the fractions change continuously with the degree of hydration. Thus, the effective properties of the cement paste are time dependent. It is assumed that the cement particles have a 3D spherical structure with the same radius and a uniform distribution. All of the particles are hydrated at the same rate and embedded in the cement gel shells with uniform thickness. The present model is time dependent, at the anhydrous state of the cement, the cement particles are discrete. The cement gel shells on the surface of the particles are formed and the material keeps discrete at the early stage of hydration. As hydration progresses, the volumes of gels are growing and the volumes of the pores become gradually smaller. The cement paste becomes a continuous body once the adjacent clusters make contact and overlap each other. The discrete statuses of the paste only exist in the early stage of the hydration and lasts a very short time, usually less than a day.

2.2 Material Properties of Cement Paste

2.2.1 Cement paste in compression. In the study reported by Cao and Chung (2002), electrical resistivity was used for measurement for nondestructive monitoring, since the measurement is fast and known to provide damage monitoring of cement paste. Upon damaging, the resistivity increases (Wen & Chung, 2000). In their work, Type I Portland cement and natural sand was used. The sand-to-cement ratio was 1 and the water/cement ratio was 0.35. A water reducing agent was used in the amount of 1% by weight of cement.

Compression testing was performed following ASTM C109, where specimens were prepared using a two-inch-side cube mold. Strain was measured by using a strain gage attached to the middle of one of the side surfaces of the cube. The strain gage was centered on the side surface and placed parallel to the stress axis. Testing was implemented in load control on a hydraulic mechanical testing system (MTS Model 810). Testing was conducted under static loading until failure. Three different loading rates were used: 0.144, 0,216 and 0.575 MPa/second. For each loading rate, six specimens were tested.

A direct current electrical resistance measurement was recorded in the stress axis, using the four probe method, in which silver paint and copper wires served as electrical contacts. Due to the voltage present during electrical resistance measurement, electric polarization occurs as the resistance measurement is continuously made. The polarization-induced resistance increase, as separately measured as a function of the time of resistance measurement in the absence of stress, was subtracted from the resistance measurement change obtained during cyclic loading in order to correct the effect of polarization. Due to the short time taken for loading up the failure, the correction was almost negligible.

Results from Cao and Chung (2002) show that the resistivity increases monotonically with stress and strain, such that the resistivity increase was most significant when the stress or strain was low compared to the strain or stress at fracture. The resistivity abruptly increases when the fracture point is reached. The stress-strain curve is linear up to failure for all of the loading rates, indicating the brittleness of the failure. The higher the loading rate, the lower was the fractional change in resistivity at fracture and the higher was the compressive strength. The modulus and ductility essentially did not vary with the loading rate in the range of loading rate used. However, the modulus did slightly increase and the ductility slightly decreased with increased loading rate. The steady increase in resistivity observed at any of the loading rates as the stress-strain increased indicates the occurrence of a continuous microstructural change. This involves the generation of defects that cause the resistivity to increase. During the early part of loading, this is when the microstructural change is most significant. At any strain, the extent of microstructural change, as indicted by the fractional change in resistivity, decreased with increasing loading rate. The amount of damage at failure also indicated by the fractional change in resistivity at failure, decreases with increasing strain rate. Hence, the loading rate not only affects the failure conditions, but also the damage evolution, all the way from the early part of loading. A higher loading rate results in less time for microstructural changes, which results in less damage build-up.

In this experiment, Cao and Chung (2002) concluded that electrical resistivity of cement mortar increased monotonically with compressive stress-strain up to failure, such that the increase was more significant in the early part of the loading. An increase in the strain rate caused the resistivity at any strain level to decrease also it caused the resistivity at failure to decrease. What this means is the microstructure changed continuously during loading, such that the change was most significant in the early part of the loading. Further investigation revealed that at any strain level, the extent of microstructural change decreased with increasing strain rate, thereby causing the compressive strength to increase with increasing strain rate.

There are common assumptions that the microscopic properties of the fracture surfaces of porous materials bear information on macroscopic quantities like compressive strength. So far there have not been clear concepts quantifying such a relation that have been proposed and verified. A study was reported by Ficker (2012) to assess the capability of fracture surfaces to provide information about the actual value of compressive strength. It is well known that porosity of hydrated cement pastes is mainly a consequence of the water/cement ratio. Compressive strength of cement pastes is dependent mainly on capillary porosity and the porosity is a controlling factor of height irregularities of the fracture surfaces. The graphs in the research proved the existence of a close correlation between compressive strength and the height irregularities of fracture surfaces of cement pastes specimens.

Compression tests in Padevet and Zobal (2010) experiment used cylindrical specimens with a diameter of 10 mm and a length of 35 mm. The specimens were made without any plasticizer at a w/c ratio of 0.4. After mixing, the cement paste was poured into a plastic mold with length of 100 mm. Then after hardening process was complete, they were cut at a length of 35 mm.

Compression test in Padevet and Zobal (2010) experiment were conducted on cylindrical specimens one day after finishing heating, The best strength value was achieved for cement paste CEM I with water/cement ratio of 0.3 at a temperature of 20°C. The lowest strength value achieved at for CEM II with a water/cement ratio of 0.5 at a temperature of 600°C which was shuttered by the influence of temperature. From the test results, it was a visible trend of decrease of strength with increasing temperature. Compression strength of specimens embodied the enhancement value at 200°C, Strength values then rapidly decrease up to 450°C. After 450°C, there is not a rapid fall in strength.

Another test program reported by Majeed (2009), studied the effects of varying sand/cement ratio and water/cement ratio used on the compression and flexure tests. It consisted of using twelve mix proportions having different sand/cement ratios and water/cement ratios. The water/cement ratios used were 0.35, 0.45 and 0.55 and the sand/cement ratios were 1:1.5, 1:2, 1:2.5 and 1:3. Each batch contained three cubical specimens of two-inch-side cubes for compressive strength and three prismatic specimens of 1 in x I in x 6 in for flexural strength tests. All specimens contained the same graded river sand and the fineness modulus of the sand was 2.86. Type I Portland cement was used for all specimens. Tap drinking water was used was used for mixing and curing and the temperature of the water was at 25°C. The specimens were kept in the mold for twenty-four hours from the time of casting and kept in the curing water until testing at twenty-eight days.

Compression testing followed ASTM C109 using compression test machine (ELE) with a loading rate ranging from 900-1800 N/second. The testing for the flexural modulus of rupture followed ASTM C348 using third-point loading test over a span of 200 mm to obtain a zone of pure bending along the specimen. All specimens were tested immediately after they were removed from the curing tank.

The conclusions from Majeed (2009), states that an increase in sand/cement ratio leads to a decrease in compressive strength from 13% to 66% and modulus of rupture from 10% to 45% of the mortar. The change of water/cement ratio also affects the mortar strength. A water/cement ratio of 0.45 gives the highest mortar strengths for all sand/cement ratios.

2.2.2 Cement paste in flexure and direct tension. The direct tension test in the past on briquettes specimens used to be commonly employed but pure tension is rather difficult to apply so that the results of such a test show a fairly large scatter. The direct tensile strength of cement is of lesser interest than its compressive strength since structural design mainly exploits the good strength of concrete in compression. Similarly, flexure strength is usually of lesser interest than its compressive strength, although in pavements the knowledge of the strength of concrete in tension is of importance. Today, it is the compressive strength of cement that is considered to be crucial, and it is believed that the appropriate test on cement is that on cement-sand mortar.

Prismatic form specimens were prepared for flexure testing and these were placed in a water basin the second day after being cast. These specimens contained a 2 mm deep notch for localization of the crack in the flexure specimen. Beams were prepared with dimensions 20 mm x 20 mm x 100 mm. The main factor for obtaining good strength results for cement paste is water/cement ratio. Quantity of water used in cement is selected based on the workability of the cement paste and the strength of hardened cement paste. For their experiment, Padevet and Zobal (2010) chose three water/cement ratios of 0.30, 0.40 and 0.50. The cement paste becomes more workable for higher water/cement ratio.

In Padevet and Zobal (2010) research, all sets of specimens for the bending test were made using both CEM I and CEM II. The specimens made from CEM II a 2 mm deep notch on the side of the tension stress. All specimens were heated before testing in the furnace just like the compression test. Maximum tensile strength for the CEM I sets with water/cement ratio of 0.3 was 4.8 MPa. For the CEM II sets with water/cement ratio of 0.3, the maximum tensile strength was 9.5 MPa. Both of these values were from a temperature of 200°C. These values correspond to approximately one tenth of the compressive strength. Strength values increase for temperature to about 200°C, but specimens tested at higher temperatures than 200°C lose their tensile strength. Specimens were impossible to be tested for both CEM I and CEM II for water/cement ratio of 0.50 because they were damaged by cracks.

The advantage of cement paste is the homogeneity. In smaller testing equipment, homogeneous fine-grained materials are more suitable for testing. In Padevet and Zobal (2011) experiment, 20 x 20 x 100 mm beam specimens were selected for preparation. Portland cement CEM I 42.5R was used for the specimens. Intentions were to not use plasticizer so water/cement ratios of 0.35, 0.4 and 0.45 were selected. Grout with a water/cement ratio higher than the specified limit has high fluidity, which may cause segregation of cement and water. Grout can also be too rigid and treated by practically no plasticizer. Consistency of water/cement of 0.40 was chosen as a tougher type of cement paste while thinner type of cement paste was defined by water/cement ratio of 0.45. Once the specimens were cast, the specimens were stored in a water basin for about thirty days.

The specimens were cured in water and removed two days prior to testing. They were dried at 60°C for 48 hours. The saturated samples had a weight loss from 11% to 12%. Each specimen had a notch cut about 7 mm deep into it before testing. The notch width of each specimen was about 1 mm.

Specimens that were prepared with fly ash and cement paste had a water/cement ratio of 0.40. This water/cement ratio had a good consistency in which there was no separation of cement and water. The addition of fly ash, which in principle is the non-wetted surface, does not impair the mixture. However, the mixture is more liquid, but the individual components do not segregate.

The degree of fluidity of the mixture depends on the quantity of fly ash in the cement paste for this study. The cement/ash ratio defines the quantity of fly ash, which expresses the weight of cement to fly ash. In the first set of specimens, there was a 50/50 cement/ash ratio. In the second set, there was a 40/60 cement/ash ratio used: that is 40% cement and 60% fly ash.

The experiment (Padevet & Zobal, 2011) was carried out on a MTS Alliance RT 30 kN testing machine. Using relatively small specimens can achieve the desired results for the test method. Two important parameters for achieving good results are the size and stiffness of the test specimens. If the stiffness of the testing machine is too small and the specimen is too large, then there is a snapback and only the maximum load will be achieved without measuring the softness of the material. The three-point bending test was performed to measure the fracture energy. The loading span of the specimen was 80 mm. The notch was located in the middle of the range below the point of the applied load. Two parameters were required for the assessment of the test; strength and vertical deflection of the specimen.

The results of Padevet and Zobal (2011) experiment showed that there was a 95% decrease in strength relative to the maximum achieved strength. During the loading phase, there is a linear deformation portion of the loading curve. Once the load reached about 90% of the maximum strength, the deformation of the specimen accelerated.

Specimens whose properties have been experimentally verified at first view did not show signs of failure but if the focus were on the area of the notch, Padevet and Zobal (2011) would have seen a typical crack front on the notch directed into the place where the specimen was loaded.

Increasing the water/cement ratio causes a decrease in fracture energy. Tensile strength in bending decreases with increasing water/cement ratio. The strength of water saturated specimens decreased in value by 1 MPa. Similarly, the tensile strength in bending decreased for dried specimens by 1 MPa.

In the experiment report, Padevet and Zobal (2011) concluded that fracture energy for water-saturated specimens decreased by 18%, when the water/cement ratio increased from 0.35 to 0.45. The change in fracture energy for the dried specimens was only 5%. The fracture energy for water/cement ratio of 0.40 for dried specimens showed the highest value of 25.81 N/mm.

2.2.3 Elastic properties of cement paste. Young's modulus and Poisson's ratio are important parameters used in structural design and analysis of cement-based materials. The chemical and physical changes of the cement paste microstructure results in the evolution of mechanical properties. Porosity plays a major role in determining the strength, but elastic properties depend on the intrinsic elastic values of individual components and their connectedness.

The Modulus of Elasticity in Padevet and Zobal (2010) experiments was determined during the cube compression test by using an extensometer. The length of measurement was 25 mm. The value for the modulus was calculated for the stress at one third of the compressive strength and the corresponding value of strain measured. Evolution of the modulus was similar to the compression strength but only for CEM I at water/cement ratios of 0.30 was the maximum value at temperature of 200°C. Trends for the modulus of elasticity decreased for water/cement ratios of 0.30 and 0.40. The moduli of elasticity measured for specimens tested at 20°C are very similar to typical values of concrete. Properties of cement paste can possibly be characterized by rapid loss of quality over the temperature of 300°C. Moduli are very low at temperatures of 450°C and 600°C. For the specimens prepared with a water/cement ratio of 0.50 was not possible to measure the modulus of elasticity because the specimens contained opened cracks.

The model of Qing-Sheng and Chun-Jiang (2006) research describes the microstructural evolution of the continuous cement paste from the contacting state of the shells till the end of the hydration. The analysis is carried out only for a representative volume element (RVE) for such a periodic microstructure. The present model uses three parameters, which are the volume fractions of anhydrous cement particles, cement gel and pores. These parameters can be easily measured (Igarashi et al., 2004). The experimental data for volume fractions of components depending on the degree of hydration of the cement have been reported in the existing literature. The microstructural parameters are determined for a specific degree of the hydration based on the experimental measured relations between the volume fractions of components and degree of hydration.

Considering the evolution of the microstructure and properties of Portland cement in the hydration process, the material parameters are as follows (Paulini & Gratl, 1995): for the anhydrous cement, the Young's modulus E_{cem}=60 GPa, the Poisson's ratio ν_{cem}=0.27; for cement gel, the Young's modulus E_{gel}=30 GPa, the Poisson's ratio ν_{gel}=0.21. The range of the degree of hydration is from α=0.2 up to α=0.75. This range corresponds to the stage of hydration from less than 1 day to 91 days.

The results of effective stiffness show that the stiffness of the cement paste increases with the progression of the hydration process. Although the fraction of anhydrous cement with larger stiffness decreases and the fraction of the cement gel with smaller stiffness increases, the effective stiffness of the cement paste increases with the progression of the degree of hydration, This is a result from the decrease of the pores in cement paste and shows that the fraction of the pores is an important factor for the effective properties of the cement paste.

Results also show that the Poisson's ratio decreases as the degree of hydration increases. For the Young’s modulus, results show that it increases when the degree of hydration increases. On the other note, both the Young's modulus and Poisson's ratio do not relate linearly to the degree of hydration. The elastic properties of cement paste are time dependent. The elastic properties can be obtained through the relation between the time and the degree of hydration. During the early stages of hydration, the hydration rate is very fast, making both the Poisson' s ratio and Young ' s modulus of the cement paste change dramatically. While the hydration progresses, the rate of hydration becomes progressively slower so that the elastic properties tend to stabilize.

The present model research develops a systematic method for modeling the microstructure and the effective elastic properties of the cement paste. This simple model is established based on measured data experimentally and can reflect the microstructural development of the cement paste in the hydration process. Comparison of the results by Qing-Sheng and Chun-Jiang (2006) show's that the present model and results are in good agreement with experimental data for concrete.

The conclusions from Qing-Sheng and Chun-Jiang (2006) research state that the hydration of cement is a complicated physico-chemical process. The medium is discrete in the first stage of the hydration process, which only last a very short time. The volume fractions change of the components in the cement paste change continuously with the progression of the hydration process. The microstructure is completely determined at a certain time. The microstructure is then homogenized and the effective properties can be obtained. The effective elastic properties and deformation of the cement paste are time dependent. The properties change dramatically during the early stages of the hydration process. In the last stages of the hydration process, the effective properties approach their stable values.

2.2.4 Drying shrinkage and cracking behavior in cement paste. Drying shrinkage is defined as the volume reduction that concrete suffers as a consequence of the moisture migration when exposed to a lower relative humidity environment than the initial one in its own pore system. Drying shrinkage of concrete has been given a great deal of attention during the past century. One of the main factors affecting shrinkage stains is drying-induced micro-cracking. The mechanisms involved in the drying process are complex and are often interrelated, which is mainly due to the wide range of the pore size distribution in standard concrete mixes This determines the different transport mechanisms during drying. The pore system evolves in time as a result of hydration and aging. Moisture transport within porous solid involves liquid water as well as water vapor (Bear & Bachmat, 1991), and mechanisms such as permeation due to a pressure head, diffusion due to a concentration gradient, capillary suction due to surface tension acting in the capillaries, or adsorption-desorption phenomena, involving fixation and liberation of molecules on the solid surface due to mass forces, may act simultaneously within the drying material.

Capillary tension is the most documented phenomenon in drying porous media. A meniscus is formed in the capillaries of the hardened cement paste pores when it is drying. This causes tensile stresses in the capillary water due to surface tension forces. These tensile stresses are balanced by compressive stresses in the surrounding solid, bringing about elastic shrinkage strains. This mechanism is supposed to act in the high relative humidity range until approximately 50%, but since the well-known Kelvin equation fails to explain shrinkage deformations at low relative humidity it can be explained that the maximum capillary stresses are reached at a relative humidity of from 40% to 50%.

Environmental factors play a major role on the external conditions of the cement paste. These factors include humidity level and ambient temperature. The environmental conditions will determine the severity of the drying process. It is more detrimental when there is a combination of dry conditions such as low relative humidity and elevated temperatures. A low ambient relative humidity will produce strong gradients near the drying surface, thus increasing the drying rate. The effects of temperature are much smaller than that of relative humidity and its consideration is more important for determining the early age shrinkage strains.

Another factor affecting drying shrinkage is the water/cement ratio, also the content of water and content of cement. These three factors are interrelated. The effects of the concentration of water and cement can be shown to be that the greater the concentration, the greater the shrinkage deformations. Increasing the amount of water will lead to an increasing amount of evaporable water, and thus the potentiality to suffer shrinkage strains. On the other hand, increasing the cement content will obviously lead to a greater shrinkage.

The water/cement ratio determines how much water there is in the cement paste. The higher the water/cement ratio, the higher the porosity, thus its durability will be poor and the strength will be lower. Reducing the water/cement ratio will lead to a considerable decrease in the shrinkage strains and the porosity of the cement paste.

Drying-induced micro cracking is an important aspect when it comes to the effects of the mechanical properties of concrete. Experiments have shown that excessive drying may cause a reduction of the Young's modulus and the Poisson's ratio of up to 15% and 25%, respectively (Burlion et al., 2005, & Yurtdas et al., 2004). Drying shrinkage affects the mechanical properties of concrete in two ways. First, there is an increase in the strength due to an increase in the surface energy and the bonding between C-S-H particles. From a geotechnical aspect, there is an increase in capillary pressure as saturation decreases, and this pressure acts in the material like an isotropic pre-stress, leading to a stiffening effect. On the other hand, there should be a decrease in stiffness and strength due to micro-crack formation. For experimental studies that focus on the influence of drying on the mechanical properties, this may explain why dissimilar results and high levels of scatter are shown (Yurtdas et al., 2004). These experimental studies were mostly based on a uniaxial compression test for evaluating the drying effect. It was documented by Pihlajavaara (1974), that drying induces an increase in compressive strength of up to two thirds in mortars with a water/cement ratio of 0.60 and a decrease in the elastic modulus (Burlion et al., 2005).

Cement paste undergoes a volumetric contraction called drying shrinkage when it is placed in a low relative humidity environment. The volume of a hydrated cement paste or concrete specimen is sensitive to its moisture content, which can be controlled by the relative humidity of the surrounding environment. A contraction is observed called drying shrinkage in less than 100% relative humidity. Some of the specimens' volume is regained if the specimen is re-immersed in water. This portion of the total drying shrinkage is thus called reversible or recoverable. Correspondingly, some of the deformation is permanent, called irreversible or irrecoverable. Drying shrinkage is typically non-uniform throughout a sample. This leads to cracking and warping, which in turn causes durability problems including mechanical or aesthetic failure, and pathways for the ingress of corrosive ions. The shrinkage component of concrete is the cement paste. Several characteristics influence the degree of drying shrinkage. Two of these characteristics include the water/cement ratio and age. These both affect the amount of capillary porosity, which is known to strongly affect drying shrinkage. The age of a specimen is also a reflection of how much of the main hydration product C-S-H is present. C-S-H will shrink upon drying because it is highly porous. Not only is drying shrinkage affected by the amount of C-S-H present, but by its microstructure as well. Cement paste composition, curing temperature and chemical and mineral admixtures are possible ways of changing the nature of C-S-H formed during hydration.

Varying curing temperature and cement chemistry necessarily changes the rate at which a paste hydrates. Total dry shrinkage is highly dependent on the age of the specimen before drying for samples cured at 40°C. It is clear that the younger the paste, the more it shrinks during drying at 50% relative humidity. Reversibility of shrinkage is similarly affected with sample age. A degree of hydration of 0.55, which is equivalent to the 1-day old sample, was chosen as the standard for further studies because samples of high shrinkage should be analyzed.

Cement paste surface area as measured by nitrogen is dominated by the porosity of the C-S-H phase in pore radius range of 1-40 nm. This porosity can be broken down into several pore size components. Pore size distribution is useful in that it can be used to pinpoint which size range of C-S-H porosity has the strongest relationship to drying shrinkage.

Curing at higher than normal temperature (40°C) has no effect on the type of drying shrinkage at a relative humidity of 50% for water/cement ratio of 0.45, α=O.55, but at low temperature curing (2°C) increases total and irreversible drying shrinkage and has no effect on reversible shrinkage. Higher shrinkages of all types are caused by calcium chloride. Sodium hydroxide retards the rate of drying shrinkage, but the total value is the equivalent to the control. It decreases the irreversible component and increases the reversible component.

Juenger and Jennings (2002) concluded that the nitrogen surface area and pore volume as well as drying shrinkage of cement paste could be manipulated using curing temperature regimes and chemical admixtures. They made comparisons at a constant water/cement ratio and degree of hydration because these are known to strongly influence drying shrinkage and may have masked the subtler effects of curing temperature and chemical admixtures. Observations show that high surface areas and pore volumes corresponded with high values of total and irreversible drying shrinkage. Pore volume and surface area was independent of reversible drying shrinkage as measured by nitrogen. Experimental results suggest that one mechanism may be dependent on the morphology of C-S-H, which can be chemically manipulated. The C-S-H can be split into two types (Tennis & Jennings, 2000), one being a high density "HD" and the other being a low density "LD". The HD is inaccessible to nitrogen and perhaps non-shrinking, and the LD portion may irreversibly shrink during drying at 50% relative humidity.

A special type of shrinkage that has received a lot of attention recently is the autogenous shrinkage also known as self-desiccation shrinkage (Lura et al, 2003; Schlangen et al, 2004; Bentz, 2005; Li et al, 2012). This is caused by the loss of pore water to the reaction with the cement particles, the emptying of the pores induces capillary pressures and these pressures result in shrinkage of the pore walls. If the specimens are cured in a water bath, the pore water pressure is replaced and the capillary pressures are not generated, thus, the autogenous shrinkage is not taking place. During sealed curing (Lura et al, 2003), there are significant drops in the internal relative humidity in the pores of the curing concrete, and this can result in significant cracking of the newly formed pore walls.

CHAPTER 3

Methodology

3.1 Experimental Program

In order to determine the mechanical properties of the cement paste, three types of test were chosen. The first test was the compression test, to follow ASTM standard C109 (Standard Test Method for Compressive Strength of Hydraulic Cement Mortars). The next two are the flexure test to follow ASTM standard C348 (Standard Test Method for Flexural Strength of Hydraulic Cement Mortars) and the direct tension test to follow AASHTO standard T- 132 (Standard Method of Test for Tensile Strength of Hydraulic Cement Mortars). The last test used is the elastic modulus test to follow ASTM standard C469 (Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression).

3.2 Sample Preparation

The neat cement paste mix was implemented using a Hobart mixer following ASTM standard C305 (Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency). First the cement was mixed with distilled water for each corresponding water/cement ratio. For this purpose, the amount of distilled water was poured into the mixing bowl; then the cement was added into the mixing bowl and allowed to absorb the water for thirty seconds. The mixer was then started at low speed for thirty seconds. Once it stopped, any paste that was collected on the sides was scrapped down back into the batch for the next fifteen seconds. After scrapping, the mixer was then started at medium speed for sixty seconds.

Once the mixing process was completed, the cement paste was poured into the molds using a rubber scrapper. The molds were then vibrated on a vibrating table for approximately five minutes. Vibration was used for compaction of the paste and to decrease any air bubbles that were present. After the vibrating was complete, the samples were allowed to sit overnight in the molds for twenty-four hours. All samples were covered with a plastic sheet to prevent any drying. The samples were then removed from the molds and vacuum-sealed in plastic bags and placed in a storage container at 26°C for the specified curing time.

3.3 Material Testing

3.3.1 Determination of the degree of hydration. This determination followed a methodology proposed by Copeland and Hayes (1953). The procedure was the following: about 10 g of cement paste was placed into a plastic wrap, the plastic wrap was folded and then contents were flatten to about 1-1.5 mm slab thickness of paste. Once flattened, the plastic wrap containing the mortar was placed inside the water bath at 26°C until the specified curing time. Upon reaching the specified curing time, the slab of paste was ground to a particle size of sieve number 40. Then the samples were placed in a crucible, where the crucible was weighed first, and then the crucible with the sample was weighed. The crucible was then placed in the oven at 105°C for twenty-four hours. Next the sample was taken out the oven and weighed to measure the amount of evaporable water. Then the sample was placed in the furnace and heated up to 1000°C for eight hours. After furnace, the sample was then taken out and placed in a desiccator to allow cooling to room temperature and then placed back in the oven at l05°C to evaporate any water that may have been absorbed from the air. Then the sample was weighed again to measure the amount of non-evaporable water. Once this measurement was taken, the hydration rate was calculated.

3.3.2 Mechanical testing. Mechanical testing was performed on a MTS Model 810 testing machine. Three of the mechanical tests were performed on this machine. These were the compression test, flexural test using the three-point bending method for beams and the direct tension test using briquette specimens. Each set of test contained a total of three replicate samples. The elastic modulus test was performed on a Forney testing machine subjecting 4 inch diameter and 8 inch long cylindrical specimen to compression testing, and the axial strains were measured using a compressometer attached to the central half of the specimen.

A displacement rate was chosen for all test performed on the MTS Model 810 testing machine. For the compression test, a 50 kip load cell was used. This test followed ASTM C109 (Standard Test Method for Compressive Strength of Hydraulic Cement Mortars). A displacement rate of 0.025 in/min was chosen for this test.

For the flexure test, a 1 kip load cell was used. This test followed ASTM C348 (Standard Test Method for Flexural Strength of Hydraulic Cement Mortars). A displacement rate of 0.01 in/min was chosen for this test.

For the direct tension test, the 1kip load was used. This test followed AASHTO T-132 (Standard Method of Test for Tensile Strength of Hydraulic Cement Mortars). A displacement rate of 0.2 in/min was chosen for this test.

Cubes that were used in compression testing were turned on their side to achieve a flat contact area with the compression fixtures because the top surface that was exposed to the air was relativity rough. Flexure beams were also turned on their side to achieve a flat contact area because the top surface was relatively rough. Flexure beams were approximately 6.3 inches in length. The loading span of the beams was approximately 5.6 inches. For the direct tension test, briquette specimens were placed into the grips. First, the tension grips had to be centered and aligned with each other then placed approximately l/4 inch apart so the specimen could fit into.

Enough space was left between the grips so that the specimen was allowed to hang freely on the top grip so there was no initial load on the sample.

All specimens were loaded up to failure. Load and displacement data was recorded in order to document the mechanical performance of the cement paste specimens under the different type of loading of each test.

CHAPTER 4

Results and Discussion

The present chapter presents the results of the degree of hydration determinations and the development of mechanical properties with curing time. The mechanical properties include compressive strength, flexural strength, direct tensile strength and elastic modulus of neat cement paste specimens. The effects of sample preparation, curing method, curing period, and mixing water/cement ratio "w/c" on cement paste is also discussed.

4.1 Degree of Hydration

The degree of hydration **"α"** was determined using three replicate specimens, each of ten grams, of neat cement paste. These specimens were prepared for each combination of mixing water/cement ratios from 0.35 to 0.40 and lengths of curing times from three days, seven days, fourteen days and twenty-eight days.

For each determination, after the specimen had been cured for the appropriate length of time, the specimen was ground with a mortar to a maximum particle size, passing sieve No. 40. Then, the specimen was placed in a crucible and the weight of specimen and crucible were recorded.

The crucible/specimen was, then, placed in an oven set at 105°C for a drying period of at least twenty-four hours. The heating at 105°C released all evaporable water in the specimen (that is, water not chemically combined with the cement compounds). The weight of the specimen after this process was recorded as "ω_{100}". This weight includes the weights of all cement compounds plus the water already chemically combined with these compounds due to the hydration reaction.

Following this determination of "ω_{100}", the crucible with the specimen was placed in a furnace and heated to a temperature of at least 1000°C to determine the amount of non-evaporable water. Upon the furnace reaching the 1000°C, the furnace was turned off and the specimen/crucible was allowed to cool down to room temperature. During the cooling down, the specimen was enclosed with a cover on the crucible to limit the exposure of the specimen to the atmosphere.

The weight of the specimen after the furnace exposure was recorded as "ω_{1000}". The amount of non-evaporable water is calculated as: "ω_{100} - ω_{1000}". This amount of non-evaporable water is compared to the theoretical minimum "0.24 * ω_{1000}" to reach a one hundred percent hydration of the cement compounds. In summary, the degree of hydration is calculated based on the following relationship:

$$\alpha = (\omega_{100} - \omega_{1000}) / (0.24 * \omega_{1000})$$

This approach was adapted from Copeland and Hayes (1953).

4.1.1 Results of Degree of Hydration. Specimens of neat cement paste of ten grams were prepared for two different water/cement ratios of 0.35 and 0.40. Upon mixing the specimens were enclosed in vacuum-sealed plastic bags and were cured in a water bath set at 26°C. For each combination of water/cement ratio and curing time, three replicate specimens were prepared and tested. The complete set of results is shown in Appendix A. The results obtained are presented below under separate subsections for each different water/cement ratio.

4.1.1.1 Specimens with water/cement ratio of 0.35. The results obtained with these specimens are summarized in Table 4.1 below:

Table 4.1

Effect of Curing Time on the Degree of Hydration Water/Cement Ratio of 0.35

Curing Time (days)	Degree of Hydration	
	Mean "α"	C.O.V.
3	0.5	0.002
7	0.53	0.013
14	0.64	0.018
28	0.65	0.01

The results presented in Table 4.1 are averages of three determinations for each curing time. These results indicate that the degree of hydration increases for increasing length of curing time; nevertheless, some scatter is present in these results since the rate of increase of the degree of hydration would be expected to reduce for longer curing times. In this manner, it would be expected that the increase in degree of hydration would be smaller from seven to fourteen days than the increase from three to seven days. This unexpected trend is believed to be the result of scatter or random errors in the determinations.

4.1.1.2 Specimens with water/cement ratio of 0.40. The results obtained with these specimens are summarized in Table 4.2 below:

Table 4.2

Effect of Curing Time on the Degree of Hydration Water/Cement Ratio of 0.40

Curing Time (days)	Degree of Hydration	
	Mean "α"	C.O.V.
3	0.57	0.003

Table 4.2

Cont.

7	0.59	0.007
14	0.68	0.002
28	0.7	0.009

The results presented in Table 4.2 are averages of three determinations for each curing time. These results indicate that the degree of hydration increases for increasing length of curing time; nevertheless, some scatter is present in these results since the rate of increase of the degree of hydration would be expected to reduce for longer curing times. In this manner, it would be expected that the increase in degree of hydration would be smaller from seven to fourteen days than the increase from three to seven days. This unexpected trend is believed to be the result of scatter or random errors in the determinations.

4.1.1.3 Comparison of degrees of hydration for 0.35 vs. 0.40 water/cement ratios. The degrees of hydration for the two water/cement ratio specimens are summarized together for comparison purposes in Table 4.3 below:

Table 4.3

Effect of Curing Time and Water/Cement Ratio on the Degree of Hydration

Curing Time (days)	Mean Degree of Hydration "α"	
	w/c of 0.35	w/c of 0.4
3	0.5	0.57
7	0.53	0.59
14	0.64	0.68

Table 4.3

Cont.

28	0.65	0.7

The results that are shown in Table 4.3 exhibit similar patterns. Furthermore, the specimens prepared for the higher water/cement ratio consistently show somewhat larger degrees of hydration at each curing period. This last behavior is expected since the larger the amount of water, more water is available to combine with the cement compounds and the porosity allowing the water to flow is also larger.

The results shown in Table 4.3 are plotted in Figure 4.1. This figure also includes the degree of hydration published by Tennis and Jennings (2000) for an average Type I cement. These values had been calculated based on the rate of hydration of individual cement components.

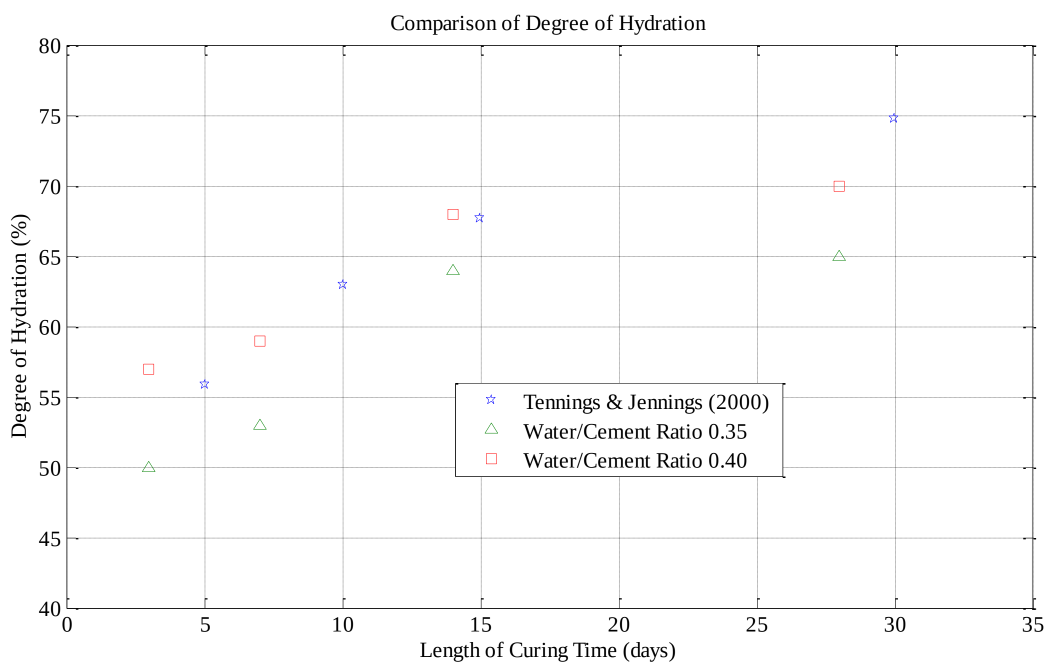

Figure 4.1. Comparison of Degrees of Hydration

The degrees of hydration shown in Figure 4.1 show a remarkable agreement for about fourteen days of curing. In general, the results for a water/cement ratio of 0.40 matches the trends indicated by the published degrees of hydration better than the results for a water/cement ratio of 0.35. The comparisons of these three sets of data do not indicate similar degrees of hydration after the longest curing period of twenty-eight days. There is not an obvious explanation for this discrepancy; nevertheless, it is possible that the longer the curing period, the non-evaporable water is held tighter and would thus require a harsher treatment of the specimen in the furnace to release this non-evaporable water.

4.2 Compressive Strength Results of Neat Cement Paste Specimens

The compressive strength of neat cement paste specimens was investigated using nominal 2 in x 2 in x 2 in cubes formed with neat cement paste for two different water/cement ratios of 0.35 and 0.40. A set of three specimens were prepared and cured for each of four different curing periods of three, seven, fourteen, and twenty-eight days. These results were complemented with several tests on cylindrical specimens of four inches in diameter and eight inches long. These cylindrical specimens afforded the possibility of documenting the elastic modulus in addition to the compressive strength.

The results obtained on these two types of specimens are discussed below under separate headings. Finally, towards the end of this chapter, the results obtained with these two techniques are compared.

4.2.1 Compressive strength of 2-inch cubes. The specimens prepared with a neat cement paste of water/cement ratio of 0.40 were allowed to set for twenty-four hours in the forming molds. After removal from the mold, the specimens were sealed in a vacuum bag and placed into a temperature controlled water bath (set at 26°C) for the specified time of curing (such as, a three day curing included one day in the mold and two additional days in the controlled temperature bath). Upon completion of the curing process, the specimens were tested. For one set of specimens, cured for seven days, the vacuum bag leaked and resulted in a set of specimens that behaved differently than the remaining set of specimens. These differences will be highlighted in the appropriate subsection below.

To avoid additional potential problems with leaks of the vacuum bags, the specimens prepared with a water/cement ratio of 0.35 were sealed in the vacuum bags, but the curing process was carried out with the specimens enclosed in a dry plastic box kept at room temperature.

For compression testing, the specimens were placed between two load platens of an MTS general purpose testing facility. A view of a specimen at the beginning of the load test is shown in Figure 4.2. The testing phase was performed in strain controlled mode, to allow for a better view of the specimen at the end of the loading phase; thus, allowing to observe the initiation and progression of the failure mechanism of the specimen.

The data acquisition system recorded elapsed time (seconds), load applied on the specimen (pounds) and platen displacement (micro-inches). A new set of data was recorded at 0.2 seconds intervals. These resulted in very large data files of nearly one thousand records. For the purposes of summarizing and presenting the data in this thesis, only one of every five or six records is actually reported in this thesis.

At the beginning of the test, the platen was brought to close proximity of the top of the specimen under manual control leaving a small gap between the platen and the specimen. At this point, the test system was switched to strain control and the test was initiated. The presence of the small gap above the specimen resulted in a load vs displacement curve nearly horizontal at first until the specimen started being loaded. This initial part of the load vs displacement was discarded and the record only includes the loading part; that is, the displacements presented start from the point when the specimen loading began.

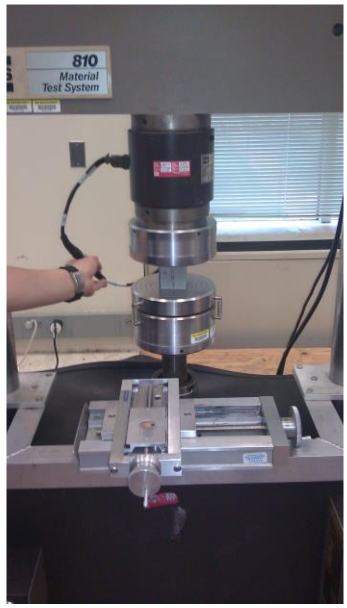

Figure 4.2. View of Specimen B.3 at the Beginning of the Testing Phase

4.2.1.1 Specimens with water/cement ratio of 0.35. The complete set of results is presented in Appendix B. In this appendix, the specimens are identified by the following designations:

1.) The three trials for three day curing: A.1, A.2, and A.3;

2.) The three trials for seven day curing: B.1, B.2, and B.3;

3.) The three trials for fourteen day curing: C.1, C.2, and C.3;

4.) The three trials for twenty-eight day curing: D.1, D.2, and D.3.

The data in Appendix B is presented in the same sequence listed above for increasing curing time. First, for each curing time, there is a table summarizing all the dimensions recorded in 0.001 inches using a caliper for the three trial specimens. Next is a table of numerical values recorded for load and displacement, and a figure showing the plot of load (lb.) versus the displacement of the platen (inch). For each curing time, the table and the plot corresponding to trial 1 are included first, and then trial 2 and last is trial 3.

At the end of all sets covering the four curing times there is a table summarizing average specimen's dimensions after curing, specimen's masses after curing, and the failure load identified as the maximum load applied on the specimen during the test.

ASTM standard C109 indicates that mortar cubes should be loaded in a controlled load mode with a loading rate from 200 to 400 pounds/second. In the present study, the tests were performed in strain-controlled mode. The resulting loadings rates achieved in these tests are summarized in Table 4.4.

Table 4.4

Average Loading Rates Applied on the Cubical Specimens with Water/Cement ratio of 0.35

Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)
A.1	507	B.1	514	C.1	525	D.1	525
A.2	494	B.2	479	C.2	519	D.2	529
A.3	485	B.3	427	C.3	473	D.3	522

The results shown in Table 4.4 indicate that the loading rates for this set of specimens were consistently larger by about 100 lb. /sec than the loading rates required by ASTM Standard C109. These larger loading rates could have resulted in somewhat larger compressive strength measurements due to the viscoelastic behavior of the neat paste specimens.

The densities of the specimens for the neat paste at a water/cement ratio of 0.35 are summarized in Table 4.5. The compressive strengths for these same specimens are presented in Table 4.6.

Table 4.5

Densities after Curing of the Cubical Specimens for Water/Cement Ratio of 0.35

Trial Number	Density of Specimen (Mg/m^3)			
	A	B	C	D
1	2.0523	2.0637	2.0468	2.0095
2	2.0445	2.0568	2.0458	2.0096
3	2.0464	2.0590	2.0475	2.0268
Average	2.0477	2.0598	2.0467	2.0153
Std. Deviation	0.0041	0.0035	0.0009	0.0100
C.O.V. (%)	0.199	0.171	0.042	0.494

Table 4.6

Stresses at Failure of the Cubical Specimens for Water/Cement Ratio of 0.35

Trial Number	Compressive Stress at Failure (MPa)			
	A	B	C	D
1	69.936	66.351	75.391	72.408
2	61.484	65.213	77.991	83.730
3	65.669	56.481	67.178	81.029
Average	65.696	62.682	73.520	79.056
Std. Deviation	4.226	5.400	5.644	5.913
C.O.V. (%)	6.432	8.615	7.677	7.480

The results presented in Tables 4.5 and 4.6 are also shown in graphical form in Figure 4.3 (a) and (b). In order to compare strength versus densities it is normally expected that higher densities would result in higher strengths. However, it is necessary to keep in mind that the densities reported in Table 4.5 include the mass of evaporable water in the specimen; thus, the data of density does not exactly reflect solid's density in the specimens.

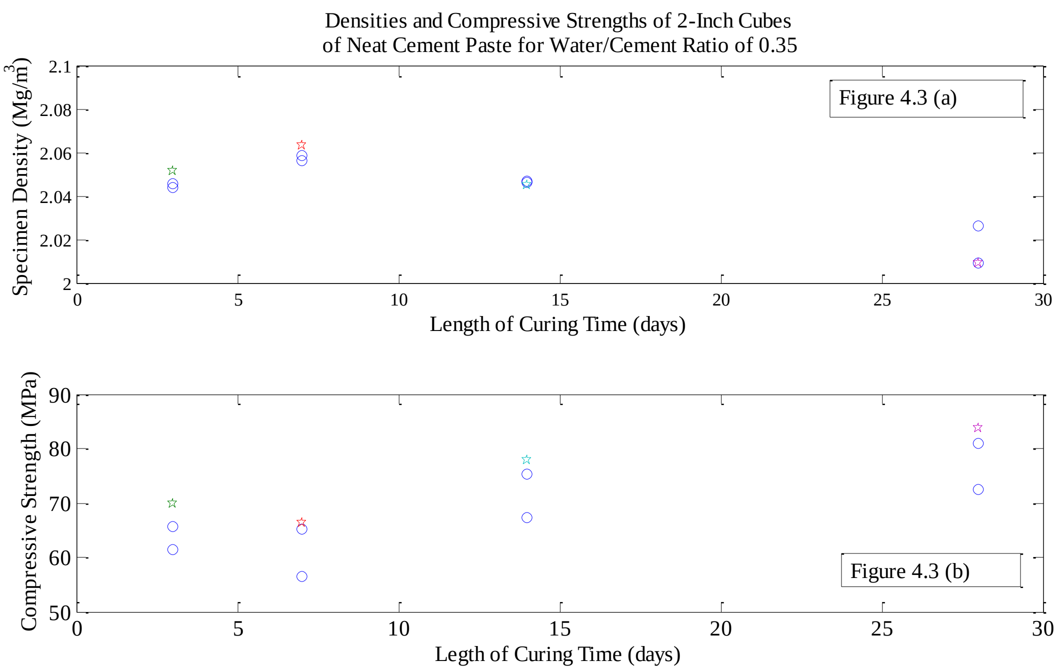

Figure 4.3 (a) and (b). Densities and Compressive Strengths of Cubes with w/c of 0.35

The results shown in Figure 4.3 (b) include a different symbol for the compressive strength of the specimen of each batch with the highest strength. For specimens cured for three days and twenty-eight days, the specimens with the lowest compressive strength coincide with the specimens with the lowest density; thus, for these two batches, this coincidence might indicate the presence of occluded air bubbles in the particular test specimen. The densities of the fourteen-day batch are remarkably similar for all specimens. For this batch, the highest compressive strength was obtained from the specimen with the lowest density. In a similar fashion, for the seven day batch, the specimen with the lowest density reached the second highest compressive strength for the batch which very nearly matched the top strength.

These considerations do not allow reaching a firm conclusion as to the source of variability observed in the batches. Nevertheless, irrespective of the cause of variability, it is expected that the measured compressive strength of poorly formed specimens would only decreased relative to the sought strength of perfectly formed specimens. Thus, from the point of view of providing a reference compressive strength to be matched with the macroscopic behavior from atomic-level simulations, it is probable reasonable to expect that a perfectly formed specimen used in the simulations would exhibit a compressive strength about the maximum compressive strengths measured in the experimental program for each batch. This assertion is believed to be appropriate since specimen imperfections such as: occluded air bubbles, micro-cracks formed during the curing process, different densities within the specimen, etc. would not be included in the macroscopic model to predict the cube compressive strength. In accordance to these considerations, the best estimates thus recommended are summarized in Table 4.7.

Table 4.7

Best Estimate of Compressive Strength of the Cubical Specimens for Water/Cement Ratio of 0.35

Curing Time (days)	Specimen Designation	Specimen Density (Mg/m^3)	Compressive Strength (MPa)
3	A.1	2.05	69.9
7	B.1	2.06	66.4
14	C.2	2.05	78.0
28	D.2	2.03	83.7

The trends exhibited by the estimates shown in Table 4.7 are consistent with the fact that an increase in curing time results in an increase of compressive strength. The only exception occurs for the results of seven day curing that do not follow this trend. There is not an obvious explanation for this fact, the only difference may lie in the lower loading rates applied to all the seven day specimens relative to the fourteen and twenty-eight day specimens. The conclusion is that perhaps the seven-day results should be excluded, or should not be attempted to simulate with the numerical simulation from the nano-level models.

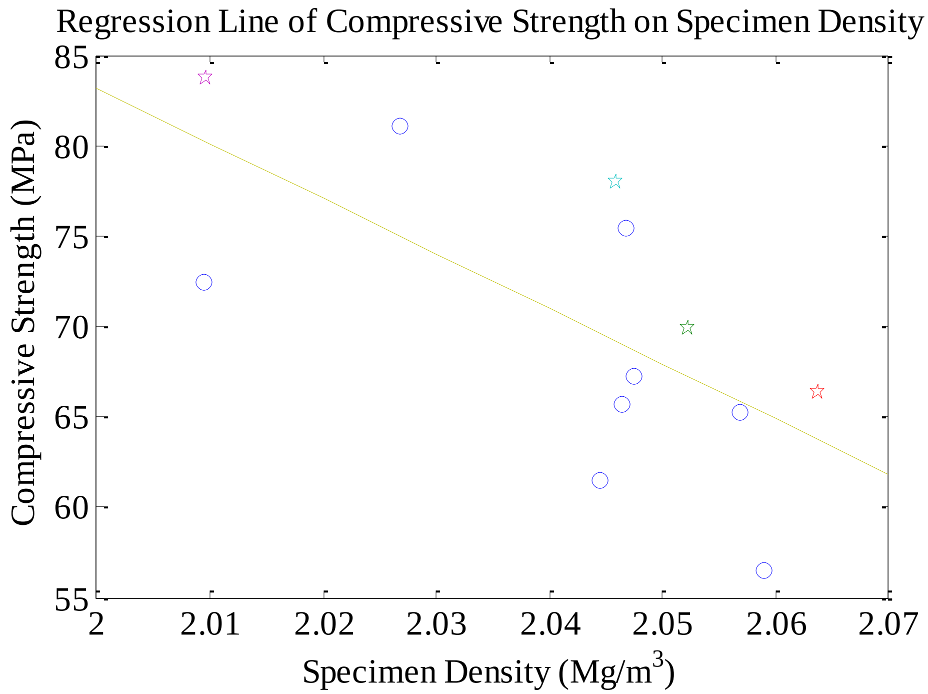

Figure 4.4. Regression Line for Density vs. Compressive Strength for w/c of 0.35

4.2.1.2 Specimens with water/cement ratio of 0.40. The complete set of results is presented in Appendix C. In this appendix, the specimens are identified by the following designations:

1.) The three trials for three day curing: E.1, E.2, and E.3;

2.) The three trials for seven day curing: F.1, F.2, and F.3;

3.) The three trials for fourteen day curing: G.1, G.2, and G.3;

4.) The three trials for twenty-eight day curing: H.1, H.2, and H.3.

The data in Appendix C is presented in the same sequence listed above for increasing curing time. First, for each curing time, there is a table summarizing all the dimensions recorded in 0.001 inches using a caliper for the three trial specimens. Next is a table of numerical values recorded for load and displacement, and a figure showing the plot of load (lb.) versus the displacement of the platen (inch). For each curing time, the table and the plot corresponding to trial 1 are included first, and then trial 2 and last is trial 3.

At the end of all sets, covering the four curing times, there is a table summarizing average specimen's dimensions after curing, specimen's masses after curing, and the failure load identified as the maximum load applied on the specimen during the test. It is worthwhile to point out those specimens F.1, F.2 and F.3 behaved differently than any other cube specimen tested; this difference was that these specimens gained mass during the curing process, while all the remaining specimens lost some mass.

ASTM standard C109 indicates that mortar cubes should be loaded in a load controlled mode with a loading rate from 200 to 400 pounds/second. In the present study, the tests were performed in strain-controlled mode. The resulting average loadings rates achieved in these tests are summarized in Table 4.8.

The results shown in Table 4.8 indicate that the loading rates for this set of specimens were very closer to the loading rates required by ASTM Standard C109. Perhaps the only exception is the loading rates applied on the fourteen-day specimens.

Table 4.8

Average Loading Rates Applied on the Cubical Specimens with Water/Cement Ratio of 0.40

Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)

Table 4.8

Cont.

E.1	400	F.1	454	G.1	460	H.1	412
E.2	400	F.2	427	G.2	455	H.2	418
E.3	418	F.3	389	G.3	456	H.3	422

The densities of the specimens for the neat paste at a water/cement ratio of 0.40 are summarized in Table 4.9. The compressive strengths for these same specimens are presented in Table 4.10.

Table 4.9

Densities after Curing of the Cubical Specimens for Water/Cement Ratio of 0.40

Trial Number	Density of Specimen (Mg/m^3)			
	E	F	G	H
1	1.9540	1.9955	2.2949	1.9576
2	1.9520	2.0030	2.2925	1.9382
3	1.9585	2.0071	2.3024	1.9508
Average	1.9548	2.0019	2.2966	1.9489
Std. Deviation	0.0031	0.0059	0.0052	0.0098
C.O.V. (%)	0.170	0.294	0.225	0.505

Table 4.10

Stresses at Failure of the Cubical Specimens for Water/Cement Ratio of 0.40

Trial Number	Compressive Stress at Failure (MPa)			
	E	F	G	H

Table 4.10

Cont.

1	45.232	55.684	59.824	51.083
2	45.173	47.911	58.783	57.885
3	41.904	53.114	55.932	58.036
Average	44.103	52.236	58.180	55.668
Std. Deviation	1.904	3.960	2.015	3.972
C.O.V. (%)	4.318	7.581	3.463	7.135

The results presented in Tables 4.9 and 4.10 are also shown in graphical form in Figure 4.5 (a) and (b). In order to compare strength versus densities it is normally expected that higher densities would result in higher strengths. However, it is necessary to keep in mind that the densities reported in Table 4.9 include the mass of evaporable water in the specimen; thus, the data of density does not exactly reflect solid's density in the specimen

The results shown in Figure 4.5 (b) include a different symbol for the compressive strength of the specimen of each batch with the highest compressive strength. For specimens cured for three days and twenty-eight days, the specimens with the lowest compressive strength coincide with the specimens with the lowest density; thus, for these two batches, this coincidence might indicate the presence of occluded air bubbles in the particular test specimen. The densities of the fourteen-day batch are remarkably similar for all specimens. For this batch, the highest compressive strength was obtained from the specimen with the lowest density. In a similar fashion, for the seven day batch, the specimen with the lowest density reached the second highest compressive strength for the batch which very nearly matched the top strength.

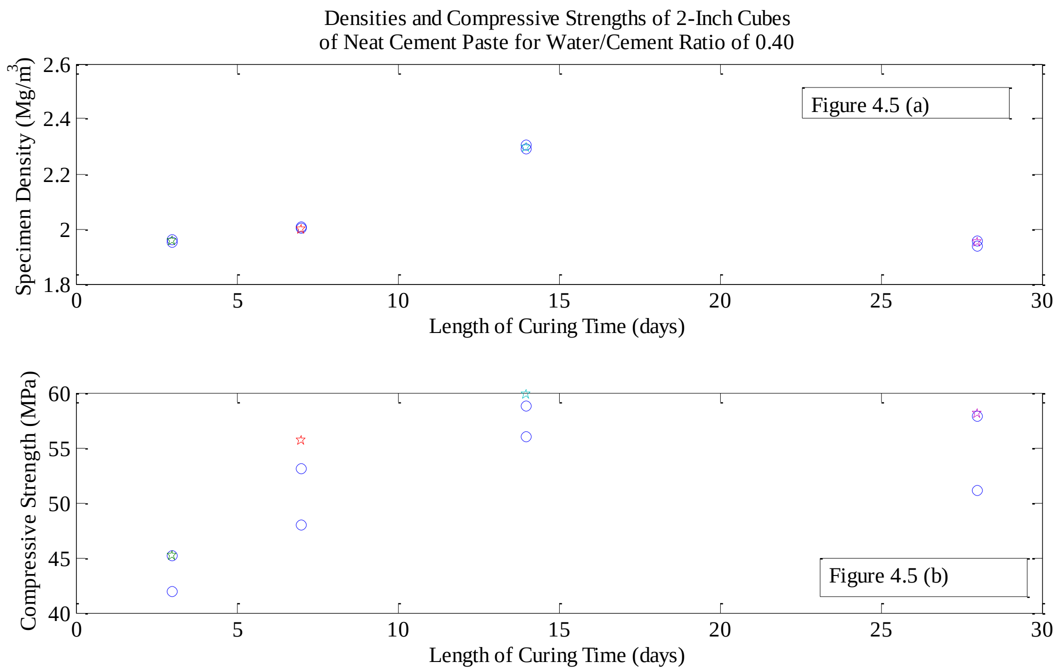

Figure 4.5 (a) and (b). Densities and Compressive Strengths of Cubes with w/c of 0.40

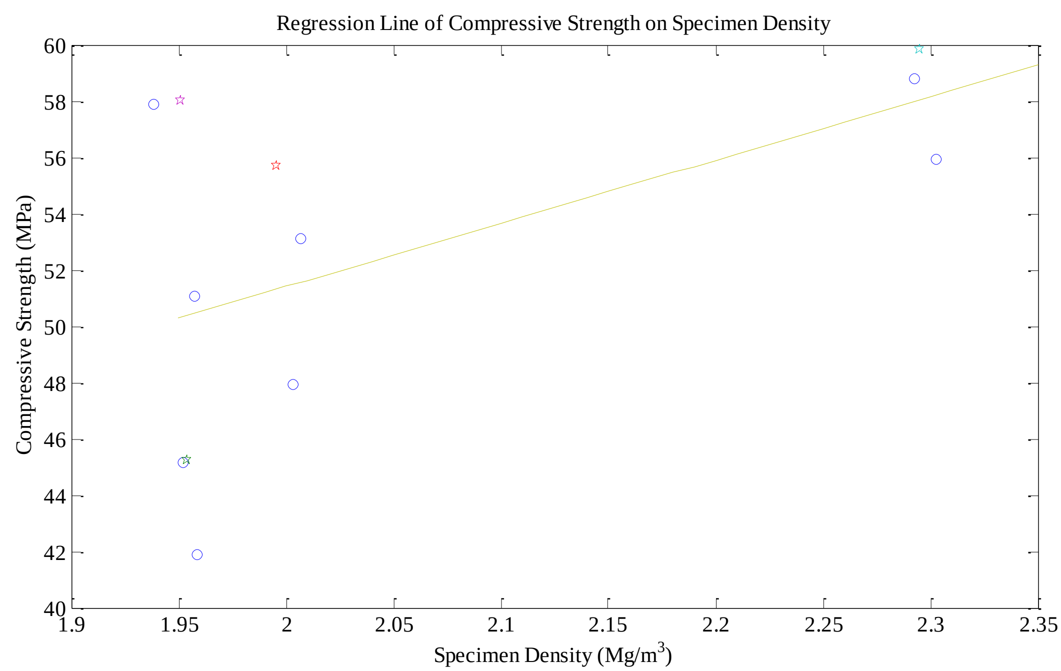

Figure 4.6. Regression Line for Density vs. Compressive Strength for w/c of 0.40

The regression line, for the four batches, of the compressive strength versus the density of the specimen is presented in Figure 4.6. The regression line has a positive slope of increasing compressive strength for increasing density of the specimen. At least part of this trend could be explained by the inclusion of evaporable water that affects differently the specimens of each batch. The contribution of occluded air bubbles in the specimens would be expected to be random and is probably not the reason behind the trend of the regression line. In a similar fashion, the presence of inhomogeneity’s within the specimens that could have caused stress concentrations during testing that would also be expected to be random in nature. For these batches of water/cement ratio of 0.40, all the test result cluster in a cloud of points with no indication of a trend. The only exception is for fourteen-day specimens (F series) that achieved significantly higher densities.

These considerations do not allow reaching a firm conclusion as to the source of variability observed in the batches. Nevertheless, irrespective of the cause of variability, it is expected that the measured compressive strength of poorly formed specimens would only decreased relative to the sought strength of perfectly formed specimens. Thus, from the point of view of providing a reference compressive strength to be matched with the macroscopic behavior from nano-level simulations, it is probable reasonable to expect that a perfectly formed specimen used in the simulations would exhibit a compressive strength about the maximum compressive strengths measured in the experimental program for each batch. This assertion is believed to be appropriate since specimen imperfections such as: occluded air bubbles, micro-cracks formed during the curing process, different densities within the specimen, etc. would not be included in the macroscopic model to predict the cube compressive strength. In accordance to these considerations, the best estimates thus recommended are summarized in Table 4.11.

Table 4.11

Best Estimate of Compressive Strength of the Cubical Specimens for Water/Cement Ratio of 0.40

Curing Time (days)	Specimen Designation	Specimen Density (Mg/m^3)	Compressive Strength (MPa)
3	E.1	1.95	45.2
7	F.1	2.00	55.7
14	G.1	2.29	59.8
28	H.3	1.96	58.0

The trends exhibited by the estimates shown in Table 4.11 are consistent with the fact that an increase in curing time results in an increase of compressive strength. The only exception occurs for the results of fourteen day (or twenty-eight) day curing that do not follow this trend. A plausible explanation could be attributed to poorly prepared specimens that also clearly achieved significantly different densities and perhaps the fourteen-day (or the twenty-eight day) results should be excluded, or should not be attempted to simulate with the numerical simulation from the nano-level models.

4.2.1.3 Comparison of compressive strengths for different water/cement ratios. The results discussed in the two previous subsections that were presented in Tables 4.7 and 4.11 are summarized and listed together in Table 4.12.

Table 4.12

Comparison of Test Results for Water/Cement Ratios of 0.35 and 0.40

Curing Time (days)	Specimen Density (Mg/m^3)		Compressive Strength (MPa)	
	Water/Cement Ratio 0.35	Water/Cement Ratio 0.40	Water/Cement Ratio 0.35	Water/Cement Ratio 0.40
3	2.05	1.95	69.9	45.2

Table 4.12

Cont.

7	2.06	2.00	66.4	55.7
14	2.05	2.29	78.0	59.8
28	2.03	1.96	83.7	58.0

The densities of the specimens decrease slightly, when the water/cement ratio increases. This pattern occurs for all the curing times with the exception of the specimens for fourteen day curing. In general, the densities of the specimens increase from about 3% to 5% when the water/cement ratio decreases from 0.40 to 0.35. The only exception is for the fourteen-day specimen, for which the density decreased by about 10% when the water/cement ratio decreased from 0.40 to 0.35.

This anomaly suggests that the specimen with a water/cement ratio of 0.40 and for fourteen day curing is probably not representative. Thus the data in Table 12 indicates that this specimen might not be a good candidate to try to predict the compressive strength from numerical modeling using numerical simulations from nano-level models.

The other property listed in Table 12 is the compressive strength that increases for decreasing water/cement ratios. The increases for the three day and twenty-eight day specimens range from 44% to 56%. The ratio for the fourteen-day specimen is questionable because the density anomaly discussed above. The ratio for the seven-day shows only an increase of 19%; thus, the low strength obtained for water/cement ratio of 0.35 after seven days appears to be also questionable.

In summary, based on these considerations, it is believed that the results for the following two cases should not be attempted for the simulation:

1.) Specimen cured for seven days for a water/cement ratio of 0.35; and

2.) Specimen cured for fourteen days for a water cement ratio of 0.40.

4.2.1.4 Compression testing failure progression. Some selected specimens, such as B.2 and B.3, were photographed using a high-speed camera during the last stages of testing. A view of specimen B.2 towards the end of the loading phase is shown in Figure 4.7. From this figure, it appears that failure was initiated at the left-lower corner of the specimen, perhaps due to the presence of a defect, occluded air bubble, etc. The picture shows that some material of the specimen had spalled. The vertical crack initiated at this point, then, continued propagation vertically in the direction of the major principal stress within the central part of the specimen.

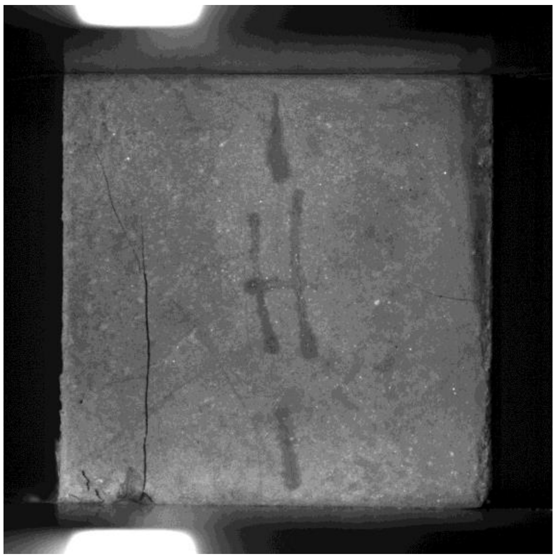

Figure 4.7. Failure Pattern of Cubical Specimen B.2

At about the mid-point of the specimen, the crack branches off towards the left-upper corner of the specimen. As the crack propagates upwards, the major principal stress in the top of the specimen rotates due to the presence of friction at the specimen-platen contact and this is the direction shown of crack propagation. These considerations suggest that the presence of micro-cracks, occluded air bubbles, defects, etc. have played a role in the decrease of compressive strength for some specimens in the batches.

4.2.2 Compressive testing of cylindrical specimens. A complete set of nominal four-inch diameter and eight-inch long cylinders were prepared to be tested for compressive strength and to document the elastic modulus of the neat cement paste for a water/cement ratio of 0.35. The tests were performed in a Forney testing device with a manual data acquisition requiring the use of two operators. The tests were performed following ASTM standard C469.

The steps included testing the first cylinder in the batch as a reference to determine the compressive strength. The second and third cylinders were loaded twice to forty percent of the strength found in the reference cylinder. The first loading is intended to aid the setting of the specimen and the platens, and the second loading is the loading used to calculate the modulus of elasticity. After these two loadings, the specimens were loaded to failure.

Due to unforeseen circumstances, the three day cured batch (A.1, A.2, and A.3) was only used to determine the compressive strength. The seven day cured batch (B.1, B.2, and B.3) was never tested at the appropriate time of curing and no data was collected for these specimens.

4.2.2.1 Compressive strength results of cylindrical specimens. The results of compressive strength determinations are summarized in Table 4.13. It is worthwhile to notice the large coefficients of variation “COV”, around twenty percent, for the fourteen-day cured batch (C.1, C.2, and C.3) and the twenty-eight day cured batch (D.1, D.2, and D.3). These large values of COV’s place some uncertainty about the homogeneity of these two batches of specimens.

For the fourteen day cured batch, specimen C.1 is the reference specimen and exhibited the largest compressive strength of the batch. For the twenty-eight day cured batch, specimen D.1 is the reference specimen and exhibited the lowest compressive strength of the batch. The result of this disparity is that the maximum stress to be reached in the first and second loadings for the elastic modulus measurements is significantly different.

Table 4.13

Compressive Strength of Cylinders for Water/Cement Ratio of 0.35

Curing Time (days)	Cylinder Designation	Compressive Strength (MPa)	Average Strength (MPa)	COV (%)	Stress/Limit Modulus Tests (MPa)
3	A.1	38.295	41.203	8.42	N/A
	A.2	40.270			
	A.3	45.043			
7	N/A	-	-	-	-
14	C.1	61.557	52.011	19.80	-
	C.2	53.383			24.623
	C.3	41.093			24.623
28	D.1	39.853	50.574	23.52	-
	D.2	63.368			15.941
	D.3	48.500			15.941

4.2.2.2 Elastic modulus determinations on cylindrical specimens. The records of elastic modulus measurements on the two specimens for each of the two batches are presented in Appendix D. For each determination, a numerical table is presented first and the stress-strain plot for the two loading sequences is presented next. The results calculated based on ASTM C469 are summarized in Table 4.14.

The results indicate a modulus of elasticity similar for both batches, although the twenty-eight day cured batch shows a somewhat higher modulus. This trend is opposite of the compressive strength for these two batches: average compressive strength of the fourteen day cured batch is larger than the average for the twenty-eight day cured batch. Part of this conflict could be explained based on the significantly lower maximum stress reached in the elastic modulus determinations which for the twenty eight day cured batch is only sixty five of the fourteen day cured batch.

Table 4.14

Elastic Modulus of Cylinders for Water/Cement Ratio of 0.35

Curing Time (days)	Cylinder Designation	Compressive Strength (MPa)	Stress/Limit Modulus Tests (MPa)	Reloading Elastic Modulus (MPa)	Batch Average (MPa)
3	N/A	-	-	-	-
7	N/A	-	-	-	-
14	C.1	61.6	-	Reference	-
	C.2	53.4	24.6	16,620.1	17,446.8
	C.3	41.1	24.6	18,273.5	
28	D.1	39.9	-	Reference	
	D.2	63.4	15.9	17,057.6	17,804.1
	D.3	48.5	15.9	18,550.5	

4.2.3 Comparison of cube vs cylinder compressive strength. The compressive strengths determinations on specimens of neat cement paste for a water/cement ratio of 0.35 are summarized in Table 4.15. It is clear that the compressive strengths measured on cubes are significantly higher than the strengths measured on cylinders. For comparison purposes the averages and the maximum for all these batches are also summarized in Table 4.16.

The average strength difference is approximately 25 MPa higher for cubes than for cylinders. The differences between maximum strengths recorded for each batch are also an average of 20 MPa higher for cubes. This pattern is very consistent and, thus, cannot be ignored. The reasons for these differences are not obvious and are probably the results of several effects. The main reasons have to be found in two main potential effects.

The first one is the differences in the state of stress in the cubical specimens, which is significantly different than in the cylinders. In this sense, the confining stresses induced by the friction specimen platens are much more significant in altering the state of stress within the cubes. This effect would result in inducing higher compressive strengths for the cubical specimens.

The second effect is related to the size of the specimens. The cylindrical specimens entail much larger volume of neat cement paste, and, thus, the forming and consolidation of specimens can be expected to be more difficult. In other words, the inclusion of air bubbles, defects and in-homogeneities can be expected to be more significant.

Table 4.15

Comparison of Compressive Strength Measured on Cubes and Cylinders for Water/Cement Ratio of 0.35

Curing Time (days)	Specimen Designation	2-Inch-Side Cubes			4-Inch Diameter Cylindrical Specimens		
		Strength (MPa)	Average (MPa)	COV (%)	Strength (MPa)	Average (MPa)	COV (%)
3	A.1	69.9	65.7	6.4	38.3	41.2	8.4
	A.2	61.5			40.3		
	A.3	65.7			45.0		
7	B.1	66.4	62.7	8.6	-	-	-
	B.2	65.2			-		
	B.3	56.5			-		

Table 4.15

Cont.

14	C.1	75.4	73.5	7.7	61.6	52.0	19.8
	C.2	78.0			53.4		
	C.3	67.2			41.1		
28	D.1	72.4	79.1	7.5	39.9	50.6	23.5
	D.2	83.7			63.4		
	D.3	81.0			48.5		

These effects are probably the reason behind the much larger COV's of the cylindrical in the fourteen and twenty-eight day cured batches.

Table 4.16

Summary of Compressive Strength Differences between Cubes and Cylinders

Curing Length (days)	Batch Averages (MPa)			Batch Maximum (MPa)		
	Cubes	Cylinders	Differences	Cubes	Cylinders	Differences
3	65.7	41.2	24.5	69.9	45.0	24.9
7	62.7	-	-	66.4	-	-
14	73.5	52.0	21.5	78.0	61.6	16.4
28	79.1	50.6	28.5	83.7	63.4	20.3

In order to decrease the influence of the second effect, it is believed that rather than using averages for the batches, it would be better to use the largest determination for each batch. If this estimate of strength is selected, it would eliminate or reduce significantly the effects of in-homogeneities, occluded air bubbles, etc. on the compressive strength. With this estimate, the compressive strength of cylinders is still about 20 MPa lower than the compressive strengths recorded on cubes.

Consistent with these observations, the estimates of compressive strength of neat cement paste specimens for a water/cement ratio of 0.35 are the maximum batch values recorded for the cylindrical specimens. That is the following:

1.) For three day curing 45.0 MPa;

2.) For fourteen day curing 61.6 MPa; and

3.) For twenty eight day curing 63.4 MPa.

In order to provide some confirmation of these compressive properties, the technical literature had been searched and some results published on neat paste and on mortar have been plotted together with the results of this study and are shown in Figure 4.8. The results presented cannot be taken as validation of the results of the present study because some significant differences existed in the materials, the specimen shapes, and the curing processes. In the following paragraphs, these differences are highlighted.

The compressive strengths of neat cement paste specimens with a water/cement ratio of 0.35 are shown in the top of Figure 4.8. The large difference found earlier can now be clearly seen in this graph. These are compared to several results published. The first one is denoted in the figure as “Boumiz et al” (Boumiz et al, 1996). These results were obtained on mortar specimens with a water/cement ratio of 0.387, the cement was high performance cement, and the specimens tested were prisms 4 cm x 4 cm x 16 cm. These results are fairly close to the compressive strengths measured on cylinders in the present study. The second set of results presented in this figure is for a neat paste of a type I cement, for a water/cement of 0.37 and determined on cubic specimens of 150 mm side (six inches) (Principallo, el al, 2003). These results are much closer to the results of the present study on 2-inch cubes. In this fashion, the results of the literature tend to also indicate the large difference between the strengths measured in cubes and cylinders.

The lower part of Figure 4.8 shows results of elastic modulus on cylindrical or prismatic specimens. The results labeled “Princigallo et al” were obtained on neat paste specimens for a water/cement ratio of 0.37, and the specimens were prismatic 50 mm x 50 mm x 150 mm (2 in x 2 in x 6 in) (Princigallo et al, 2003). These results are fairly close to the trends shown by the results of the present study. The results labeled “Boumiz et al #1” were obtained using acoustic emission on neat paste specimens of high performance cement for a water/cement ratio of 0.35. These results seam to overshoot the modulus of the present study. The results labeled “Boumiz #2” were obtained on mortar mixes for a water/cement ratio of 0.387 and mortar prisms. These results are significantly larger than the moduli documented in the present study.

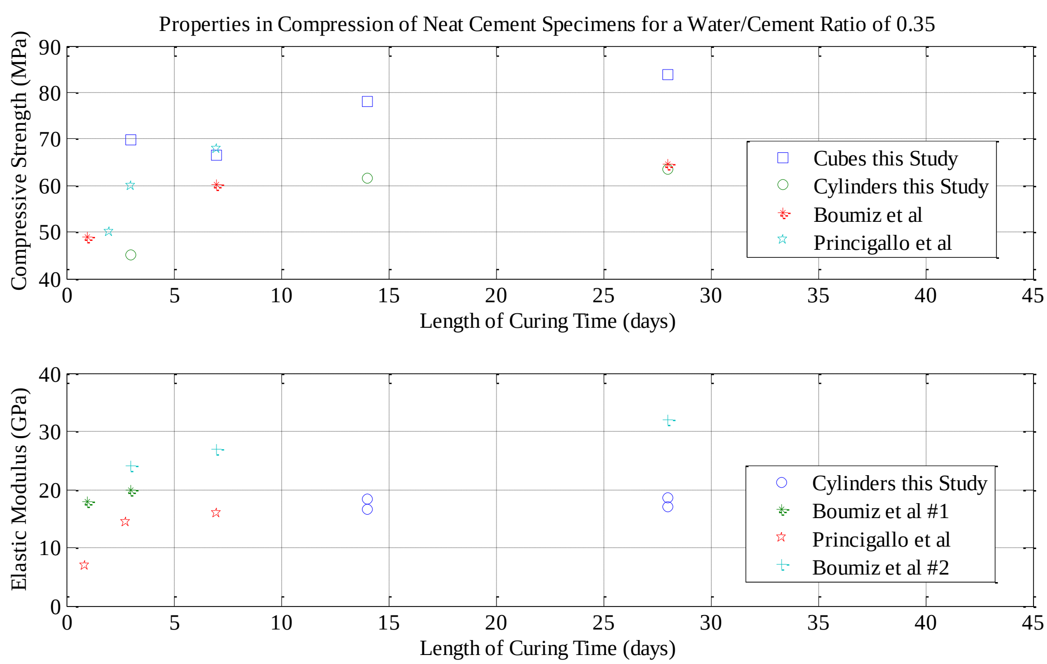

Figure 4.8. Properties in Compression for a w/c of 0.35

Although the differences between test materials, conditions and specimens used do not allow a validation of the results of the present study. In general, the results in the literature support the findings on compressive strength of neat paste cement specimens of the present study.

4.3 Tensile Strength Results of Neat Cement Paste Specimens

The tensile strength of neat cement paste specimens was investigated using flexure tests and direct tension tests. For each test technique, the tensile strength was evaluated for two different water/cement ratios of 0.35 and 0.40 and different curing times. A set of three specimens were prepared and cured for each of four different curing periods of three, seven, fourteen, and twenty-eight days.

The results obtained using these two techniques are discussed below under separate headings. Finally, towards the end of the present chapter, the results obtained with these two techniques are compared.

4.3.1 Flexural strength of neat cement paste specimens. The specimens were prepared in prisms of nominal size 1.6 in x 1.6 in x 6.3 in. The specimens prepared with a neat cement paste with a water/cement ratio of 0.40 were allowed to set for twenty-four hours in the forming molds. After removal from the mold, the specimens were sealed in a vacuum bag and placed into a temperature controlled water bath (set at 26°C) for the specified time of curing (such as, a three day curing included one day in the mold and two additional days in the controlled temperature bath). Upon completion of the curing process, the specimens were tested. For one set of specimens, cured for seven days, the vacuum bag leaked and resulted in a set of specimens that behaved differently than the remaining set of specimens. These differences will be highlighted in the appropriate subsection below.

In order to avoid additional potential problems with leaks of the vacuum bags, the specimens prepared with a water/cement ratio of 0.35 were sealed in the vacuum bags, but the curing process was carried out with the specimens enclosed in a dry plastic box kept at room temperature.

For the flexural strength testing, the specimens were loaded in a center point jig between two load platens of an MTS general purpose testing facility. A view of a specimen at the beginning of the load test is shown in Figure 4.9. The testing phase was performed in strain controlled mode, to allow for a better view of the specimen at the end of the loading phase; thus, allowing to observe the initiation and progression of the failure mechanism in the specimen.

The data acquisition system recorded elapsed time (seconds), load applied on the specimen (pounds) and platen displacement (micro-inches). A new set of data was recorded at 0.1 seconds intervals. These resulted in very large data files of nearly one thousand records. For the purposes of summarizing and presenting the data in this thesis, only one of every five or six records is actually reported in this thesis.

At the beginning of the test, the central loading yoke was brought to close proximity of the top of the specimen under manual control leaving a small gap between the yoke and the specimen. At this point, the test system was switched to strain control and the test was initiated.

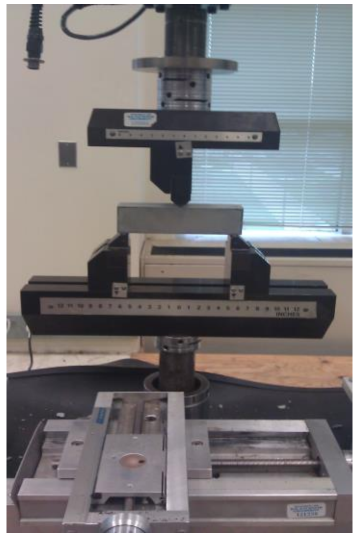

Figure 4.9. Test Set Up for the Flexure Test

The presence of the small gap above the specimen resulted in a load-vs-displacement curve nearly horizontal at first until the specimen started being loaded. This initial part of the load-vs-displacement was discarded and the record only includes the loading part; that is, the displacements presented start from the point when the specimen loading began.

4.3.1.1 Flexure test results for water/cement ratio of 0.35. The complete set of results is presented in Appendix E. In this appendix, the specimens are identified by the following designations:

1.) The three trials for three day curing: A.1, A.2, and A.3;

2.) The three trials for seven day curing: B.1, B.2, and B.3;

3.) The three trials for fourteen day curing: C.1, C.2, and C.3;

4.) The three trials for twenty-eight day curing: D.1, D.2, and D.3.

The data in Appendix E is presented in the same sequence listed above for increasing curing time. First, for each curing time, there is a table summarizing all the dimensions recorded in 0.001 inches using a caliper for the three trial specimens. Next is a table of numerical values recorded for load and displacement, and a figure showing the plot of load (lb.) versus the displacement of the loading yoke (inch). For each curing time, the table and the plot corresponding to trial 1 are included first, trial 2 is next, and last is trial 3.

At the end of all sets covering the four curing times there is a table summarizing average specimen's dimensions after curing, specimen's masses before and after curing, and the failure load identified as the maximum load applied on the specimen during the test.

ASTM standard C348 indicates that mortar prisms should be loaded in a controlled load mode with a loading rate from 575 to 625 pounds/minute. In the present study, the tests were performed in strain-controlled mode. The resulting loadings rates achieved in these tests are summarized in Table 4.17.

Table 4.17

Average Loading Rates Applied on the Flexural Prisms with Water/Cement Ratio of 0.35

Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)
A.1	902	B.1	824	C.1	812	D.1	646
A.2	897	B.2	845	C.2	874	D.2	821
A.3	904	B.3	855	C.3	1002	D.3	614

The results shown in Table 4.17 indicate that the loading rates for this set of specimens were consistently larger by about 200-300 lb. /minute than the loading rates required by ASTM Standard D-348. These larger loading rates could have resulted in somewhat larger flexural strength measurements due to the viscoelastic behavior of the neat paste specimens.

The densities of the specimens for the neat paste at a water/cement ratio of 0.35 are summarized in Table 4.18. The flexural strengths for these same specimens are presented in Table 4.19.

Table 4.18

Densities after Curing of the Flexural Prisms with Water/Cement Ratio of 0.35

Trial Number	Density of Specimen (Mg/m^3)			
	A	B	C	D
1	1.9897	2.0324	2.0345	2.0274
2	2.0311	2.0473	2.0453	2.0144
3	2.0569	2.0460	1.9960	2.0123
Average	2.0259	2.0419	2.0253	2.0180
Std. Deviation	0.0339	0.0083	0.0259	0.0082
C.O.V. (%)	1.673	0.404	1.280	0.405

Table 4.19

Tensile Flexural Strength of the Flexural Prisms with Water/Cement Ratio of 0.35

Trial Number	Tensile Flexural Strength (MPa)			
	A	B	C	D
1	2.7444	2.6649	2.0174	1.5692
2	3.2787	5.1929	4.0763	1.1740
3	3.2493	4.8545	4.6574	1.6653
Average	3.0909	4.2371	3.5837	1.4695
Std. Deviation	0.300	1.372	1.387	0.260
C.O.V. (%)	9.717	32.387	38.708	17.718

The results presented in Tables 4.18 and 4.19 are also shown in graphical form in Figure 4.10 (a) and (b). The results indicate a noticeable scatter in the densities of the specimens. In an attempt to remove this effect, there is in these two figures, a set of results that were selected based on the specimens having very similar densities. These specimen densities are highlighted by an asterisk in Figure 4.10 (a). The same group of specimens is also highlighted with an asterisk in Figure 4.10 (b). The pattern indicated in this Figure 4.10 (b) is one of decreasing flexural strength with length of curing time.

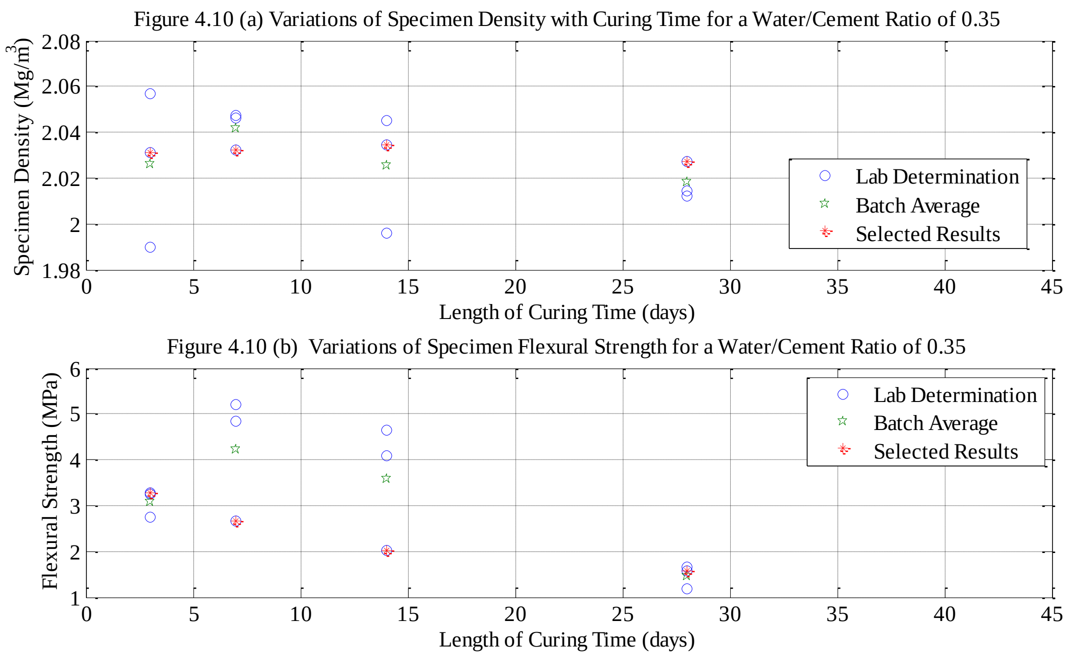

Figure 4.10 (a) and (b). Variations of Density and Flexure Strength for w/c of 0.35

The patterns indicated by these results clearly show that the specimens cured under sealed conditions underwent “autogenous shrinkage” induced by the loss of pore water due to the progression of the reaction with the cement particles. This effect has been well documented in the literature; nevertheless, there is much less of a consensus of the effects of this shrinkage. Some authors suggest that this shrinkage only comes into play when the reaction products are restrained by the skeleton of aggregate (Li, Y., et al, 2012) and then is responsible for crack initiation and growth. In fact the results of the present study indicate that crack initiation and growth will occur in specimens of neat cement paste induced by autogenous shrinkage.

The main reasons of why this shrinkage will create crack initiation and growth in neat cement paste specimens has to be found in the fact that the water loss by reaction progress will not be uniformly distributed through the mass of the specimen and thus will create strains in the cement paste around the areas where the drying will take place.

4.3.1.2 Specimens for water/cement ratio of 0.40. The complete set of results is presented in Appendix F. In this appendix, the specimens are identified by the following designations:

1.) The three trials for three day curing: E.1, E.2, and E.3;

2.) The three trials for seven day curing: F.1, F.2, and F.3;

3.) The three trials for fourteen day curing: G.1, G.2, and G.3;

4.) The three trials for twenty-eight day curing: H.1, H.2, and H.3.

The data in Appendix F is presented in the same sequence listed above for increasing curing time. First, for each curing time, there is a table summarizing all the dimensions recorded in 0.001 inches using a caliper for the three trial specimens. Next is a table of numerical values recorded for load and displacement, and a figure showing the plot of load (lb.) versus the displacement of the platen (inch). For each curing time, the table and the plot corresponding to trial 1 included first, then trial 2, and last is trial 3.

At the end of all sets, covering the four curing times, there is a table summarizing average specimen's dimensions after curing, specimen's masses after curing, and the failure load identified as the maximum load applied on the specimen during the test. It is worthwhile to point out that specimens F.1, F.2 and F.3 (to a lesser extent specimens E.1, E.2, and E.3 also gained mass during the curing process) behaved differently than any other prismatic flexural specimen tested; this difference was that these specimens gained mass during the curing process, while all the remaining specimens lost some mass.

ASTM standard C348 indicates that mortar prisms should be loaded in a controlled load mode with a loading rate from 575 to 625 pounds/minute. In the present study, the tests were performed in strain-controlled mode. The resulting loadings rates achieved in these tests are summarized in Table 4.20.

Table 4.20

Average Loading Rates Applied on the Flexural Prisms with Water/Cement Ratio of 0.40

Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)
E.1	858	F.1	726	G.1	971	H.1	506
E.2	846	F.2	743	G.2	941	H.2	484
E.3	681	F.3	712	G.3	891	H.3	621

The results shown in Table 4.20 indicate that the loading rates for this set of specimens were consistently larger than the loading rates required by ASTM Standard C348. Perhaps the only exceptions are the loading rates applied on the twenty-eight day specimens.

The densities of the specimens for the neat paste at a water/cement ratio of 0.40 are summarized in Table 4.21. The compressive strengths for these same specimens are presented in Table 4.22.

Table 4.21

Densities after Curing of the Flexural Prisms with Water/Cement Ratio of 0.40

Trial Number	Density of Specimen (Mg/m^3)

Table 4.21

Cont.

	E	F	G	H
1	1.9684	1.9864	2.2487	1.9432
2	1.9532	1.9629	2.2550	1.9448
3	1.9674	1.9739	2.2617	1.9447
Average	1.9630	1.9744	2.2551	1.9442
Std. Deviation	0.0085	0.0118	0.0065	0.0008
C.O.V. (%)	0.433	0.596	0.290	0.044

Table 4.22

Tensile Flexural Strength of the Flexural Prisms with Water/Cement Ratio of 0.40

Trial Number	Tensile Flexural Strength (MPa)			
	E	F	G	H
1	2.0214	2.1165	2.6753	1.3567
2	2.3821	1.7530	2.7083	1.6257
3	3.0262	1.6882	3.9792	2.1422
Average	2.4765	1.8526	3.1208	1.7082
Std. Deviation	0.5090	0.2308	0.7435	0.3992
C.O.V. (%)	20.554	12.461	23.822	23.369

The results presented in Tables 4.21 and 4.22 are also shown in graphical form in Figure 4.11 (a) and (b). The main purpose of this figure is to allow a simultaneous comparison of specimen density and flexural strength. The densities of the specimens G.1, G.2, and G.3 are much larger than the remaining specimens. In order to afford a high definition of the remaining batches, the densities of these fourteen-day specimens were not included in Figure 4.11 (a).

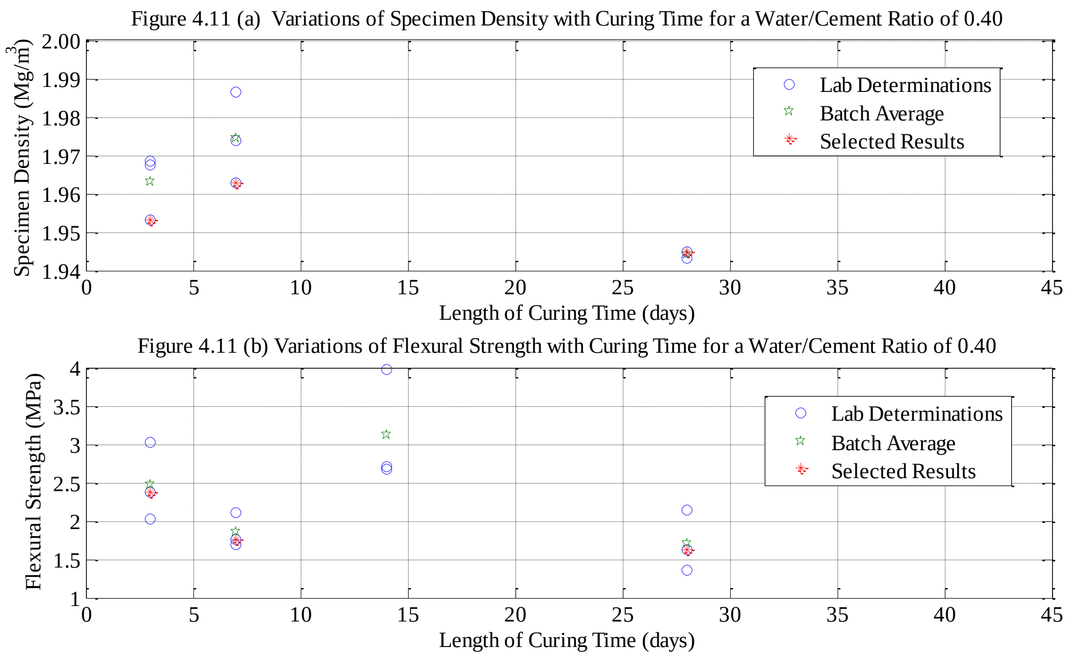

Figure 4.11(a) and (b). Variations of Density and Flexure Strength for w/c of 0.40

The laboratory measurements shown in Figures 4.11 (a) and (b), exhibit a significant amount of variability. An important source of this scatter in the flexural strength could be attributed to the differences in densities of the different specimens. To eliminate this effect, the specimens that reached the closer densities, were selected and are marked in these two figures with an asterisk. Thus the selected results include the specimens with the closest densities, one each from the three batches. These specimens are the following: E.2, F.2, and H.2.

Although some specimens in the batches cured for three and seven days experienced some mass gain during the curing period, the two specimens E.2 and F.2 experienced the lowest mass gains of these batches during the curing period. The specimens from batch E cured three days did not show consistent mass increases; the specimens from batch F cured seven days all experienced significant mass gains of the order of 7 and 11 grams, the mass gain of specimen F.2

was only 2.89 grams. In this manner, it appears that the results selected were not dramatically changed by whatever exposure to the bath water that might have occurred during the curing time.

The pattern of change of flexural strength with curing time is a decrease of the flexural strength with increasing curing time. This pattern is not consistent with that of a material gaining strength but with the fact that the specimens were cured in a sealed container and autogenous shrinkage was taking place during the curing period. This shrinkage induced the formation or propagation of existing micro-cracks that resulted in the reduced flexural strength observed. These results cannot be matched with molecular simulations unless the formation or propagation of cracks has been incorporated into the model; thus, at this time there is no recommendation of the values to be selected for flexural strength at different curing times.

4.3.1.3 Comparison of flexural strengths for different water/cement ratios. The results discussed in the two previous subsections that were presented in Tables 4.18 and 4.19 as well as Tables 4.21 and 4.22 are summarized and listed together in Table 4.23. The results presented in this last table are the results of the selected specimen highlighted in Figures 4.10 and 4.11. These specimens for each water/cement ratio had been selected by picking the specimens with the most consistent densities.

Table 4.23

Comparison of Densities and Flexural Strengths for the Selected Specimens for Water/Cement Ratios of 0.35 and 0.40

Curing Time (days)	Specimen Density (Mg/m^3)		Flexural Strength (MPa)	
	Water/Cement Ratio 0.35	Water/Cement Ratio 0.40	Water/Cement Ratio 0.35	Water/Cement Ratio 0.40
3	2.0311	1.9532	3.2787	2.3821
7	2.0324	1.9629	2.6649	1.7530

Table 4.23

Cont.

14	2.0345	-	2.0174	-
28	2.0274	1.9448	1.5692	1.6257

The densities of the prismatic specimens decrease slightly, when the water/cement ratio increases from 0.35 to 0.40. This pattern occurs for all the curing times with the exception of the specimens for fourteen day curing that showed a much larger density than those listed in Table 4.23. In general, the densities of the specimens increase from about 4% when the water/cement ratio decreases from 0.40 to 0.35.

The other property listed in Table 4.23 is the flexural strength that increases for decreasing water/cement ratios. The increases for the three day and seven day specimens are about 40% for the 0.35 water/cement ratio specimens. The ratio for twenty-eight day specimens is nearly the same for both water/cement ratios. The ratio of flexural strength lost from the three day curing strength to the twenty eight day curing strength is 52% of the original three day curing strength for the specimens with a water/cement ratio of 0.35, and only about 32% for the specimens of water/cement ratio of 0.40. This effect is consistent with the technical literature that suggests that the autogenous shrinkage decreases with increasing water/cement ratio (Schlangen et al., 2004; Li et al, 2012).

In summary, based on these considerations, it is believed that the results of tensile flexural strength show consistently that the sealed curing used in this test program resulted in the formation or propagation of micro-cracks in the neat cement for the two cases of water/cement ratios of 0.35 and 0.40. These results would be appropriate to be matched with results from molecular simulations unless the model incorporates the simulation of cracks such as the models proposed by Schlangen et al (2004).

4.3.1.4 Failure Progression in Specimens Undergoing Flexural Strength Testing. Some selected specimens, such as F.1, F.2 and F.3, were photographed using a high-speed camera during the last stages of loading to document the onset/progression of the failure.

A view of specimens F.1, F.2, and F.3 towards the end of the loading phase are shown in Figures 4.12, 4.13, and 4.14, respectively. These three specimens had very similar densities of 1.986, 1.963, and 1.974 Mg/m^3. These densities were the average density of each specimen. These do not provide any information about in-homogeneities within the specimen.

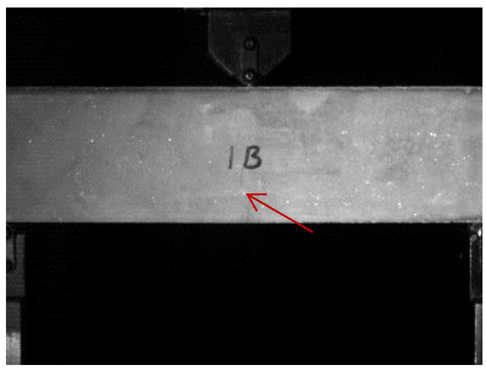

Figure 4.12. Failure Mechanisms for Specimen F.1

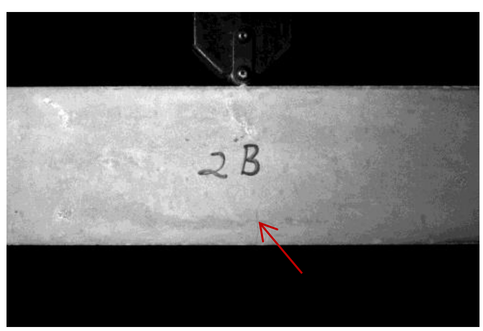

Figure 4.13. Failure Mechanisms for Specimen F.2

Specimen F.1 experiences a crack initiated right below the loading yoke and propagating vertically. This is the expected mode of failure, it is befitting that the flexural strength of this specimen was 2.12 MPa. This flexural strength was the higher for the three specimens. The failure of the other two specimens were quite different, for specimen F.2 the crack is initiated offset of the point below the point of application of the loading yoke, and for specimen F.3 there

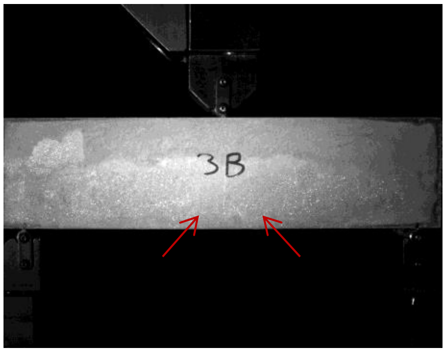

Figure 4.14. Failure Mechanisms for Specimen F.3

are two cracks both offset from the point right below the loading yoke that then converge towards the point of application of the loading yoke. These two specimens F.2 and F.3 resisted flexural strengths of 1.75 and 1.69 MPa, respectively. The implication of this finding is that there were weaker zones within the specimen than the part of the specimen right under the point of application of the loading yoke.

A puzzling fact is the difference in behavior of the four different batches based on the average density of the specimens. In this fashion, the largest coefficient of variation was 0.6% corresponding to the seven-day batch (F.1, F.2, and F.3). For the other batches the coefficients of variation of the average density of the specimen were 0.4%, 0.3%, and 0.04% for the E, G, and H specimens respectively. The trend is completely reversed for the flexural strength, where the lowest coefficient of variation was 12% for the F specimens, while for the remaining batches the coefficients of variation were 21%, 24%, and 33% for the E, G, and H specimens respectively. This fact highlights the importance of homogeneous specimens (with similar average densities) to reduce the large variability of the flexural strength results.

4.3.2 Tensile strength in direct tension tests. The specimens were prepared in briquettes in the gang molds specified by AASHTO T-132-87. The specimens prepared with a neat cement paste with a water/cement ratio of 0.40 were allowed to set for twenty-four hours in the forming molds. After removal from the mold, the specimens were sealed in a vacuum bag and placed into a temperature controlled water bath (set at 26°C) for the specified time of curing (such as, a three day curing included one day in the mold and two additional days in the controlled temperature bath). Upon completion of the curing process, the specimens were tested. For one set of specimens, cured for seven days, the vacuum bag leaked and resulted in a set of specimens that behaved differently than the remaining set of specimens. These differences will be highlighted in the appropriate subsection below.

To avoid additional potential problems with leaks of the vacuum bags, the specimens prepared with a water/cement ratio of 0.35 were sealed in the vacuum bags, but the curing process was carried out with the specimens enclosed in a dry plastic box kept at room temperature.

For the direct tension strength testing, the specimens were placed in the clips specified by the standard. These were mounted on the table and on the actuator of an MTS general purpose testing facility. A view of a specimen mounted in the clips is shown in Figure 4.15. The testing phase was performed in strain controlled mode, to allow for a better view of the specimen at the end of the loading phase; thus, allowing to observe the initiation and progression of the failure mechanism in the specimen.

The data acquisition system recorded elapsed time (seconds), load applied on the specimen (pounds) and platen displacement (micro-inches). A new set of data was recorded at 0.1 seconds intervals. These resulted in very large data files of nearly one thousand records. For the purposes of summarizing and presenting the data in this thesis, only one of every five or six records is actually reported in this thesis.

Figure 4.15. Test Set Up for the Direct Tension Test

At the beginning of the test, the briquettes were placed snugly in the clips. At this point, the test system was switched to strain control and the test was initiated. The presence of the small gap above the specimen resulted in a load-vs-displacement curve nearly horizontal at first until the specimen started being loaded. This initial part of the load-vs-displacement was discarded and the record only includes the loading part; that is, the displacements presented start from the point when the specimen loading began.

4.3.2.1 Direct tension test results for water/cement ratio of 0.35. The complete set of results is presented in Appendix G. In this appendix, the specimens are identified by the following designations:

1.) The three trials for three day curing: A.1, A.2, and A.3;

2.) The three trials for seven day curing: B.1, B.2, and B.3;

3.) The three trials for fourteen day curing: C.1, C.2, and C.3;

4.) The three trials for twenty-eight day curing: D.1, D.2, and D.3.

The data in Appendix G is presented in the same sequence listed above for increasing curing time. First there is a table summarizing average specimen’s dimensions after curing, specimen's masses before and after curing, and the failure load identified as the maximum load applied on the specimen during the test. Then, for each test specimen there is a table of numerical values recorded for load and displacement, and a figure showing the plot of load (kip) versus the displacement of the clips (inch). For each curing time, the table and the plot corresponding to trial 1 included first, then trial 2, and last is trial 3.

At the end of all sets covering the four curing times ASHTO standard T-132 indicates that briquettes should be loaded in a controlled load mode with a loading rate from 575 to 625 pounds/minute. In the present study, the tests were performed in strain-controlled mode. The resulting loadings rates achieved in these tests are summarized in Table 4.24.

Table 4.24

Average Loading Rates Applied on Direct Tension Briquettes with Water/Cement Ratio of 0.35

Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)
A.1	5,764	B.1	5,882	C.1	6,236	D.1	3,420
A.2	5,609	B.2	6,119	C.2	6,037	D.2	3,913
A.3	10,436	B.3	5,942	C.3	6,342	D.3	3,742

The results shown in Table 4.24 indicate that the loading rates for this set of specimens were consistently much larger, from seven to ten times larger than the loading rates of about 600 lb. /min. required by ASHTO Standard T-132. These much larger loading rates could have resulted in significantly larger direct tension strength measurements due to the viscoelastic behavior of the neat paste specimens.

Due to the necking of the briquettes and the fact that only the densities in the necking area would be relevant, it was decided to only compare specimen masses after curing with the hope that these differences might also be reflected in the necking area. The masses of the briquettes of neat cement paste for a water/cement ratio of 0.35 are summarized in Table 4.25. The direct tension strengths for these same specimens are presented in Table 4.26.

Table 4.25

Masses after Curing of the Briquettes for Water/Cement Ratio of 0.35

Trial Number	Mass of Briquette after Curing (gram)			
	A	B	C	D
1	135.72	134.09	131.85	128.25
2	133.69	132.99	130.23	130.75
3	134.46	129.61	132.55	129.91
Average	134.62	132.23	131.54	129.64
Std. Deviation	1.02	2.33	1.19	1.27
C.O.V. (%)	0.76	1.77	0.90	0.98

It is important to notice that there is a trend of decreasing briquette mass for increasing curing time. This fact could lead to assume that the decreases in tensile strength that will be described later could be due to this decrease of specimen density for increasing curing time. It is also worthwhile to notice that the C.O.V. is very small for each batch on the order of one percent.

Table 4.26

Direct Tension Strength of Briquettes with Water/Cement Ratio of 0.35

Trial Number	Direct Tensile Strength (MPa)			
	A	B	C	D

Table 4.26

Cont.

1	2.16	2.14	2.22	1.08
2	1.77	2.21	1.74	0.94
3	2.05	2.11	2.22	0.89
Average	1.99	2.15	2.06	0.97
Std. Deviation	0.20	0.05	0.28	0.10
C.O.V. (%)	10.11	2.33	13.61	9.99

The first striking observation is that the C.O.V.'s of the tensile strength are much larger than the observed C.O.V. for the masses of the specimen as described above and shown in Table 4.25. A possible explanation is that the performance of the clips/briquette introduced this variability. The second observation is whether the lowest masses of the D batch could be responsible for the lower tensile strength of this batch.

The results presented in Tables 4.25 and 4.26 are also shown in graphical form in Figure 4.16 (a) and (b). The results indicate a noticeable trend of decreasing mass of the briquettes for increasing curing time. In an attempt to remove this effect, there is, in these two figures, a set of results for seven, fourteen and twenty eight curing days, that were selected based on the specimens having very similar masses around 130 grams. These specimen masses are highlighted by a triangular shape around the data point in Figure 4.16 (a). The same group of specimens is also highlighted with a triangular shape in Figure 4.16 (b). The group of briquettes includes the three lowest mass briquettes. The pattern indicated in this Figure 4.16 (b) is one of decreasing flexural strength with length of curing time, from 2.1 MPa at seven days, to 1.75 MPa at fourteen days, and about 1.1 MPa at twenty-eight days.

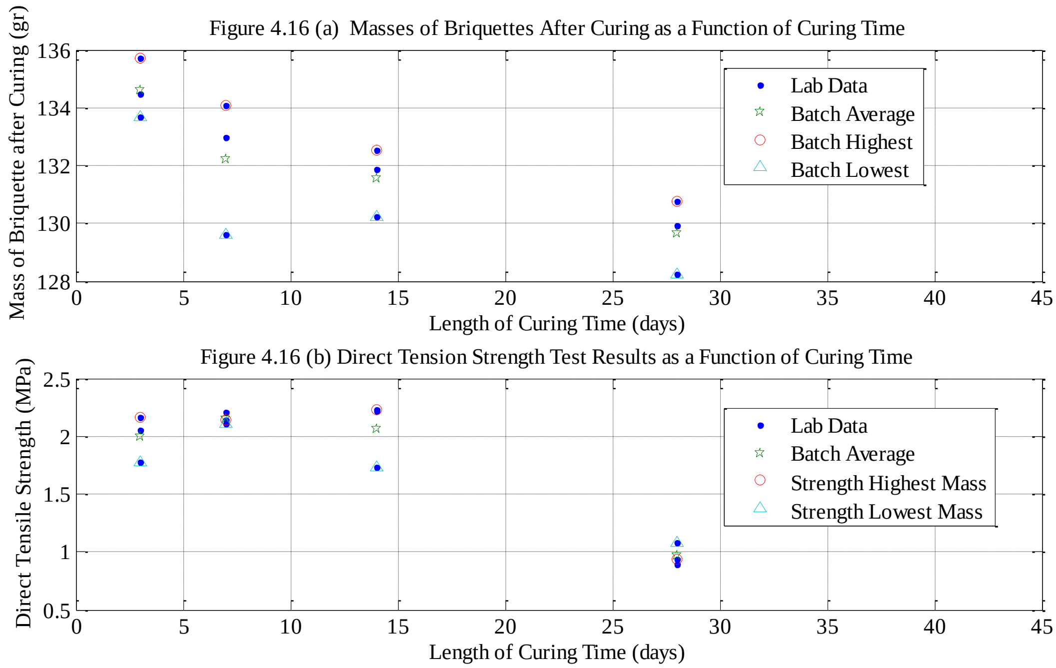

Figure 4.16 (a) and (b). Masses and Direct Tensile Strength for w/c 0.35

If we assume that the mass of the specimen is representative of the density at the neck of the briquette, then, the patterns indicated by these results show that the specimens cured under sealed conditions underwent “autogenous shrinkage” induced by the loss of pore water due to the progression of the reaction with the cement particles.

The main reasons of why this shrinkage will create crack initiation and growth in neat cement paste specimens has to be found in the fact that the water loss by reaction progress will not be uniformly distributed through the mass of the specimen and thus will create strains in the cement paste around the areas where the drying will take place. This differential shrinkage is responsible for initiation/propagation of cracks in the gel of the reaction products.

4.3.2.2 Direct tension test results for a water/cement ratio of 0.40. The complete set of results is presented in Appendix H. In this appendix, the briquette specimens are identified by the following designations:

1.) The three trials for three day curing: E.1, E.2, and E.3;

2.) The three trials for seven day curing: F.1, F.2, and F.3;

3.) The three trials for fourteen day curing: G.1, G.2, and G.3;

4.) The three trials for twenty-eight day curing: H.1, H.2, and H.3.

The data in Appendix H is presented in the same sequence listed above for increasing curing time. First, there is a table summarizing average specimen's dimensions after curing, specimen's masses before and after curing, and the failure load identified as the maximum load applied on the specimen during the test. This table is followed by a table of numerical values recorded for load and displacement, and a figure showing the plot of load (kip) versus the displacement of the platen (inch). For each curing time, the table and the plot corresponding to trial 1 included first, then trial 2, and last is trial 3.

It is worthwhile to point out that none of these briquettes gained mass during the curing process. The implication is that the specimens were not flooded in the curing tank. Thus all the briquette specimens lost some amounts of mass during the curing process.

ASHTO standard T-132 indicates that mortar briquettes should be loaded in a controlled load mode with a loading rate from 575 to 625 pounds/minute. In the present study, the tests were performed in strain-controlled mode. The resulting loadings rates achieved in these tests are summarized in Table 4.27.

Table 4.27

Average Loading Rates Applied on Direct Tension Briquettes with Water/Cement Ratio of 0.40

Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)	Specimen	Loading Rate (lb./sec)
E.1	2,569	F.1	1,948	G.1	3,318	H.1	1,851
E.2	3,125	F.2	1,810	G.2	1,610	H.2	1,628

Table 4.27

Cont.

E.3	1,515	F.3	3,251	G.3	3,318	H.3	2,036

The results shown in Table 4.27 indicate that the loading rates for this set of briquettes were consistently larger than the loading rate of 600 lb. /min required by ASHTO Standard T-132. The rates are about three to four times those required by the standard. These results are sensibly lower than the loading rates of the briquettes for a water/cement ratio of 0.35. Some effect of over-estimation of tensile strength might be present due to the viscoelastic effects, although, perhaps not as important as for the briquettes of water/cement ratio of 0.35.

The masses of the briquette specimens of neat cement paste for a water/cement ratio of 0.40 are summarized in Table 4.28. The direct tensile strengths for these same specimens are presented in Table 4.29.

Table 4.28

Masses after Curing of the Briquettes for Water/Cement Ratio of 0.40

Trial Number	Mass of Briquette after Curing (gram)			
	E	F	G	H
1	104.26	115.00	119.92	114.35
2	117.49	113.65	118.35	114.28
3	120.57	109.74	104.53	118.50
Average	114.11	112.80	114.27	115.71
Std. Deviation	8.67	2.73	8.47	2.42
C.O.V. (%)	7.59	2.42	7.41	2.09

Table 4.29

Direct Tension Strength of Briquettes with Water/Cement Ratio of 0.40

Trial Number	Direct Tensile Strength (MPa)			
	E	F	G	H
1	1.76	1.63	1.53	1.11
2	1.09	0.86	1.07	0.75
3	0.63	0.72	0.97	0.66
Average	1.16	1.07	1.19	0.84
Std. Deviation	0.56	0.49	0.30	0.24
C.O.V. (%)	48.66	45.97	24.96	28.66

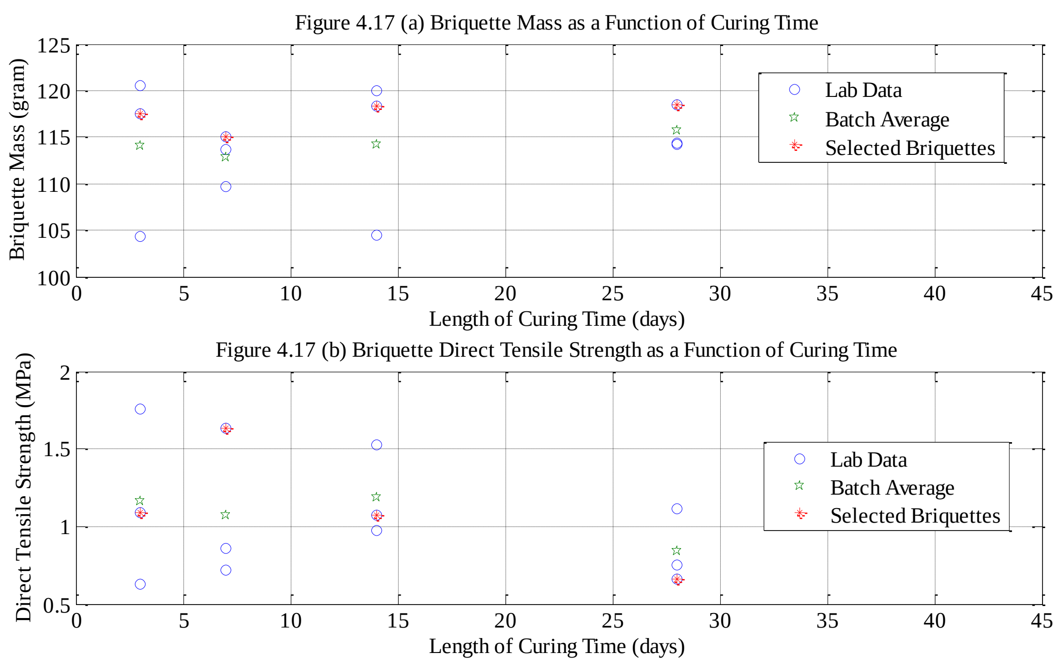

Figure 4.17 (a) and (b). Masses and Direct Tensile Strength for w/c 0.40

The very large coefficients of variation "C.O.V." of the strength results are not conducive to place much conviction on the patterns or trends that might be apparent. Direct tension is a difficult test to ensure proper performance, and these results show this concern. Nevertheless, the results presented in Tables 4.28 and 4.29 are also shown in graphical form in Figure 4.17 (a) and (b). The main purpose of this figure is to allow a simultaneous visual comparison of briquette mass and direct tensile strength.

Assuming that the mass of the briquette is representative of the density in the neck area of the briquette, then, several briquettes have been selected trying to have a group with small variability of the mass. These specimens are shown in Figure 4.16 (a) and are labeled selected briquettes. The direct tensile strength of this group of briquettes is also highlighted in Figure 4.16 (b) and these are also labeled selected briquettes. The pattern that these exhibit is an initial increase of strength from three day curing to seven day curing. Then there is a consistent drop from seven to fourteen and from fourteen to twenty eight day curing. This pattern also would indicate that autogenous shrinkage caused cracks/propagated cracks in the gel resulting from the hydration reaction of the cement particles. Avery important implication is that modeling the behavior of these materials would require including a micro-crack formation/propagation model at several different scales such as HYMOSTRUC (Schlangen et al., 2004).

4.3.2.3 Comparison of direct tensile strengths for different water/cement ratios. The results discussed in the two previous subsections that were presented in Tables 4.25 and 4.26 as well as Tables 4.28 and 4.29 are summarized and listed together in Table 4.30. The results presented in this last table are the results of the selected specimen highlighted in Figures 4.16 and 4.17. These specimens for each water/cement ratio had been selected by picking the briquettes with the most consistent masses.

Table 4.30

Comparisons of Masses and Direct Tensile Strength for Selected Briquettes for Water/Cement Ratios of 0.35 and 0.40

Curing Time (days)	Briquette Mass (gram)		Direct Tensile Strength (MPa)	
	Water/Cement Ratio 0.35	Water/Cement Ratio 0.40	Water/Cement Ratio 0.35	Water/Cement Ratio 0.40
3	-	117.5	-	1.09
7	129.6	115.0	2.11	1.63
14	130.2	118.4	1.74	1.07
28	128.2	118.5	1.08	0.66

The masses of the briquette specimens decrease slightly, when the water/cement ratio increases from 0.35 to 0.40. The other property listed in Table 4.30 is the direct tensile strength that increases for decreasing water/cement ratios. Both sets of direct tensile strength consistently decrease from seven day curing to twenty-eight day curing. This effect is consistent with the technical literature that suggests that the autogenous shrinkage that affects differently the neat cement paste for different water/cement ratios (Schlangen et al., 2004; Li et al, 2012).

In summary, based on these considerations, it is believed that the results of direct tensile strength show consistently that the sealed curing used in this test program resulted in the formation or propagation of micro-cracks in the neat cement for the two cases of water/cement ratios of 0.35 and 0.40. These results would not be appropriate to be matched with results from molecular simulations alone unless the model incorporates the simulation of cracks such as the models proposed by Schlangen et al (2004).

4.3.2.4 Failure progression in direct tension strength testing. Some selected briquettes, such as F.1, F.2 and F.3, were photographed using a high-speed camera during the last stages of loading to document the onset/progression of failure.

Three photographs of briquette F.1 are shown in Figures 4.18, 4.19, and 4.20. These are views of the briquette at several different stages of the failure process.

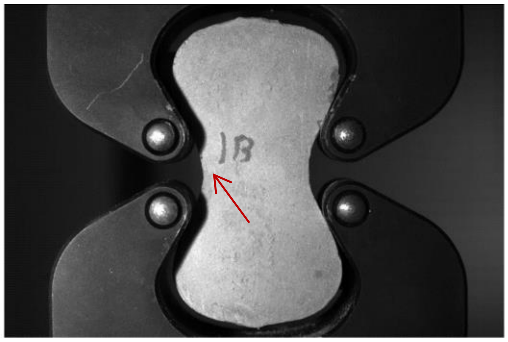

Figure 4.18. View of Briquette F.1 at the Initiation of Failure

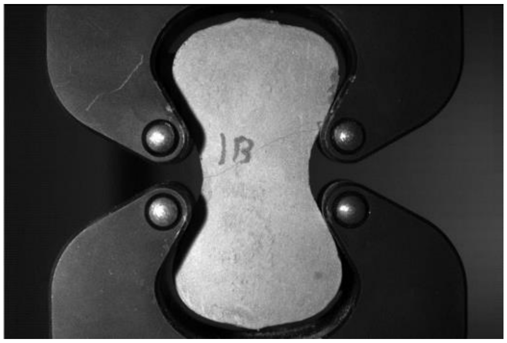

Figure 4.19. View of Briquette F.1 with the Crack Propagated through the Briquette

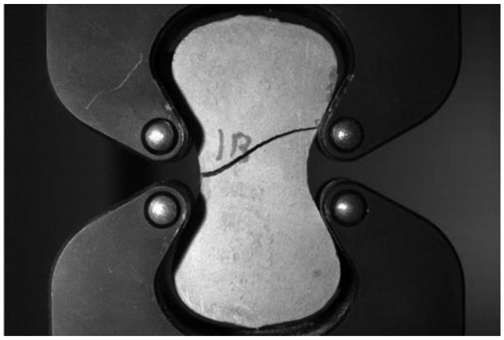

Figure 4.20. View of Briquette F.1 at the End of the Test

In Figure 4.18 the crack initiated on the left side of the neck and propagates through the lower part of the B label on the briquette. From this view, it is not clear whether the crack extends to the opposite side of the briquette. The next view is shown in Figure 4.19; now the crack is clearly visible through the whole briquette and extends to the upper clip on the right hand side of the briquette. This view of the briquette suggests that stress concentrations at the contact with the upper clip might have caused the propagation of the crack. The last view of the briquette in Figure 4.20 shows a view towards the end of the process, this view shows larger deformations of the left side of the briquette. This last view might show some evidence of miss-alignment of the displacements of the two clips. This fact agrees also with the view of Figure 4.18, which appears to show that the crack initiated on the left hand side of the briquette. This fact would imply the presence of stress concentrations that could be much higher than the tensile strength calculated for this briquette.

Three photographs of briquette F.2 are shown in Figures 4.21, 4.22, and 4.23. These are selected views of the briquette at several different stages of the failure process.

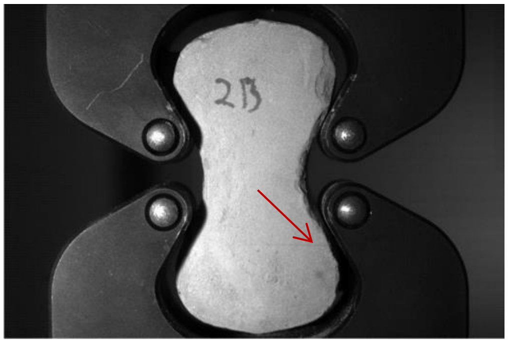

Figure 4.21. View of Briquette F.2 at the Initiation of Failure

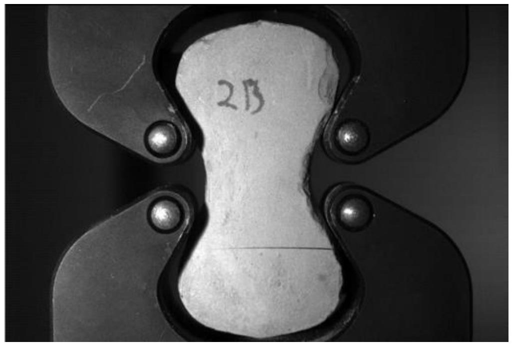

Figure 4.22. View of Briquette F.2 with the Crack Propagated through the Briquette

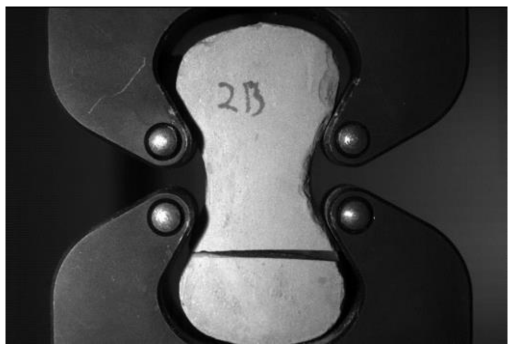

Figure 4.23. View of Briquette F.2 at the End of the Test

In Figure 4.21 the crack initiates on the right hand side of the briquette just below the lower clip. The crack is visible on the right hand side and shows an extent to about the middle of the briquette. There is no indication that the crack extends to the left had side of the briquette. In Figure 4.22, the crack is more visible on the right hand side of the briquette, but still does not extend to the opposite left side of the briquette. The last view of this briquette is shown in Figure 4.23, now the crack has propagated through the whole briquette, but still shows that the crack opening on the right had side of the briquette is significantly larger than on the opposite side. The failure of this briquette shows that some miss-alignment of clip displacement did actually occur. The failure of this briquette illustrates also quite eloquently the presence of in-homogeneities within the briquette, since the crack did not occur in the necking area of the briquette.

Three photographs of briquette F.3 are shown in Figures 4.24, 4.25, and 4.26. These are selected views of the briquette at several different stages of the failure process. The crack initiation is shown in Figure 4.24, although it is blurry, it appears that the crack initiates through the whole section of the necking area. In Figure 4.25, the crack clearly extends through the necking area of the specimen, however, it appears that the crack opening is somewhat larger on the left hand side of the briquette, and narrows down towards the right had side. Figure 4.26 supports the same impression, where the crack opening is clearly larger on the left side of the briquette. This fact is one of the main concerns with direct tension testing; it is nearly impossible to achieve a perfect alignment of the displacements of the clips. Furthermore, this is also hindered by in-homogeneities in the briquettes having one side more complaint than the other; this results in specimens that strain differently on different sides of the briquette.

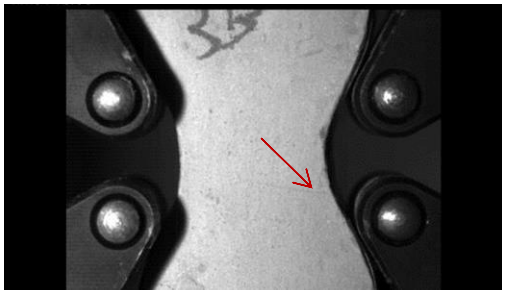

Figure 4.24. View of Briquette F.3 at the Initiation of Failure

Figure 4.25. View of Briquette F.3 with the Crack Propagated through the Briquette

Figure 4.26. View of Briquette F.3 at the End of the Test

4.3.3 Comparisons of flexural and direct tensile strengths. The results of the test program that were described earlier and were listed in Table 4.23, and Table 4.30 are laid side by side in the following Table 4.31.

Table 4.31

Comparisons of Flexural and Direct Tensile Strength of Selected Specimens for Water/Cement Ratios of 0.35 and 0.40

Curing Time (days)	Flexural Strength (MPa)		Direct Tensile Strength (MPa)	
	Water/Cement Ratio 0.35	Water/Cement Ratio 0.40	Water/Cement Ratio 0.35	Water/Cement Ratio 0.40
3	3.28	2.38	-	1.09
7	2.66	1.75	2.11	1.63
14	2.02	-	1.74	1.07
28	1.57	1.63	1.08	0.66

The results shown in Table 4.31 are not a complete set of test results, but rather the selected group of specimens chosen to be of similar density/mass. The flexural strength results indicate somewhat larger tensile strength than the direct tensile strength. Both sets of results for each water/cement ratio support the fact that the tensile strength decreases for increasing curing time. This finding is attributed to the sealed curing that was performed on all the specimens for the present test program. For sealed curing the hydration reaction robs the interstitial water in the pores of the cement gel. The loss of pore water results in an increase of the capillary tension in the pores. This increase in capillary tension causes autogenous shrinkage, and to accommodate this shrinkage the gel cracks or existing cracks extent. The increase of the micro-cracks results in the loss of tensile strength for increasing curing time.

The nature of hydrating cement paste has been compared to a complex composite material (Ghebrab & Soroushian, 2010) with multiple phases at micro and nano scales. These authors describe this composite material in the following paragraph:

> "It is heterogeneous at micro-scale, where capillary pores, large CH crystals and shrinkage microcracks are distributed randomly. The presence of these micro-defects produces stress concentrations which weaken the strength and stiffness of the material"

This structure of the neat cement paste has contributed to the progressive weakening of the material with the increase of curing time that is reflected in Table 4.31. We could not find in the literature published data on the effect of autogenous shrinkage on the strength and stiffness of the paste with curing time.

The common wisdom is that cement paste cracks only in the presence of sand or aggregate, but it would not crack if the skeleton of aggregate would not be available. This is a simplistic assessment that views the neat cement paste as a homogeneous continuum, when in fact is a collection of different particles of different properties. Perhaps one of the more relevant might be the platelets of calcium hydroxide which play a role very similar to the aggregate in concrete.

Only partial data is available documenting tensile strength for specific hydration levels. The results published for a ninety percent hydration (De Schutter & Taerwe, 1996) show flexural strength of a CEM I of 2.52 MPa while the direct tensile strength is only 2.1 MPa. These results are in the same ballpark as the results in Table 4.31. The specimens for their study were cured in a moist room, so the autogenous shrinkage did not interfere. The data published by Padevet and Zobal (2011) show tensile strengths for a CEM I of 2.2 MPa for a water/cement ratio of 0.3 and 1.9 MPa for a water cement ratio of 0.40. In summary the data summarized in Table 4.31 is reasonable and the trends that it indicates are grounded in sound material considerations.

4.4 Microscopic Observation of Failure Planes

Selected specimens were subjected to examination in an optical microscope. One of the main reasons was to confirm whether shrinkage cracks caused by the autogeneous shrinkage might be visible in the failure planes of the specimen. The beams and briquettes used in flexure and direct tension were the specimens selected. These types of specimen had shown a decrease in strength for an increase of curing time, thus, were the better candidates to be checked. In this regard, the beams A.3 and D.1 were selected. The beam A.3 was cured for three days and the beam D.1 were cured for twenty-eight days; the respective flexural strength decreases from 3.25 MPa for A.3 to about 1.5 MPa for beam D.1.

The failure plane for beam D.1 did not yield any indication of shrinkage cracks that could be seen in the optimal microscope at the highest resolution available. Furthermore, this plane did show indications of air voids/bubbles but at very low frequency. On the contrary, the failure plane for beam A.3, did exhibit a large number of air voids/bubbles. A microscopic view of this failure plane at a low magnification factor is shown in Figure 4.27.

Figure 4.27. Microscopic View at Magnification Factor of 8x of the Failure Plane for Beam A.3

In this figure, the right hand surface is the top of the beam where the load was applied. This view covers a section of the failure plane of 12,460 μm by 18,721 μm. In this view there is a large number of air voids ranging from 1,818 μm to 984 μm and 192 μm. Adding up the areas of all these voids, the sum represents about 1.87% of the total area of the section observed. This percentage is representative for other areas observed in this failure plane. Although not evident to the naked eye at this magnification, there are a number of cracks present in this failure plane. Some of the cracks observed are shown in Figures 4.28 through 4.30.

The cracks observed in these figures show an opening of about 7 μm and they all have an association with some of the air voids/bubbles present in this failure plane. The indication being that the cracks could have initiated at these air voids/bubbles. Furthermore, all these cracks run from the top or bottom of the beam in the direction of the external force applied on the beam in the flexural test. The state of stress at the point of application of the load on the beam is clearly affected by the bending moment and stress distribution due to the external bending force applied on that section. The principal stresses determine the direction of propagation of the cracks and, thus, it is apparent that the origin of these cracks has to be found in the fracture process of the beam rather than by any autogenous shrinkage that might have occurred.

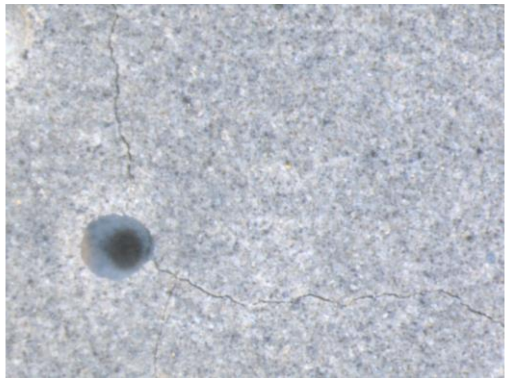

Figure 4.28. Example #1 of Associated Cracks and Voids/Bubbles of Failure Plane for Beam A.3

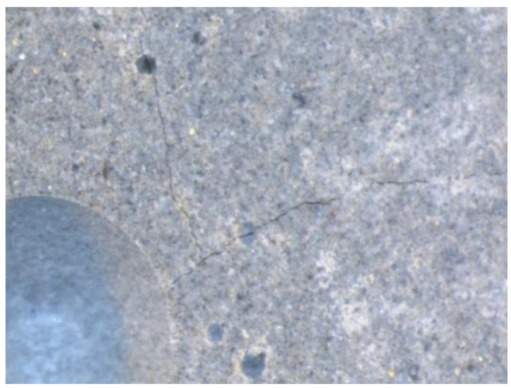

Figure 4.29. Example #2 of Associated Cracks and Voids/Bubbles of Failure Plane for Beam A.3

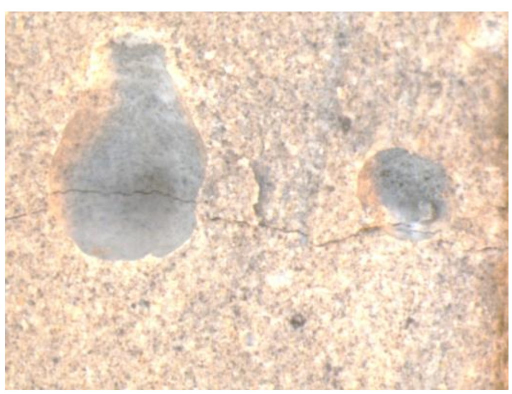

Figure 4.30. Example #3 of Associated Cracks and Voids/Bubbles of Failure Plane for Beam A.3

Besides these cracks, no evidence of other visible cracks was detected. The implication is that the possible shrinkage cracks are much smaller than the minimum size detectable with the optical microscope.

4.5 Summary of Findings

The results of the present research program have showed some significant variability. This variability has been most probably caused by the variability of the specimens prepared; namely the average densities of the specimens also show some variability that could explain the variability of the strength results. For most of the determinations, the best estimates selected based on the discussions in the preceding subsections are summarized in Table 4.32.

The degrees of hydration measured show a consistent pattern of increasing degree of hydration for increasing length of curing time. Furthermore, the degrees of hydration increase for increasing water/cement ratio of the paste; in this manner, the degree of hydration for the same length of curing is consistently higher for the paste with the higher water/cement ratio. There is a concern that perhaps some of the degrees of hydration did not increase at a reasonable rate for the longer curing times at fourteen and twenty eight days.

The compressive strength of 2-inch cubes shows a consistent pattern, with one exception, of increasing strength for longer curing times. The only exception is for a water/cement ratio of 0.35 and seven day curing that shows a minor decrease relative to the three-day curing. The cubes prepared with a water/cement ratio of 0.35 exhibit compressive strengths significantly larger than the strength for a water/cement ratio of 0.40. This fact is consistent with common knowledge that water/cement ratio affects drastically the strength of the paste.

Table 4.32

Summary of Best Estimate Properties of Neat Cement Paste Specimens

Water/ Cement Ratio	Curing Time (days)	Degree of Hydration (%)	Compressive Strength (MPa)		Tensile Strength (MPa)	
			2 Inch Cubes	Cylinders 4 in x 8 in	Flexure Test	Direct Tension Test
0.35	3	50	69.9	45.0	3.27	-
	7	53	66.4	-	2.66	2.11
	14	64	78.0	61.6	2.02	1.74
	28	65	83.7	63.4	1.56	1.08
0.40	3	57	45.2	-	2.38	1.09
	7	59	55.7	-	1.76	1.63
	14	68	59.8	-	-	1.07
	28	70	58.0	-	1.62	0.66

The compressive strength of 4 x 8 in cylinders of neat cement paste also show a consistent pattern of increasing strength for longer curing times. Nevertheless, the strength of the cylinders is significantly lower than the strength for the 2-inch cubes, on the order of about one third to one fourth. This fact it is also common knowledge that the strength of the cubes should not be considered to evaluate the compressive strength of concrete, in fact, it is a test that it is only performed for comparison purposes of cements in a standard mortar mix.

The tensile strength of neat paste cement specimens, for flexure and direct tension test, show similar patterns of decreasing strength for increasing curing time. This trend is contrary to the expectation that strength would increase with curing time. The effect is attributed to the curing "sealed" conditions that the specimens were subjected to during curing. This appears to have resulted in "autogenous" shrinkage of the paste due to the consumption of pore water by the hydration reaction. In general the flexural tests indicate somewhat larger tensile strength than the direct tension test. Furthermore, the decrease of the tensile strength appears to be somewhat less for the paste with a water/cement ratio of 0.40; this fact is in agreement with the knowledge that "autogenous" shrinkage is lower for higher water/cement ratios. This is due to the availability of extra capillary water in the paste pore space that allows for the continuation of the hydration reaction without generating high capillary pressures.

CHAPTER 5

Conclusions and Future Research

The results of the laboratory test program implemented were overwhelmed by the sealed curing method employed. This curing method resulted in “autogenous” shrinkage taking place in the specimens, especially after seven day curing set. The result was the formation of cracks or the extension of existing cracks. This additional damage resulted in the loss of tensile strength in the flexure and direct tension tests. The effects on the compression two-inch-side cubes are less diagnostic, but some of the features of the loading curves for the cubes also point in to this effect.

The main effects on the loading of the cubes is the extended initial phase where the loading curve becomes concave upwards until reaching the linear elastic portion of the load-displacement curve for the specimen. This is a well-known effect that occurs with specimens of hard rock subjected to non-deviatoric pressure – volumetric strain loading. This is an initial part of loading that is commonly attributed to closing of pre-existing features and compression of mineral grains.

The compression tests on the 2-inch side cubes are not precisely a non-deviatoric loading of the specimen. However, the friction generated between the cubes and the loading platens provide some sort of confinement on the specimen that to some extent resemble the non-deviatoric loading of the cubes. This effect has also been manifested in the large differences of compressive strength obtained between the 2-inch side cubes and the 4 x 8 inch cylindrical specimens.

This effect is well known, to the point that ASTM standard C109 states the following:

“**4. Significance and Use**

4.1 This test method provides a means of determining the compressive strength of hydraulic cement and other mortars, and results may be used to determine compliance with specifications; Caution must be exercised in using the results of this test method to predict the strength of concrete".

The major conclusion to be drawn from this observation is that the strength of concrete is best evaluated from tests on cylindrical specimens of a length equal to two times the diameter of the specimen.

The major implication is that the results of the present test program cannot be appropriately used as bench marks at the macroscopic level of results of the numerical simulation of neat cement paste specimens based on molecular and multi-scale levels of simulation of the paste. The presence of friction at the platen-specimen interface in the compression test on cubes, and the presence of micro-cracking would have to be appropriately incorporated into the model, since the presence of these impacts the results at the macroscopic significantly and, thus, could not be reasonably ignored.

The major thrust that has been researched in the technical literature about "autogenous" shrinkage has been directed to document overall volume shrinkage of the specimens. A record of tests illustrating the formation of micro-cracks in specimens of neat cement paste due to "autogenous" shrinkage has not been identified in the technical literature. The volume changes have been attributed to an increase of the capillary pressure in the gel pores. In this manner, as the reaction progresses, the capillary water is withdrawn from the pores by the reacting cement particles. This effect causes an increase in capillary tension that is supported by additional compressive stresses on the pore walls of the C-S-H gel. When the increase in capillary tension exceeds the strength of the newly formed C-S-H matrix, the additional compressive stresses can then crack the pore wall or extend an already existing crack.

This relationship of capillary pressures and “autogenous” shrinkage has been confirmed in the technical literature by comparing the behavior of duplicate specimens cured in a limed water bath versus those sealed cured. Specimens cured in water do not experience “autogenous” shrinkage. This is because, as the capillary water reacts with the cement particles, the bath water replaces the capillary water and, thus, capillary pressures are not increased.

It is believed that the results of the present test program provided a first indication that “autogenous” shrinkage of neat cement paste will crack or propagate existing cracks. The common assertion found in the technical literature is that the neat cement paste will require a stiffer skeleton of sand/aggregate grains for the C-S-H gel to actually crack. This assertion is unproven, just advanced, in the technical literature; the cement paste is far from a homogeneous media with quite different components such as calcium hydroxide crystals, unreacted cement particles, etc. that would provide a reaction skeleton for the C-S-H gel to crack upon large increases of the capillary pressures. The findings of the present research are a good indication that some additional research in this area would be beneficial to clarify and demonstrate the effects of “autogenous” shrinkage in neat cement paste.

In any future research efforts, a very important aspect that would need improvement is in the area of specimen preparation. Mixing and preparing specimens using ASTM recommended procedures has proven to be inadequate based on the very large standard deviations obtained for the different test and batches. In this sense, the two-inch-side cubical specimens exhibited C.O.V.’s of about 10%, the cylindrical compressive tests showed C.O.V. from about 10% to

20%, the flexural tests showed C.O.V.'s of about 25%, and the direct tension tests exhibited C.O.V. up to about 50%.

With these very large standard deviations, the 95% confidence interval of the mean of a specific batch is very wide. To reduce this interval to about plus/minus 0.1 MPa, it would require hundreds of tests in each batch using the standard deviations of the present research program. This large number of specimens is unreasonable, and it only highlights the need to improve the specimen preparation and testing in any future research program.

In any future research effort, it appears that the number of replicates should be increased to may be six or nine, and it appears based on the present results that the best test candidates would be the following tests:

1.) Compression: 4 x 8 inch cylindrical specimens;

2.) Tension: Flexural tests only.

Furthermore, the proposed future research should contemplate the need to prepare and test duplicate sets of specimens subjected to different curing conditions. At least initially, the minimum number of curing conditions should be the following:

1.) Cured submerged in lime water for all the curing period, and

2.) Sealed cured for all curing periods.

Specimens should also be prepared to measure the overall shrinkage of the bars that have been subject to the two types of curing methods.

Finally, it would also be necessary to switch the load testing phase from the strain controlled to the load controlled mode advised by ASTM to eliminate viscoelastic effects on the strength results.

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Appendix A

Table

Degrees of Hydration for Neat Paste Specimens with a Water/Cement Ratio of 0.35

Curing Time (days)	Trial Number	Crucible Weight (gram)	Crucible and Cement Weight (gram)	Weight of Crucible and Cement Oven-Dried at 105 °C (gram)	Weight of Crucible and Cement Furnace-Dried at 1005 °C (gram)	Degree of Hydration 'α'
3	1	28.42	38.45	36.95	36.05	0.49
	2	32.84	43.34	41.38	40.46	0.50
	3	35.11	45.14	43.64	42.71	0.51
7	1	28.43	38.47	36.83	35.88	0.53
	2	32.84	42.91	41.27	40.3	0.54
	3	35.11	45.16	43.54	42.59	0.53
14	1	28.42	38.46	36.8	35.68	0.64
	2	32.84	42.86	41.3	40.18	0.64
	3	35.11	45.14	43.61	42.46	0.65
28	1	28.42	38.45	36.99	35.84	0.65
	2	32.84	42.89	41.4	40.25	0.65
	3	35.13	45.16	43.67	42.54	0.64

Table

Degrees of Hydration for Neat Paste Specimens with a Water/Cement Ratio of 0.40

Curing Time (days)	Trial Number	Crucible Weight (gram)	Crucible and Cement Weight (gram)	Weight of Crucible and Cement Oven-Dried at 105 °C (gram)	Weight of Crucible and Cement Furnace-Dried at 1005 °C (gram)	Degree of Hydration 'α'
3	1	28.42	38.44	36.54	35.57	0.57
	2	32.84	42.85	40.96	39.99	0.57
	3	35.11	45.16	43.27	42.3	0.56
7	1	28.43	38.51	N/A	N/A	N/A
	2	32.84	42.87	41.03	40.02	0.59
	3	35.11	45.12	43.31	42.29	0.59
14	1	28.42	38.45	36.62	35.47	0.68
	2	32.84	42.89	41.03	39.88	0.68
	3	35.11	45.17	43.33	42.18	0.68
28	1	28.42	38.44	36.73	35.53	0.70
	2	32.84	42.88	41.13	39.95	0.69
	3	35.11	45.17	43.43	42.24	0.70

Appendix B

Table

Summary of Laboratory Measurements of the Dimensions of 2-Inch Cube Specimens for a Water/Cement Ratio of 0.35 Cured for 3 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Length	Width	Height		
3	A1	2.018	1.998	2.009		
		2.008	2.001	2.001		
		2.015	2.007	2.001		
	Average	2.014	2.002	2.004	4.032	8.080
3	A2	2.028	1.998	2.007		
		2.023	1.998	2.009		
		2.027	1.999	2.009		
	Average	2.026	1.998	2.008	4.048	8.128
3	A3	2.047	2.000	2.003		
		2.038	1.998	2.002		
		2.040	2.003	2.003		
	Average	2.042	2.000	2.003	4.084	8.180

Table

Results of Compressive Test on Specimen A.1

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0.002869	0	0.01581	119	0.031712	10734	0.048743	30665
0.000397	3	0.016237	133	0.032139	11244	0.0492	31100
0.000794	2	0.016665	150	0.033757	13281	0.049597	31530
0.001221	3	0.017092	168	0.034184	13791	0.050024	31968
0.001648	5	0.017519	191	0.034581	14296	0.050452	32389
0.002075	3	0.017916	214	0.035008	14814	0.050848	32807
0.002472	6	0.018343	238	0.035466	15325	0.051245	33216
0.002869	8	0.018771	267	0.035863	15825	0.051673	33631
0.003296	11	0.019167	305	0.03629	16338	0.052069	34036
0.003754	14	0.019564	359	0.036717	16840	0.052497	34434
0.004151	12	0.01993	421	0.037083	17342	0.052954	34831
0.004548	17	0.020388	505	0.037511	17847	0.053321	35214
0.004975	21	0.020846	607	0.037938	18348	0.053748	35576
0.005402	26	0.021243	725	0.038335	18853	0.054175	35951
0.00583	29	0.02167	887	0.038732	19355	0.054603	36319
0.006226	32	0.022097	1070	0.039189	19850	0.05506	36688
0.006654	35	0.022525	1274	0.039647	20349	0.055396	37044
0.00705	40	0.022922	1502	0.039983	20841	0.055854	37395
0.007447	43	0.023318	1753	0.040441	21336	0.056251	37746
0.007874	46	0.023715	2014	0.040899	21823	0.056678	38078
0.008302	47	0.024173	2307	0.041265	22310	0.057075	38419
0.008729	53	0.02457	2620	0.041692	22798	0.057563	38747
0.009126	60	0.024997	2961	0.042119	23294	0.057899	39073
0.009523	64	0.025424	3356	0.042547	23773	0.058326	39383
0.00995	69	0.025852	3785	0.042943	24246	0.058754	39705
0.010377	43	0.026248	4232	0.04334	24738	0.059211	40018
0.010805	44	0.026676	4694	0.043768	25201	0.059639	40302
0.011232	47	0.027103	5164	0.044195	25664	0.060005	40592
0.011659	47	0.027561	5654	0.044622	26134	0.060432	40859
0.012056	49	0.027927	6144	0.045049	26599	0.060859	41114
0.012514	52	0.028385	6644	0.045416	27065	0.061226	41265
0.012941	50	0.28782	7150	0.045812	27526		
0.013338	63	0.029148	7656	0.04627	27982		
0.013765	69	0.029606	8160	0.046667	28434		
0.014131	78	0.030002	8668	0.047125	28881		
0.014559	85	0.03043	9188	0.047491	29336		
0.014955	96	0.030857	9703	0.047918	29780		
0.015383	104	0.031315	10220	0.048376	30219		

Table

Results of Compressive Test on Specimen A.2

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015902	6208	0.031742	24448		
0.000458	2	0.016268	6623	0.032139	24921		
0.000885	2	0.016695	7047	0.032597	25388		
0.001313	6	0.017123	7473	0.032963	25853		
0.001709	11	0.01755	7919	0.033391	26322		
0.002076	20	0.018008	8369	0.033848	26778		
0.002533	35	0.018374	8822	0.034215	27236		
0.002961	52	0.018801	9289	0.034642	27689		
0.003388	78	0.01929	9755	0.035039	28144		
0.003785	107	0.019656	10231	0.035496	28586		
0.004243	142	0.020083	10704	0.035863	29035		
0.004609	180	0.02048	11186	0.036312	29468		
0.005097	226	0.020907	11676	0.036748	29906		
0.005464	279	0.021274	12173	0.037145	30341		
0.00586	343	0.021701	12663	0.037572	30770		
0.006288	429	0.022128	13171	0.037938	31197		
0.006654	533	0.022555	13667	0.038365	31603		
0.007142	668	0.023013	14163	0.038823	32024		
0.007539	824	0.02338	14655	0.03919	32438		
0.007936	1003	0.023807	15160	0.039647	32844		
0.008394	1190	0.024234	15656	0.040075	33242		
0.00879	1399	0.024661	16156	0.040441	33630		
0.009187	1555	0.025058	16660	0.040868	34002		
0.009614	1778	0.025486	17150	0.041326	34375		
0.010011	1972	0.025943	17646	0.041723	34742		
0.010439	2231	0.02634	18145	0.04212	35107		
0.010835	2440	0.026737	18636	0.042547	35461		
0.011263	2724	0.027164	19126	0.043005	35811		
0.01172	2895	0.02753	19616	0.043371	36142		
0.012087	3206	0.027988	20110	0.043798	36368		
0.012544	3536	0.028416	20594				
0.012972	3875	0.028812	21086				
0.013369	4218	0.02924	21572				
0.013796	4580	0.029575	22053				
0.014223	4943	0.030064	22537				
0.014681	4969	0.03046	23019				
0.015017	5413	0.030918	23498				
0.015475	5804	0.031315	23970				

Table

Results of Compressive Test on Specimen A.3

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015841	6339	0.031773	24354	0.047339	39270
0.000458	3	0.016299	6742	0.0322	24834		
0.000885	11	0.016726	7145	0.032628	25304		
0.001252	21	0.017123	7572	0.033055	25781		
0.001679	37	0.01755	7995	0.033452	26242		
0.002076	52	0.018008	8427	0.03391	26717		
0.002473	76	0.018374	8857	0.034306	27179		
0.00293	102	0.018801	9298	0.034734	27636		
0.003327	133	0.019198	9739	0.03513	28098		
0.003754	165	0.019626	10183	0.035558	28554		
0.004182	198	0.020053	10649	0.035954	28997		
0.004579	237	0.020419	11108	0.036351	29447		
0.004975	282	0.020846	11568	0.036748	29902		
0.005433	334	0.021304	12045	0.037206	30337		
0.00586	394	0.021732	12521	0.037572	30773		
0.006288	462	0.022098	13002	0.037999	31216		
0.006685	542	0.022556	13495	0.038457	31651		
0.007112	638	0.022922	13971	0.038854	32047		
0.007509	743	0.02338	14469	0.03922	32391		
0.007936	870	0.023807	14966	0.039709	32791		
0.008363	1009	0.024234	15454	0.040105	33192		
0.00876	1167	0.024631	15949	0.040533	33612		
0.009157	1348	0.024997	16451	0.040929	34007		
0.009584	1546	0.025455	16945	0.041387	34401		
0.010072	1769	0.025882	17440	0.041723	34794		
0.010439	2010	0.02631	17934	0.042211	35186		
0.010866	2272	0.026706	18429	0.042639	35580		
0.011293	2542	0.027103	18911	0.043005	35956		
0.011659	2829	0.027561	19408	0.043463	36325		
0.012148	3131	0.027958	19900	0.043859	36688		
0.012514	3434	0.028385	20391	0.044287	37041		
0.01288	3760	0.028904	20977	0.044684	37396		
0.013369	4102	0.029301	21472	0.045111	37735		
0.013796	4452	0.029698	21948	0.045508	38057		
0.014193	4807	0.030125	22436	0.045996	38371		
0.01459	5178	0.030491	22920	0.046332	38689		
0.014986	5550	0.030979	23393	0.046759	38988		
0.015444	5936	0.031376	23877	0.047186	39240		

Table

Summary of Laboratory Measurements of the Dimensions of 2-Inch Cube Specimens for a Water/Cement Ratio of 0.35 Cured for 7 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Length	Width	Height		
7	B1	1.992	2.031	1.989		
		1.995	2.021	1.992		
		1.999	2.026	1.997		
	Average	1.995	2.026	1.993	4.042	8.055
7	B2	2.027	1.997	2.000		
		2.013	1.999	1.996		
		2.008	1.997	1.997		
	Average	2.016	1.998	1.998	4.028	8.048
7	B3	1.999	1.998	2.002		
		2.009	1.997	1.997		
		2.021	1.998	1.999		
	Average	2.010	1.998	1.999	4.016	8.028

Table

Results of Compressive Test on Specimen B.1

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.01581	1886	0.031681	18447	0.047491	36050
0.000458	3	0.016237	2082	0.032139	18958	0.047918	36442
0.000855	5	0.016665	2285	0.032505	19463	0.048315	36833
0.001221	5	0.017061	2506	0.032963	19970	0.048743	37221
0.001679	8	0.017489	2730	0.03336	20472	0.049139	37595
0.002106	12	0.017947	2973	0.033757	20977	0.049567	37958
0.002472	12	0.018313	3238	0.034214	21470	0.049994	38324
0.00293	18	0.01874	3519	0.034611	21968	0.050421	38680
0.003296	23	0.019137	3826	0.034977	22473	0.050879	38994
0.003693	26	0.019564	4159	0.035405	22975	0.051184	39157
0.004151	31	0.019991	4516	0.035863	23460		
0.004578	37	0.020419	4906	0.03629	23958		
0.004975	44	0.020816	5323	0.036717	24451		
0.005433	53	0.021243	5759	0.037114	24937		
0.00583	67	0.02167	6220	0.037541	25415		
0.006226	86	0.022097	6690	0.037938	25905		
0.006623	99	0.022494	7171	0.038365	26387		
0.007111	121	0.022921	7662	0.038732	26865		
0.007478	133	0.023349	8168	0.039159	27347		
0.007936	153	0.023746	8670	0.039586	27822		
0.008332	172	0.024203	9173	0.040013	28293		
0.008729	197	0.0246	9691	0.04038	28762		
0.009187	229	0.025027	10202	0.040868	29229		
0.009523	258	0.025485	10715	0.041234	29691		
0.010011	302	0.025882	11223	0.041662	30154		
0.010377	343	0.026248	11740	0.042058	30619		
0.010805	394	0.026706	12253	0.042486	31084		
0.011262	456	0.027103	12769	0.042913	31533		
0.011659	522	0.0275	13284	0.04331	31985		
0.012086	598	0.027896	13800	0.043737	32434		
0.012514	688	0.028354	14322	0.044164	32865		
0.01288	786	0.028782	14840	0.044622	33299		
0.013368	894	0.029148	15354	0.044988	33635		
0.013735	1026	0.029636	15867	0.045416	34042		
0.014162	1175	0.030002	16388	0.045843	34460		
0.014559	1341	0.03046	16904	0.04624	34845		
0.014986	1512	0.030888	17425	0.046637	35251		
0.015383	1696	0.031284	17936	0.047125	35660		

Table

Results of Compressive Test on Specimen B.2

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.01578	3988	0.031712	20889	0.047491	36893
0.000397	3	0.016237	4326	0.032078	21380	0.047919	37163
0.000824	6	0.016685	4668	0.032566	21859	0.048346	37480
0.00116	8	0.017092	5021	0.032963	22342	0.048804	37766
0.001618	11	0.017519	5396	0.03339	22825	0.0492	38065
0.002076	15	0.017947	5775	0.033787	23300	0.049567	38327
0.002472	20	0.018343	6156	0.034184	23772	0.050025	38620
0.002869	24	0.018771	6545	0.034581	24249	0.050452	38681
0.003296	29	0.019137	6944	0.035008	24718	0.050574	38683
0.003724	40	0.019625	7339	0.035466	25197		
0.004151	50	0.019992	7751	0.035863	25659		
0.004548	66	0.020419	8169	0.036259	26111		
0.004945	82	0.020785	8586	0.036687	26554		
0.005402	104	0.021273	9027	0.037145	26985		
0.005799	128	0.02167	9466	0.037511	27398		
0.006257	157	0.022067	9901	0.037938	27773		
0.006654	198	0.022525	10332	0.038365	28205		
0.00702	243	0.022922	10759	0.038793	28637		
0.007447	279	0.02341	11229	0.03922	29024		
0.007905	327	0.023776	11688	0.039647	29363		
0.008332	391	0.024173	12170	0.040014	29784		
0.008729	447	0.0246	12636	0.040441	30213		
0.009126	516	0.025058	13115	0.040838	30628		
0.009584	600	0.025455	13590	0.041265	31059		
0.010011	704	0.025882	14069	0.041723	31483		
0.010408	824	0.026248	14560	0.042058	31902		
0.010835	966	0.026676	15053	0.042547	32319		
0.011232	1117	0.027103	15535	0.042913	32722		
0.011659	1303	0.02753	16039	0.043371	33139		
0.012087	1508	0.027927	16527	0.043737	33529		
0.012514	1732	0.028385	17016	0.044195	33941		
0.012941	1972	0.028812	17509	0.044592	34335		
0.013368	2220	0.029178	17985	0.045019	34720		
0.013735	2488	0.029606	18468	0.045416	35101		
0.014131	2762	0.030033	18951	0.045843	35496		
0.014589	3052	0.03043	19434	0.04624	35870		
0.015017	3356	0.030857	19926	0.046667	36220		
0.015444	3664	0.031284	20411	0.047095	36548		

Table

Results of Compressive Test on Specimen B.3

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015902	6733	0.031742	22558		
0.000428	2	0.016329	7082	0.0322	22990		
0.000855	5	0.016726	7444	0.032597	23196		
0.001282	14	0.017153	7813	0.032963	23590		
0.001709	24	0.017581	8186	0.033421	23990		
0.002106	44	0.017977	8563	0.033848	24393		
0.002534	72	0.018405	8947	0.034245	24799		
0.002961	110	0.018832	9333	0.034673	25229		
0.003388	160	0.019229	9706	0.03513	25646		
0.003785	226	0.019656	10099	0.035497	26082		
0.004182	261	0.020053	10493	0.035924	26441		
0.004609	340	0.02048	10899	0.036321	26856		
0.005067	424	0.020938	11310	0.036778	27257		
0.005494	528	0.021304	11719	0.037145	27655		
0.005891	644	0.021701	12140	0.037633	28072		
0.006318	786	0.022128	12556	0.037999	28461		
0.006684	931	0.022556	12981	0.038396	28847		
0.007081	1088	0.023013	13400	0.038854	29235		
0.007539	1158	0.02341	13829	0.03922	29639		
0.007905	1328	0.023837	14261	0.039647	30030		
0.008363	1517	0.024234	14693	0.040075	30416		
0.00879	1729	0.024631	15126	0.040502	30770		
0.009187	1938	0.025089	15566	0.040868	31156		
0.009615	2158	0.025516	16004	0.041357	31527		
0.010042	2402	0.025913	16428	0.041723	31861		
0.0105	2672	0.02631	16845	0.04212	32180		
0.010896	2903	0.026737	17281	0.042578	32516		
0.011293	3180	0.027195	17725	0.043005	32849		
0.01169	3472	0.027561	18162	0.043432	33169		
0.012087	3766	0.027988	18607	0.043798	33287		
0.012545	4067	0.028416	19050	0.044287	33183		
0.013002	4380	0.028843	19497				
0.013369	4711	0.02927	19935				
0.013826	5039	0.029667	20385				
0.014223	5367	0.030094	20829				
0.014651	5709	0.030491	21252				
0.015047	6046	0.030979	21681				
0.015505	6380	0.031346	22113				

Table

Summary of Laboratory Measurements of the Dimensions of 2-Inch Cube Specimens for a Water/Cement Ratio of 0.35 Cured for 14 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Length	Width	Height		
14	C1	1.993	1.991	2.008		
		1.997	1.990	2.005		
		2.006	1.988	2.003		
	Average	1.999	1.990	2.005	3.978	7.976
14	C2	1.998	1.991	2.001		
		1.992	1.992	2.001		
		2.002	1.994	2.001		
	Average	1.997	1.992	2.001	3.978	7.960
14	C3	1.994	1.997	1.991		
		1.984	2.005	1.994		
		1.992	2.002	2.004		
	Average	1.990	2.001	1.996	3.982	7.948

Table

Results of Compressive Test on Specimen C.1

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015902	3955	0.031773	22651	0.047675	40765
0.000458	1	0.016299	4283	0.0322	23171	0.04801	41177
0.000885	7	0.016757	4630	0.032597	23683	0.048468	41603
0.001282	10	0.017184	4979	0.032994	24182	0.048865	42009
0.00174	16	0.017581	5387	0.033452	24696	0.049231	42417
0.002137	21	0.018069	5791	0.033879	25216	0.04972	42822
0.002534	29	0.018466	6214	0.034276	25724	0.050147	43213
0.002961	30	0.018862	6675	0.034703	26226	0.050574	43592
0.003358	30	0.01932	7132	0.03513	26736	0.05094	43981
0.003785	35	0.019656	7608	0.035558	27250	0.051368	44262
0.004212	39	0.020083	8085	0.035954	27754	0.051703	44445
0.00464	41	0.020511	8585	0.036382	28253		
0.005067	47	0.020968	9089	0.036809	28763		
0.005494	65	0.021335	9592	0.037206	29237		
0.00586	96	0.021793	10102	0.037603	29735		
0.006318	131	0.022189	10612	0.038091	30219		
0.006746	169	0.022586	11135	0.038427	30701		
0.007173	222	0.023013	11659	0.038884	31208		
0.007509	286	0.023471	12182	0.039251	31678		
0.007997	363	0.023837	12699	0.039678	32154		
0.008424	456	0.024295	13224	0.040105	32645		
0.008852	566	0.024662	13755	0.040563	33123		
0.009248	694	0.02515	14282	0.040929	33597		
0.009676	830	0.025577	14807	0.041387	34070		
0.010072	959	0.025943	15343	0.041784	34540		
0.0105	1089	0.026371	15869	0.042181	35009		
0.010896	1260	0.026768	16379	0.042608	35470		
0.011324	1445	0.027164	16913	0.043005	35932		
0.011751	1626	0.027653	17450	0.043432	36395		
0.012178	1814	0.028049	17966	0.043829	36851		
0.012575	2003	0.028446	18489	0.044317	37306		
0.013002	2202	0.028843	18996	0.044714	37753		
0.01343	2412	0.029301	19547	0.045141	38197		
0.013888	2634	0.029728	20078	0.045538	38630		
0.014284	2843	0.030155	20594	0.045965	39082		
0.014681	3108	0.030522	21087	0.046393	39509		
0.015108	3368	0.030979	21633	0.046789	39935		
0.015475	3651	0.031376	22138	0.047186	40347		

Table

Results of Compressive Test on Specimen C.2

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015872	6750	0.031712	26067	0.047553	43327
0.000428	3	0.016268	7183	0.032139	26567	0.047949	43719
0.000794	3	0.016726	7665	0.032536	27066	0.048346	44090
0.001252	9	0.017092	8137	0.032933	27561	0.048804	44451
0.001649	18	0.01755	8622	0.03336	28063	0.049201	44796
0.002076	31	0.017947	9109	0.033788	28560	0.049628	45091
0.002473	53	0.018374	9601	0.034215	29049	0.050025	45425
0.00293	84	0.018771	10081	0.034612	29548	0.050452	45709
0.003327	122	0.019198	10594	0.035039	30030	0.050696	45875
0.003724	168	0.019656	11107	0.035436	30517		
0.004212	220	0.019992	11612	0.035866	31001		
0.004579	296	0.02048	12129	0.03629	31487		
0.005036	388	0.020816	12645	0.036718	31967		
0.005403	482	0.021274	13164	0.037114	32444		
0.005952	630	0.021732	13693	0.037542	32919		
0.006257	745	0.022128	14208	0.037938	33393		
0.006654	894	0.022525	14724	0.038335	33876		
0.007081	1062	0.022983	15242	0.038763	34338		
0.007509	1250	0.02338	15770	0.03919	34794		
0.007905	1378	0.023807	16282	0.039617	35255		
0.008333	1541	0.024204	16796	0.040044	35708		
0.00876	1717	0.024601	17325	0.040441	36166		
0.009157	1900	0.025058	17840	0.040838	36624		
0.009615	2088	0.025425	18360	0.041265	37082		
0.010011	2280	0.025883	18874	0.041723	37531		
0.010378	2484	0.02631	19390	0.04215	37967		
0.010836	2713	0.026707	19905	0.042547	38407		
0.011263	2953	0.027134	20448	0.042944	38843		
0.011629	3188	0.027561	20962	0.043371	39281		
0.012117	3493	0.027988	21479	0.043799	39698		
0.012514	3763	0.028385	21992	0.044226	40123		
0.012911	4078	0.028813	22511	0.044592	40537		
0.013369	4328	0.02924	23019	0.04508	40946		
0.013766	4713	0.029576	23530	0.045447	41347		
0.014223	5088	0.030003	24031	0.045874	41752		
0.01459	5479	0.030491	24542	0.046332	42150		
0.015047	5885	0.030857	25053	0.046668	42548		
0.015444	6313	0.031254	25557	0.047095	42936		

Table

Results of Compressive Test on Specimen C.3

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015841	6538	0.031681	23903		
0.000458	5	0.016329	6890	0.032108	24397		
0.000824	8	0.016695	7256	0.032566	24896		
0.001282	12	0.017122	7638	0.032963	25386		
0.001679	20	0.01755	8035	0.03336	25879		
0.002106	31	0.017947	8435	0.033787	26369		
0.002533	44	0.018404	8836	0.034214	26851		
0.00293	61	0.018832	9216	0.034581	27339		
0.003327	73	0.019228	9629	0.035069	27820		
0.003754	95	0.019656	10061	0.035466	28310		
0.004181	128	0.020022	10493	0.035863	28804		
0.004609	177	0.020449	10940	0.03629	29273		
0.005006	252	0.020877	11392	0.036717	29748		
0.005433	343	0.021304	11836	0.037114	30199		
0.00586	458	0.021731	12277	0.037541	30610		
0.006257	588	0.022097	12750	0.037969	31066		
0.006654	739	0.022555	13214	0.038365	31527		
0.007173	913	0.022983	13681	0.038793	31982		
0.007508	1061	0.023379	14159	0.03922	32435		
0.007936	1288	0.023837	14632	0.039617	32894		
0.008363	1494	0.024203	15110	0.040044	33351		
0.00879	1708	0.024631	15581	0.040441	33812		
0.009187	1929	0.025058	16056	0.040868	34254		
0.009584	2152	0.025485	16544	0.041295	34706		
0.010042	2399	0.025882	17042	0.041692	35153		
0.010438	2637	0.026309	17527	0.04215	35603		
0.010866	2903	0.026767	18014	0.042547	36026		
0.011262	3167	0.027164	18505	0.043005	36400		
0.01169	3437	0.027591	19001	0.043401	36813		
0.012086	3716	0.027958	19500	0.043798	37231		
0.012514	4004	0.028415	19979	0.044225	37642		
0.012972	4285	0.028812	20486	0.044622	38048		
0.013368	4581	0.02927	20983	0.045019	38457		
0.013765	4886	0.029606	21481	0.045446	38846		
0.014253	5202	0.030064	21971	0.045874	39223		
0.01462	5529	0.030491	22450	0.046331	39524		
0.015047	5859	0.030918	22934	0.046698	39675		
0.015474	6196	0.031315	23430	0.046942	39723		

Table

Summary of Laboratory Measurements of the Dimensions of 2-Inch Cube Specimens for a Water/Cement Ratio of 0.35 Cured for 28 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Length	Width	Height		
28	D1	2.004	1.995	2.0085		
		2.014	1.998	2.003		
		2.020	1.999	2.004		
	Average	2.013	1.997	2.005	4.020	8.060
28	D2	2.000	2.004	2.008		
		1.998	2.001	2.003		
		2.007	2.005	2.004		
	Average	2.002	2.003	2.005	4.010	8.040
28	D3	1.987	1.999	1.999		
		1.984	2.000	1.998		
		1.998	2.005	2.001		
	Average	1.990	2.001	1.999	3.982	7.960

Table

Results of Compressive Test on Specimen D.1

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015872	7239	0.031712	26986		
0.000458	4	0.016268	7738	0.032139	27492		
0.000825	10	0.016696	8239	0.032567	27994		
0.001221	24	0.017153	8748	0.032994	28503		
0.001679	45	0.017581	9261	0.033391	29002		
0.002076	70	0.017978	9774	0.033849	29511		
0.002503	103	0.018344	10291	0.034215	30011		
0.002931	140	0.018802	10819	0.034642	30512		
0.003358	187	0.019198	11341	0.035039	31011		
0.003785	239	0.019656	11856	0.035497	31501		
0.004182	300	0.020053	12382	0.035894	32001		
0.004609	366	0.02048	12910	0.03629	32494		
0.005006	436	0.020938	13437	0.036718	32979		
0.005433	512	0.021335	13963	0.037145	33459		
0.005861	595	0.021701	14497	0.037511	33947		
0.006257	688	0.022159	15021	0.037969	34421		
0.006685	784	0.022586	15552	0.038427	34905		
0.007081	892	0.022922	16077	0.038763	35377		
0.007509	1011	0.023441	16603	0.039251	35838		
0.007967	1144	0.023777	17131	0.039648	36321		
0.008363	1303	0.024234	17656	0.040044	36802		
0.008791	1484	0.024631	18180	0.040472	37278		
0.009187	1675	0.025058	18705	0.040868	37735		
0.009584	1886	0.025486	19231	0.041296	38189		
0.010042	2115	0.025913	19748	0.041723	38655		
0.010439	2365	0.026249	20270	0.04212	39111		
0.010866	2635	0.026707	20794	0.042578	39566		
0.011263	2917	0.027134	21303	0.042974	40019		
0.01169	3212	0.027531	21825	0.043371	40471		
0.012117	3526	0.027988	22349	0.043737	40910		
0.012545	3862	0.028416	22872	0.044226	41356		
0.012941	4210	0.028813	23386	0.044684	41795		
0.013399	4573	0.02927	23907	0.04505	42227		
0.013796	4955	0.029637	24417	0.045477	42647		
0.014223	5365	0.030064	24937	0.045843	42931		
0.01462	5808	0.030461	25451				
0.015047	6270	0.030857	25964				
0.015444	6748	0.031315	26475				

Table

Results of Compressive Test on Specimen D.2

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015841	6337	0.031681	26182	0.047522	44350
0.000397	7	0.016238	6824	0.032109	26703	0.047888	44782
0.000824	16	0.016695	7329	0.032567	27221	0.048346	45188
0.001252	24	0.017092	7821	0.032963	27730	0.048712	45589
0.001618	35	0.01755	8324	0.033391	28241	0.04917	45991
0.002076	45	0.017916	8840	0.033757	28755	0.049597	46384
0.002503	64	0.018374	9363	0.034215	29254	0.049994	46792
0.0029	82	0.018771	9867	0.034581	29753	0.050391	47164
0.003327	103	0.019198	10395	0.035008	30260	0.050849	47523
0.003785	129	0.019564	10912	0.035436	30767	0.051246	47877
0.004151	154	0.019992	11428	0.035863	31266	0.051673	48161
0.004578	183	0.020419	11952	0.03629	31751	0.052131	48473
0.005036	216	0.020846	12492	0.036656	32250	0.052558	48760
0.005372	251	0.021274	13008	0.037114	32750	0.052924	48954
0.00583	291	0.021701	13537	0.037541	33243	0.053352	49177
0.006257	334	0.022128	14071	0.037908	33733	0.053779	49392
0.006654	381	0.022494	14602	0.038366	34209		
0.007081	451	0.022922	15126	0.038793	34699		
0.007539	538	0.023319	15651	0.039129	35188		
0.007905	644	0.023776	16183	0.039617	35671		
0.008333	782	0.024204	16716	0.040014	36150		
0.008729	933	0.0246	17247	0.040441	36628		
0.009157	1115	0.024997	17789	0.040838	37112		
0.009553	1315	0.025455	18325	0.041235	37594		
0.009981	1541	0.025852	18856	0.041662	38067		
0.010439	1785	0.026279	19378	0.042089	38540		
0.010805	2057	0.026676	19913	0.042547	39003		
0.011293	2333	0.027103	20444	0.042883	39471		
0.01169	2598	0.02753	20975	0.043341	39934		
0.012087	2858	0.027958	21493	0.043768	40387		
0.012514	3137	0.028385	22024	0.044134	40825		
0.012911	3450	0.028782	22546	0.044592	41280		
0.013338	3786	0.029179	23060	0.045019	41736		
0.013765	4147	0.029606	23589	0.045385	42175		
0.014162	4535	0.030003	24110	0.045843	42629		
0.014589	4956	0.03043	24632	0.04624	43065		
0.015078	5403	0.030827	25148	0.046667	43500		
0.015414	5860	0.031285	25663	0.047095	43924		

Table

Results of Compressive Test on Specimen D.3

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015901	5153	0.031711	24356	0.047552	42796
0.000427	4	0.016268	5565	0.032139	24879	0.047949	43225
0.000854	6	0.016695	5992	0.032535	25393	0.048406	43633
0.001282	10	0.017153	6423	0.032993	25898	0.048773	44077
0.001678	13	0.017549	6873	0.03339	26411	0.04917	44475
0.002075	15	0.017977	7329	0.033787	26936	0.049627	44883
0.002533	18	0.018312	7798	0.034214	27446	0.049994	45244
0.002899	22	0.018801	8278	0.034672	27956	0.050451	45598
0.003357	32	0.019198	8764	0.035099	28467	0.050879	45971
0.003784	44	0.019625	9264	0.035496	28972	0.051306	45864
0.004181	58	0.020052	9760	0.035862	29483	0.051703	46079
0.004639	73	0.02051	10259	0.03632	29982	0.052191	46056
0.005036	94	0.020907	10770	0.036717	30490	0.052588	46232
0.005432	120	0.021304	11273	0.037175	30994	0.052954	46485
0.00586	145	0.021731	11791	0.037571	31496	0.053381	46781
0.006257	177	0.022189	12301	0.037999	31987	0.053809	47048
0.006714	213	0.022585	12817	0.038395	32488	0.054175	47201
0.007111	260	0.022982	13348	0.038792	32978	0.054633	47385
0.007508	315	0.02341	13875	0.039189	33472	0.05506	47532
0.007966	389	0.023806	14395	0.039647	33964		
0.008301	465	0.024295	14920	0.040044	34453		
0.008759	572	0.02463	15442	0.04044	34940		
0.009217	702	0.025119	15965	0.040868	35426		
0.009583	866	0.025454	16498	0.041295	35900		
0.010011	1056	0.025943	17021	0.041753	36385		
0.010438	1280	0.026309	17557	0.04215	36871		
0.010835	1524	0.026767	18080	0.042546	37339		
0.011323	1774	0.027164	18610	0.042943	37820		
0.011659	2037	0.027621	19139	0.043401	38279		
0.012117	2304	0.028018	19666	0.043798	38743		
0.012513	2589	0.028385	20180	0.044195	39215		
0.012971	2885	0.028812	20707	0.044622	39676		
0.013368	3187	0.02927	21235	0.045049	40134		
0.013765	3496	0.029636	21747	0.045507	40587		
0.014192	3821	0.030063	22271	0.045873	41038		
0.014589	3937	0.03049	22797	0.046301	41487		
0.015047	4356	0.030887	23312	0.046728	41931		
0.015443	4747	0.031345	23832	0.047094	42368		

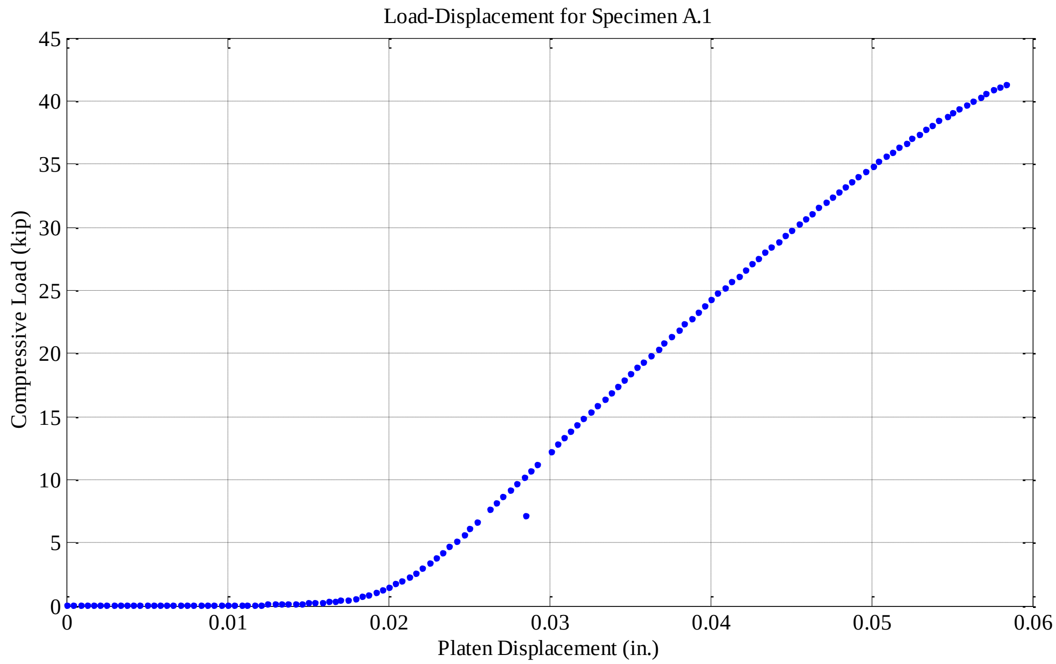

Figure Load-Displacement Curve for A.1

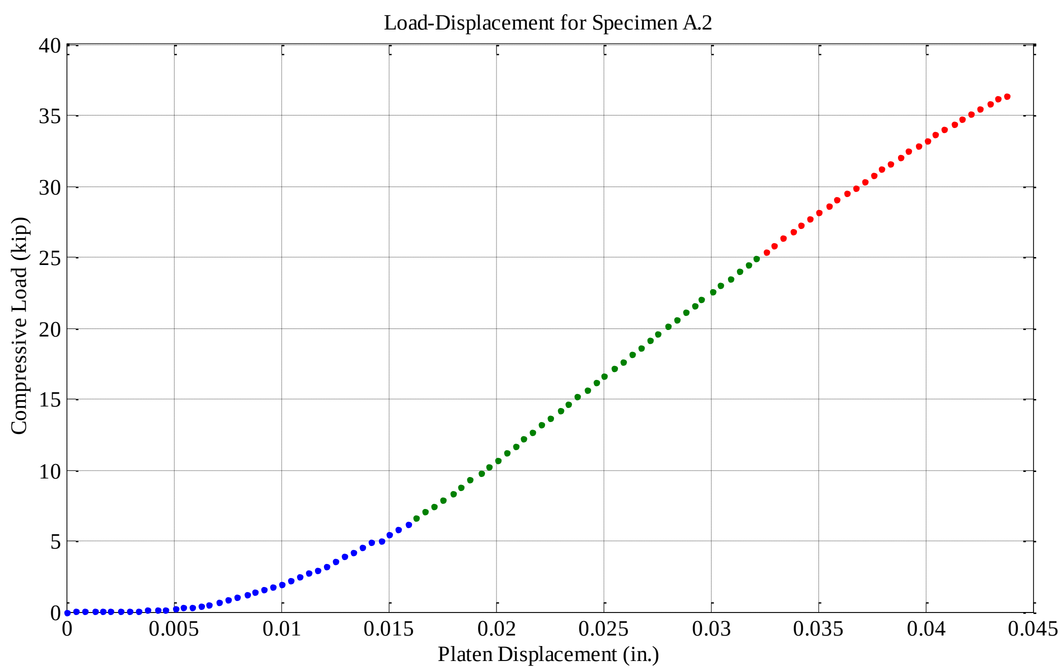

Figure Load-Displacement Curve for A.2

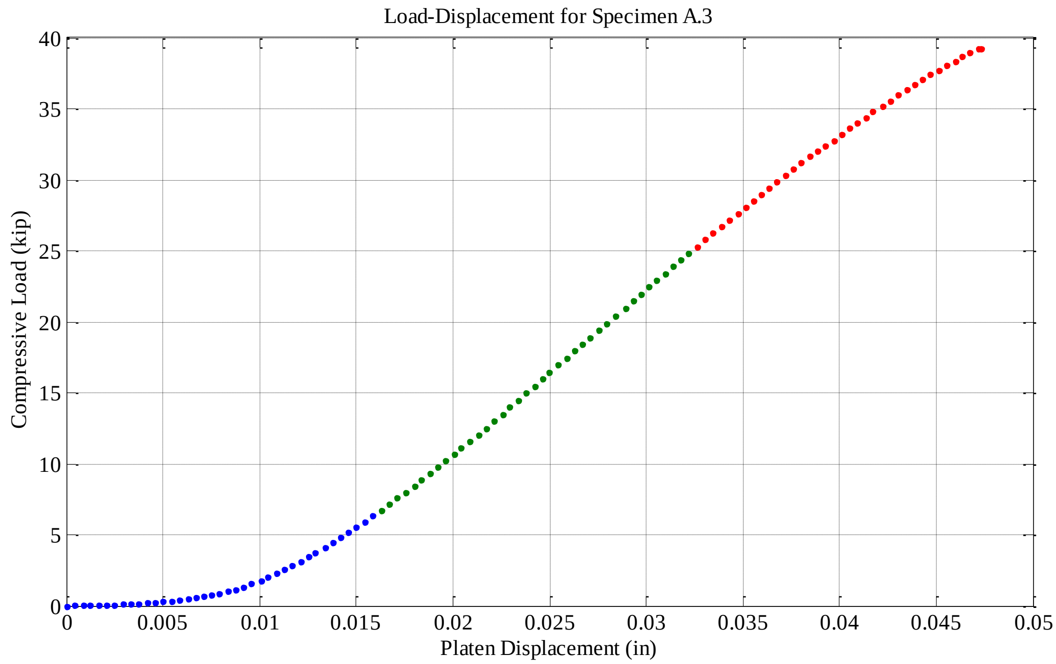

Figure Load-Displacement Curve for A.3

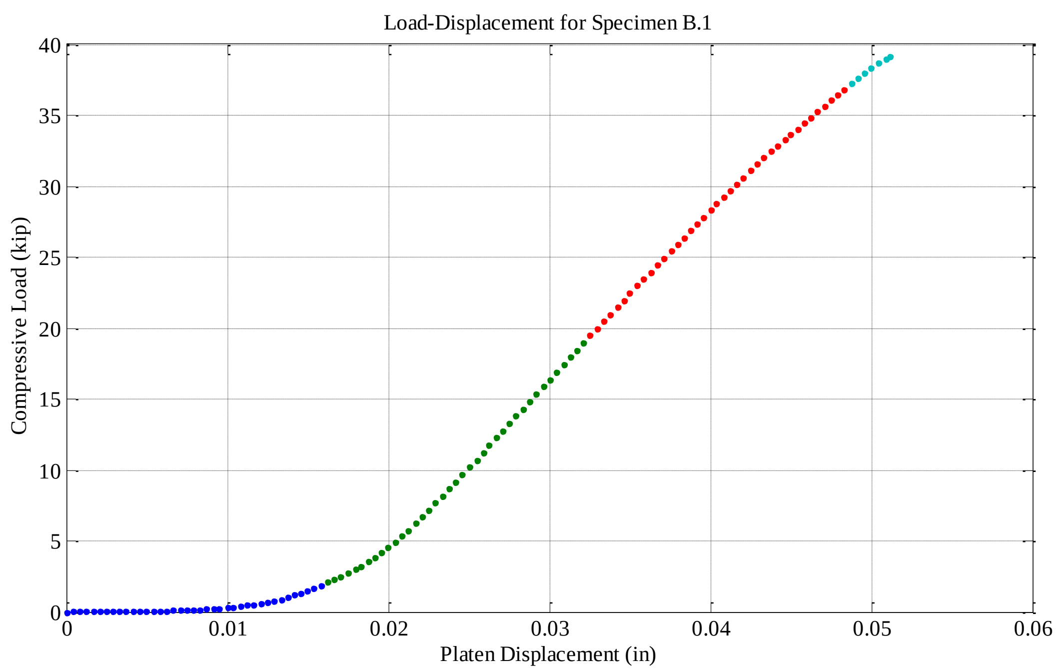

Figure Load-Displacement Curve for B.1

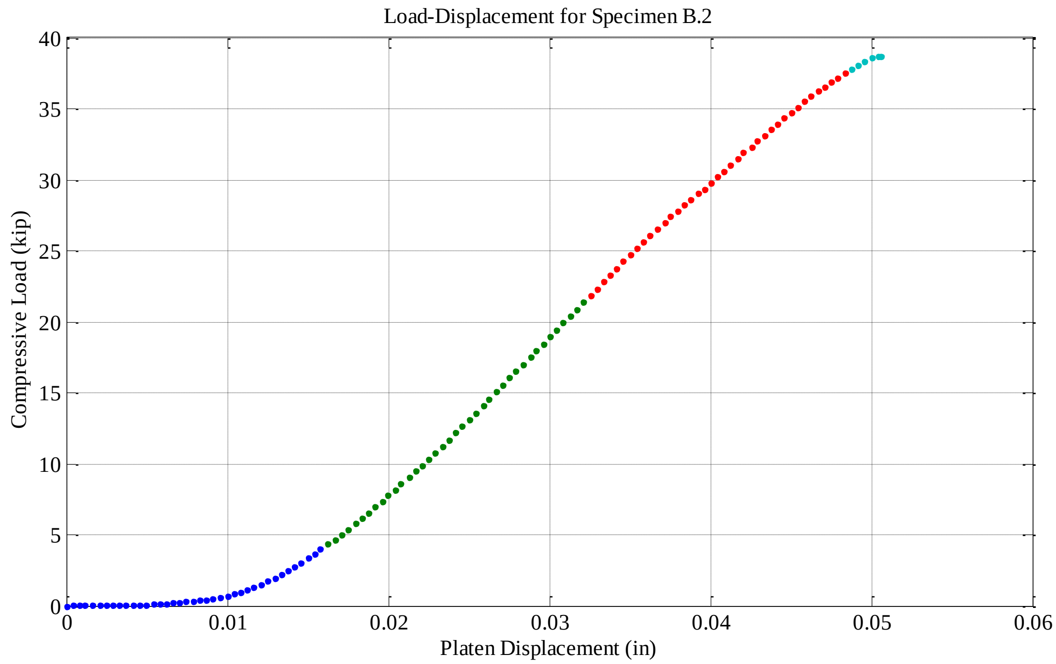

Figure Load-Displacement Curve for B.2

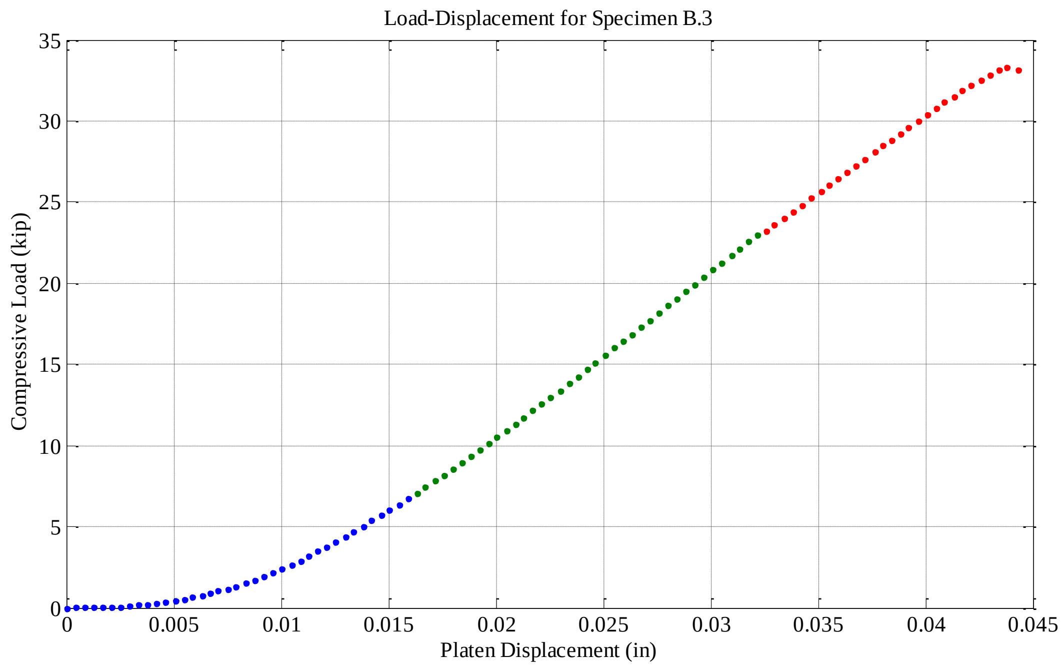

Figure Load-Displacement Curve for B.3

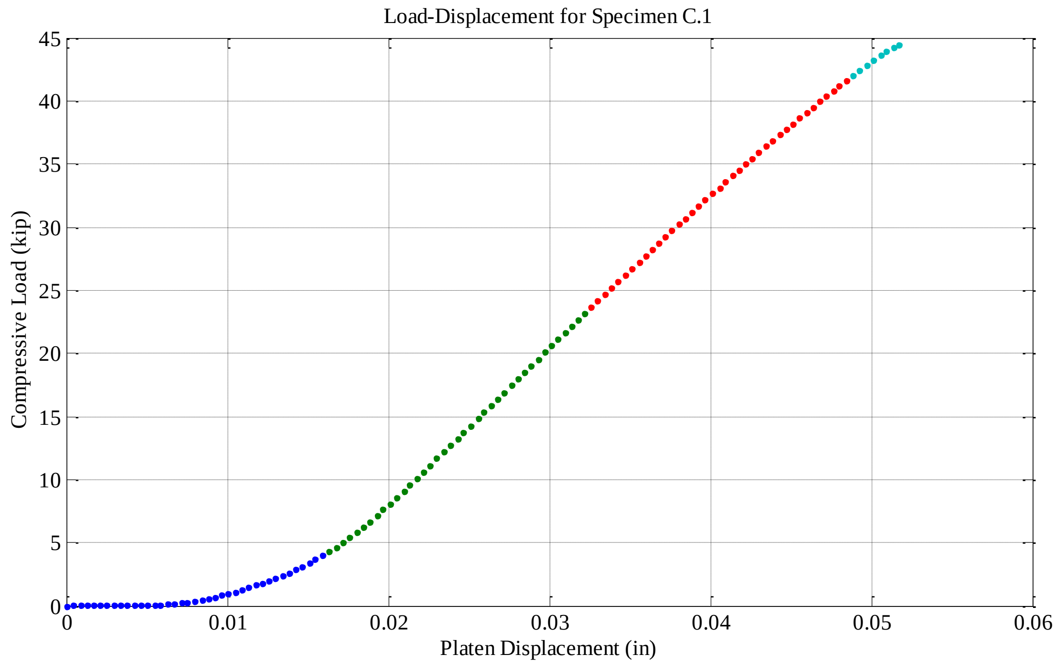

Figure Load-Displacement Curve for C.1

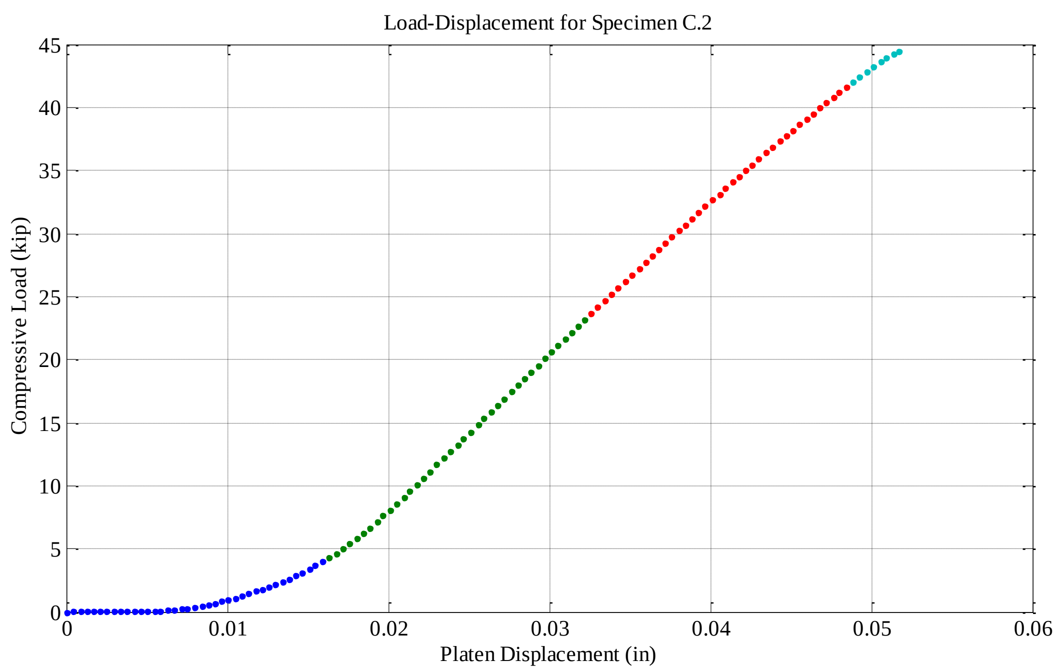

Figure Load-Displacement Curve for C.2

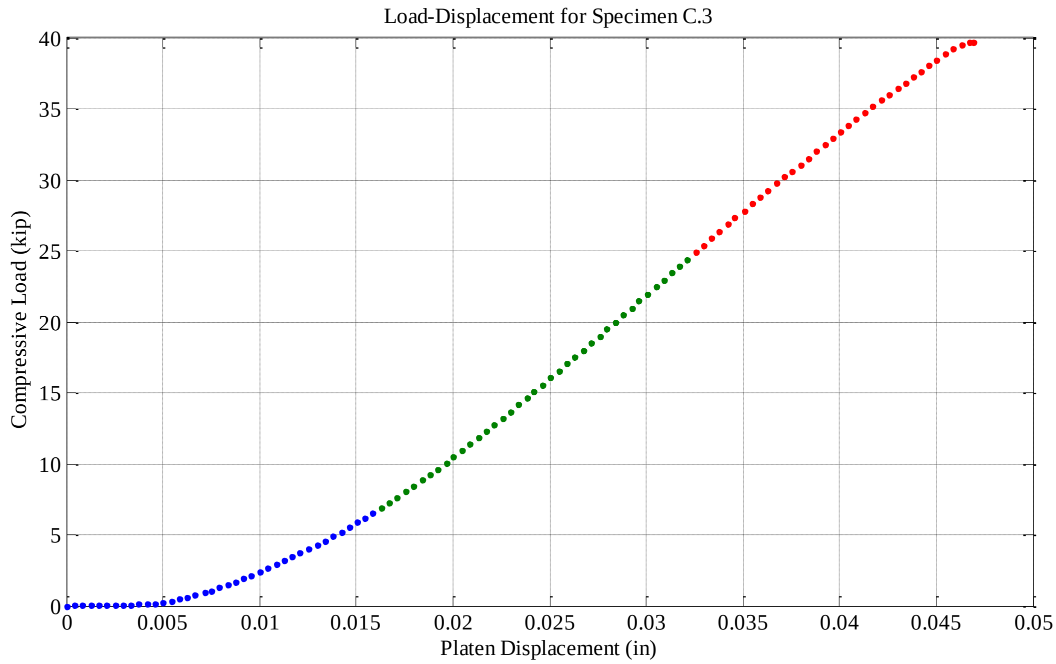

Figure Load-Displacement Curve for C.3

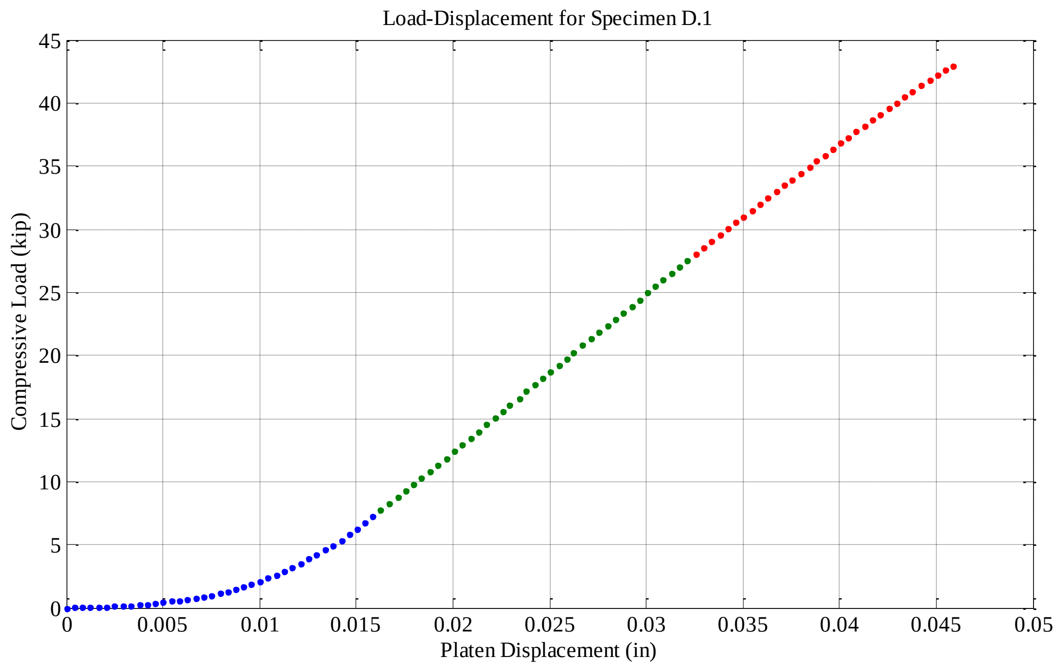

Figure Load-Displacement Curve for D.1

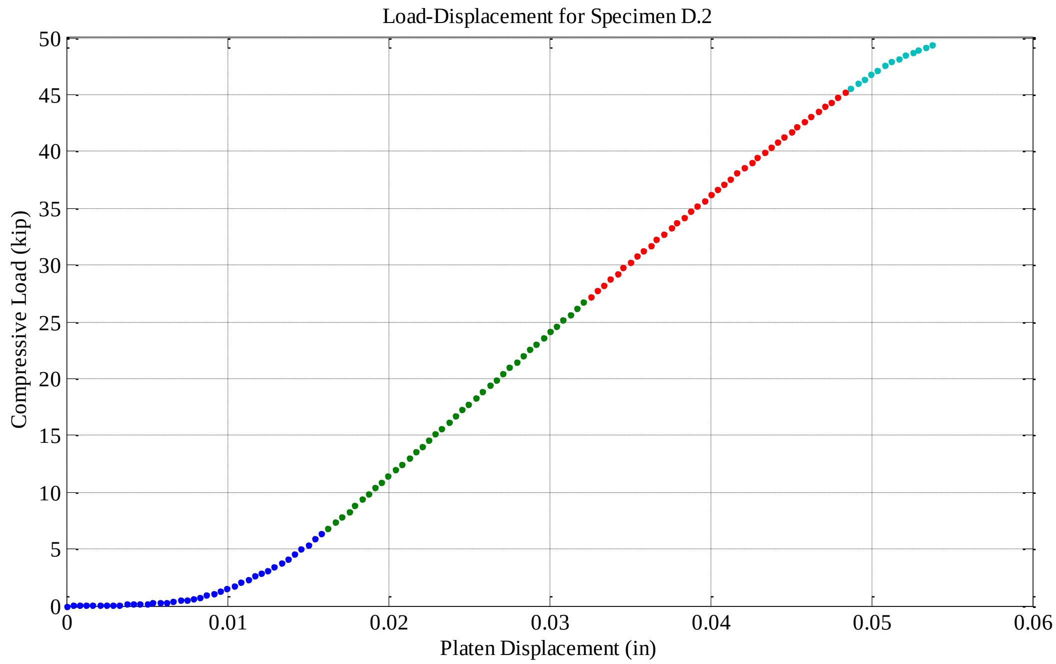

Figure Load-Displacement Curve for D.2

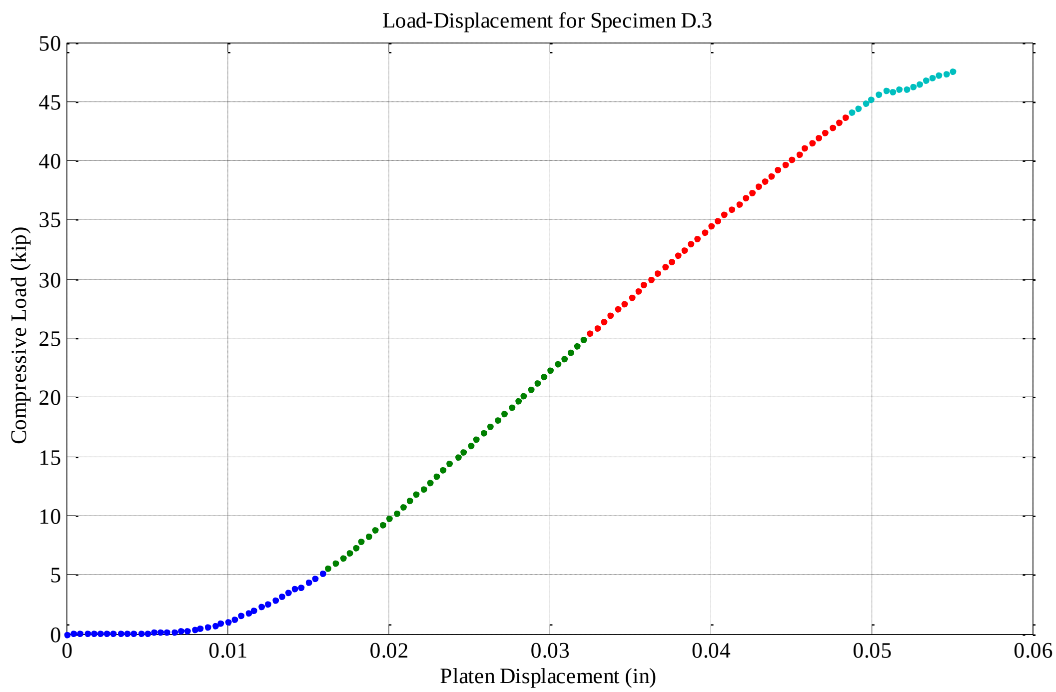

Figure Load-Displacement Curve for D.3

Table

Summary of Average Laboratory Measurements on 2- Inch Cube

Specimens for a Water/Cement Ratio of 0.35

Curing Time (days)	Specimen Designation	Average Dimensions (in)			Specimen Mass (gr)		Failure Load (lb.)
		Length	Width	Height	Before Curing	After Curing	
3	A1	2.014	2.002	2.004	271.96	271.74	40,900
	A2	2.026	1.998	2.008	272.38	272.32	36,100
	A3	2.040	2.000	2.003	274.41	274.31	38,900
7	B1	1.995	2.026	1.993	272.47	272.41	38,900
	B2	2.016	1.998	1.998	271.31	271.26	38,100
	B3	2.010	1.998	1.999	270.99	270.87	32,900
14	C1	1.999	1.990	2.005	267.69	267.52	43,500
	C2	1.997	1.992	2.001	267.02	266.85	45,000
	C3	1.990	2.001	1.996	266.77	266.68	38,800
28	D1	2.013	1.997	2.005	265.69	265.41	42,220
	D2	2.002	2.003	2.005	264.97	264.77	48,700
	D3	1.990	2.001	1.999	264.60	264.38	46,800

Appendix C

Table

Summary of Laboratory Measurements of the Dimensions of 2-Inch Cube Specimens for a Water/Cement Ratio of 0.40 Cured for 3 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Length	Width	Height		
3	E1	2.001	2.009	2.005		
		2.000	2.011	2.002		
		2.002	2.014	1.998		
	Average	2.001	2.011	2.002	4.024	8.056
3	E2	2.004	2.005	2.002		
		2.002	2.004	2.005		
		2.002	2.004	2.007		
	Average	2.003	2.004	2.005	4.014	8.048
3	E3	2.006	1.996	1.997		
		2.005	1.991	2.000		
		2.005	1.995	2.002		
	Average	2.005	1.994	2.000	3.998	7.996

Table

Results of Compressive Test on Specimen E.1

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.01462	14820				
0.000183	85	0.014986	15216				
0.000824	417	0.015352	15618				
0.001465	819	0.01578	16024				
0.001953	1219	0.016146	16423				
0.002381	1616	0.016512	16822				
0.002747	2017	0.016939	17219				
0.003205	2417	0.017336	17623				
0.003602	2817	0.017794	18021				
0.003937	3220	0.018191	18421				
0.004304	3617	0.018618	18822				
0.00467	4018	0.019045	19222				
0.005036	4419	0.019442	19624				
0.005402	4819	0.01993	20025				
0.005769	5221	0.020297	20423				
0.006135	5620	0.020724	20823				
0.006501	6020	0.021151	21226				
0.006867	6420	0.02164	21621				
0.007203	6821	0.022097	22026				
0.0078	7221	0.022555	22426				
0.007936	7621	0.023074	22825				
0.008271	8023	0.023501	23228				
0.008668	8419	0.024051	23625				
0.009034	8824	0.02457	24026				
0.009401	9224	0.025058	24426				
0.009736	9625	0.025638	24828				
0.010103	10022	0.026218	25229				
0.010469	10423	0.026859	25626				
0.010805	10821	0.027469	26027				
0.011171	11223	0.028171	26428				
0.011598	11622	0.028873	26828				
0.011873	12022	0.029697	27225				
0.0123	12424	0.030949	27608				
0.012697	12820						
0.013063	13219						
0.01346	13622						
0.013826	14025						
0.014253	14421						

Table

Results of Compressive Test on Specimen E.2

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.016298	15166				
0.00116	354	0.016665	15562				
0.002045	760	0.017061	15964				
0.002655	1158	0.017458	16361				
0.003174	1556	0.017824	16762				
0.003693	1955	0.018252	17159				
0.004151	2356	0.018649	17562				
0.004578	2756	0.019076	17965				
0.004944	3159	0.019503	18363				
0.005372	3558	0.01993	18763				
0.005769	3958	0.020327	19162				
0.006135	4355	0.020755	19562				
0.006532	4759	0.021212	19964				
0.006928	5158	0.02164	20368				
0.007356	5559	0.022067	20763				
0.007661	5959	0.022494	21165				
0.008058	6359	0.022983	21566				
0.008424	6757	0.02344	21966				
0.008821	7160	0.023898	22366				
0.009187	7558	0.024387	22764				
0.009553	7961	0.024936	23165				
0.00995	8356	0.025455	23565				
0.010316	8759	0.025943	23967				
0.010652	9159	0.026493	24368				
0.011018	9562	0.027011	24766				
0.011384	9959	0.02753	25168				
0.011751	10362	0.028171	25569				
0.012117	10761	0.028721	25966				
0.012483	11160	0.029392	26366				
0.01285	11563	0.030033	26765				
0.013246	11961	0.030796	27165				
0.013643	12361	0.031651	27554				
0.014009	12761						
0.014376	13159						
0.014711	13560						
0.015139	13963						
0.015505	14360						
0.015902	14763						

Table

Results of Compressive Test on Specimen E.3

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.01581	4806	0.032505	21094		
0.000366	9	0.016237	5154	0.032871	21458		
0.000793	16	0.016664	5515	0.033329	21809		
0.001251	28	0.017061	5880	0.033726	22165		
0.001617	40	0.017488	6253	0.034153	22508		
0.002075	52	0.017916	6637	0.034519	22842		
0.002441	64	0.018343	7028	0.034977	23151		
0.002899	78	0.01874	7426	0.035374	23467		
0.003327	93	0.019167	7834	0.035801	23764		
0.003723	110	0.019564	8246	0.036229	24046		
0.004151	135	0.019991	8655	0.036595	24309		
0.004578	153	0.020449	9071	0.037083	24552		
0.005005	176	0.020815	9498	0.03748	24750		
0.005341	199	0.021273	9920	0.037846	24983		
0.005768	231	0.02167	10347	0.038273	25211		
0.006226	263	0.022036	10774	0.038731	25434		
0.006684	302	0.022494	11211	0.039311	25638		
0.00702	351	0.022921	11638				
0.007508	423	0.023318	12073				
0.007905	525	0.023776	12508				
0.008332	643	0.024173	12935				
0.008698	782	0.024569	13369				
0.009095	934	0.024966	13794				
0.009583	1094	0.025424	14226				
0.009919	1270	0.025851	14654				
0.010377	1445	0.026218	15075				
0.010804	1645	0.026675	15496				
0.011232	1850	0.027072	15922				
0.011628	2045	0.027499	16334				
0.012086	2265	0.027896	16743				
0.012452	2501	0.028324	17158				
0.01288	2735	0.028751	17570				
0.013307	2990	0.029148	17980				
0.013734	3252	0.029514	18377				
0.014162	3538	0.029941	18783				
0.014528	3834	0.030338	19181				
0.014986	4145	0.030765	19571				
0.015413	4472	0.031193	19961				

Table

Summary of Laboratory Measurements of the Dimensions of 2-Inch Cube Specimens for a Water/Cement Ratio of 0.40 Cured for 7 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Length	Width	Height		
7	F1	1.960	2.011	2.000		
		1.965	2.011	2.002		
		1.985	2.012	2.004		
	Average	1.970	2.011	2.002	3.962	7.931
7	F2	1.983	2.006	2.011		
		1.983	2.009	2.014		
		1.988	2.010	2.014		
	Average	1.985	2.008	2.013	3.986	8.024
7	F3	1.976	2.009	2.000		
		1.974	2.009	2.001		
		1.980	2.010	2.002		
	Average	1.977	2.009	2.001	3.972	7.948

Table

Results of Compressive Test on Specimen F.1

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015841	579	0.031681	11314	0.048407	28548
0.000397	5	0.016237	637	0.032139	11754	0.048804	28922
0.000824	8	0.016665	710	0.032566	12218	0.0492	29311
0.001221	11	0.017062	797	0.032902	12680	0.049658	29649
0.001648	12	0.017458	902	0.033329	13137	0.049994	30009
0.002106	17	0.017947	1015	0.033787	13594	0.050452	30361
0.002472	22	0.018282	1131	0.034153	14060	0.050818	30729
0.0029	26	0.01871	1267	0.034611	14519	0.051276	31089
0.003327	32	0.019137	1418	0.035039	14972	0.051673	31388
0.003724	37	0.019564	1583	0.035435	15429	0.052131	31735
0.004151	43	0.019992	1734	0.035832	15873	0.052527	32073
0.004548	55	0.020419	1912	0.036259	16341	0.052955	32402
0.005006	61	0.020816	2073	0.036687	16798	0.053321	32649
0.005402	73	0.021243	2250	0.037175	17246	0.053779	32986
0.005799	84	0.02164	2454	0.037511	17695	0.054206	33303
0.006257	95	0.022036	2652	0.037999	18147	0.054603	33555
0.006623	102	0.022494	2875	0.038335	18588	0.054908	33722
0.007112	109	0.022922	3124	0.038793	19039		
0.007508	119	0.023349	3376	0.039251	19493		
0.007875	130	0.023746	3679	0.039617	19937		
0.008332	142	0.024173	3959	0.040014	20365		
0.00876	156	0.0246	4247	0.040471	20811		
0.009126	166	0.025028	4580	0.040899	21245		
0.009553	180	0.025455	4922	0.041295	21678		
0.009981	189	0.025821	5305	0.041295	21678		
0.010438	205	0.026279	5676	0.041692	22099		
0.010774	212	0.026676	6063	0.04212	22536		
0.011262	235	0.027073	6460	0.042577	22966		
0.011659	246	0.0275	6861	0.042974	23376		
0.012087	264	0.027927	7302	0.043401	23792		
0.012453	289	0.028354	7731	0.043798	24208		
0.012911	310	0.028751	8165	0.044195	24622		
0.013277	334	0.029209	8600	0.044622	25018		
0.013735	365	0.029575	9054	0.045019	25420		
0.014162	394	0.030003	9501	0.045477	25835		
0.014559	424	0.03046	9944	0.045935	26238		
0.014986	475	0.030857	10405	0.046331	26616		
0.015383	514	0.031284	10861	0.046698	27022		

Table

Results of Compressive Test on Specimen F.2

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015841	2863	0.031712	16765	0.047583	31602
0.000427	5	0.016298	3058	0.032109	17194	0.04798	31901
0.000855	6	0.016726	3292	0.032536	17623	0.048407	32163
0.001251	11	0.017092	3519	0.032994	18067	0.048834	32412
0.001679	17	0.017519	3763	0.03339	18490	0.049231	32652
0.002076	23	0.017916	3991	0.033818	18919	0.049628	32865
0.002503	32	0.018374	4294	0.034245	19352	0.050055	33038
0.0029	44	0.01874	4548	0.034672	19775		
0.003357	70	0.019167	4867	0.0351	20199		
0.003754	99	0.019625	5118	0.035496	20625		
0.004273	104	0.020053	5457	0.035893	21048		
0.004792	124	0.02048	5802	0.03632	21467		
0.005006	130	0.020816	6161	0.036748	21881		
0.005402	159	0.021273	6516	0.037145	22297		
0.00583	186	0.021701	6814	0.037602	22709		
0.006257	201	0.022128	7186	0.037999	23118		
0.006654	250	0.022555	7560	0.038365	23526		
0.007081	292	0.022952	7952	0.038762	23938		
0.007508	325	0.023379	8340	0.03922	24333		
0.007936	389	0.023776	8741	0.039556	24735		
0.008363	452	0.024234	9138	0.040075	25131		
0.008821	514	0.024631	9539	0.040471	25525		
0.009187	592	0.025058	9953	0.040899	25923		
0.009553	673	0.025516	10373	0.041295	26317		
0.010011	760	0.025882	10791	0.041723	26696		
0.010438	850	0.026309	11201	0.042119	27083		
0.010835	954	0.026767	11629	0.042547	27465		
0.011232	1068	0.027134	12045	0.042974	27834		
0.01169	1186	0.02753	12465	0.043371	28208		
0.012087	1316	0.027988	12897	0.043798	28576		
0.012514	1453	0.028385	13320	0.044256	28934		
0.012941	1598	0.028782	13753	0.044622	29290		
0.013368	1752	0.029209	14186	0.04505	29645		
0.013796	1906	0.029667	14611	0.045477	29983		
0.014131	2079	0.030064	15038	0.045904	30323		
0.01462	2260	0.03043	15474	0.046301	30665		
0.015017	2455	0.030918	15902	0.046728	30979		
0.015444	2652	0.031315	16326	0.047186	31301		

Table

Results of Compressive Test on Specimen F.3

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015811	3905	0.031651	17209	0.04737	28547
0.000397	2	0.016177	4163	0.032078	17612		
0.000794	3	0.016604	4448	0.032475	18014		
0.001221	5	0.017031	4705	0.032872	18403		
0.001618	8	0.017459	5018	0.03333	18806		
0.002045	11	0.017886	5266	0.033696	19202		
0.002503	14	0.018283	5573	0.034154	19604		
0.002869	18	0.018741	5885	0.03452	20007		
0.003297	24	0.019137	6191	0.034978	20411		
0.003694	44	0.019565	6525	0.035405	20809		
0.004121	67	0.019961	6811	0.035802	21208		
0.004548	98	0.020358	7130	0.036229	21612		
0.004975	133	0.020847	7469	0.036657	21997		
0.005433	183	0.021243	7797	0.037023	22397		
0.005769	224	0.02161	8128	0.037511	22793		
0.006196	278	0.022067	8471	0.037908	23182		
0.006624	340	0.022464	8833	0.038335	23555		
0.007051	424	0.022922	9196	0.038732	23935		
0.007417	517	0.023319	9549	0.039129	24312		
0.007875	540	0.023716	9910	0.039617	24678		
0.008302	684	0.024112	10287	0.039983	25037		
0.008699	827	0.024509	10649	0.04038	25378		
0.009126	986	0.024936	11029	0.040777	25708		
0.009523	626	0.025394	11403	0.041204	25586		
0.009981	816	0.025822	11778	0.041662	25827		
0.010378	1019	0.026188	12157	0.04212	25987		
0.010805	1222	0.026646	12534	0.042456	25906		
0.011171	1416	0.027042	12912	0.042852	26135		
0.011568	1599	0.027439	13307	0.043341	26396		
0.012026	1795	0.027866	13693	0.043707	26666		
0.012453	2007	0.028294	14078	0.044134	26943		
0.01285	2230	0.028752	14455	0.044531	27056		
0.013277	2454	0.029118	14844	0.044958	27249		
0.013735	2690	0.029515	15238	0.045386	27512		
0.014101	2912	0.030003	15641	0.045813	27719		
0.014529	3157	0.030369	16025	0.04621	27927		
0.014925	3406	0.030796	16411	0.046668	28157		
0.015383	3649	0.031224	16807	0.047064	28374		

Table

Summary of Laboratory Measurements of the Dimensions of 2-Inch Cube Specimens for a Water/Cement Ratio of 0.40 Cured for 14 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Length	Width	Height		
14	G1	1.897	1.871	1.905		
		1.897	1.873	1.902		
		1.898	1.850	1.900		
	Average	1.897	1.865	1.902	3.538	6.729
14	G2	1.896	1.857	1.903		
		1.899	1.867	1.904		
		1.899	1.873	1.903		
	Average	1.898	1.866	1.903	3.542	6.740
14	G3	1.895	1.845	1.904		
		1.900	1.845	1.903		
		1.901	1.860	1.902		
	Average	1.899	1.850	1.903	3.513	6.686

Table

Results of Compressive Test on Specimen G.1

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015841	2777	0.031681	19155		
0.000366	3	0.016207	3029	0.032078	19601		
0.000794	3	0.016634	3293	0.032505	20045		
0.001251	5	0.017061	3591	0.032902	20478		
0.001679	6	0.017458	3901	0.033329	20927		
0.002045	9	0.017916	4239	0.033787	21359		
0.002472	14	0.018313	4609	0.034123	21794		
0.002838	21	0.018679	5002	0.034581	22221		
0.003327	26	0.019076	5404	0.034947	22648		
0.003724	38	0.019564	5843	0.035405	23066		
0.004151	52	0.01993	6266	0.035832	23486		
0.004487	72	0.020388	6710	0.036229	23906		
0.004944	93	0.020816	7151	0.036656	24321		
0.005372	118	0.021212	7603	0.037114	24728		
0.005799	148	0.021701	8058	0.03745	25136		
0.006196	174	0.022036	8523	0.037877	25543		
0.006654	209	0.022433	8981	0.038335	25948		
0.00702	235	0.022921	9440	0.038732	26341		
0.007478	273	0.023318	9912	0.039159	26729		
0.007844	311	0.023715	10374	0.039586	27120		
0.008302	348	0.024142	10837	0.040013	27503		
0.008699	401	0.024539	11317	0.04038	27887		
0.009095	464	0.024966	11790	0.040746	28264		
0.009523	534	0.025424	12256	0.041204	28631		
0.00998	603	0.025821	12720	0.041631	29001		
0.010347	691	0.026218	13193	0.042028	29358		
0.010835	778	0.026615	13658	0.042455	29720		
0.011201	874	0.027072	14122	0.042852	30074		
0.011659	983	0.0275	14591	0.043279	30413		
0.012056	1096	0.02896	15058	0.043706	30744		
0.012483	1228	0.028293	15522	0.044134	31069		
0.01291	1367	0.028751	15982	0.044561	31399		
0.013277	1525	0.029148	16439	0.044958	31710		
0.013735	1699	0.029575	16897	0.045355	32024		
0.014131	1891	0.030033	17353	0.045782	32302		
0.01462	2089	0.030399	17812	0.046209	32581		
0.014986	2303	0.030857	18264	0.046606	32841		
0.015413	2539	0.031254	18707	0.047216	33076		

Table

Results of Compressive Test on Specimen G.2

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.016237	917	0.032108	14636	0.047948	30268
0.000366	3	0.016695	1051	0.032535	15096	0.048345	30598
0.000824	9	0.017122	1206	0.032963	15554	0.048742	30924
0.001281	12	0.017488	1381	0.033359	16007	0.049169	31237
0.001678	18	0.017916	1569	0.033787	16462	0.049566	31535
0.002075	24	0.018343	1764	0.034244	16915	31826	31826
0.002502	32	0.01877	1975	0.034611	17368	0.050451	32098
0.002899	38	0.019197	2207	0.035007	17815	0.050848	32356
0.003326	44	0.019594	2454	0.035435	18267	0.051245	32601
0.003754	53	0.020021	2724	0.035832	18714	0.051703	32801
0.004181	60	0.020418	2933	0.036259	19163	0.052099	32914
0.004578	67	0.020846	3206	0.036656	19599		
0.004944	73	0.021242	3498	0.037113	20037		
0.005432	81	0.02167	3803	0.03748	20475		
0.005829	89	0.022097	4122	0.037938	20909		
0.006256	95	0.022494	4445	0.038334	21339		
0.006745	102	0.022921	4804	0.038792	21765		
0.007172	107	0.023318	5193	0.039158	22192		
0.007569	118	0.023776	5598	0.039616	22607		
0.008362	134	0.024203	6008	0.039982	23028		
0.008881	142	0.0246	6432	0.04041	23443		
0.009217	151	0.025027	6867	0.040837	23866		
0.009614	162	0.025454	7296	0.041264	24277		
0.010011	182	0.025821	7737	0.041661	24684		
0.010377	204	0.026278	8187	0.042058	25087		
0.010804	229	0.026675	8636	0.042485	25488		
0.011262	258	0.027133	9097	0.042943	25882		
0.011659	290	0.02753	9549	0.04334	26283		
0.012086	319	0.027957	10016	0.043767	22663		
0.012452	357	0.028323	10476	0.044164	27043		
0.01291	392	0.028751	10946	0.044622	27425		
0.013368	433	0.029147	11409	0.044988	27802		
0.013734	478	0.029575	11865	0.045415	28167		
0.014192	528	0.030002	12331	0.045843	28519		
0.014589	583	0.030429	12790	0.046331	28885		
0.015047	642	0.030887	13248	0.046636	29242		
0.015413	710	0.031253	13721	0.047094	29587		
0.01584	806	0.031681	14180	0.047491	29931		

Table

Results of Compressive Test on Specimen G.3

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.01584	694	0.031712	13342	0.047522	28933
0.000458	8	0.016298	769	0.032139	13812	0.047918	29252
0.000824	9	0.016695	848	0.032536	14278	0.048346	29575
0.001251	12	0.017122	932	0.032993	14736	0.048773	29891
0.001709	15	0.01755	1021	0.033421	15194	0.04917	30196
0.002106	18	0.017916	1103	0.033818	15657	0.049597	30421
0.002503	21	0.018374	1251	0.034214	16117	0.050024	30564
0.00293	26	0.01874	1428	0.034642	16579	0.05033	30678
0.003357	31	0.019167	1621	0.035038	17040		
0.003754	34	0.019595	1837	0.035466	17493		
0.004212	38	0.019991	2088	0.035924	17943		
0.004578	41	0.020449	2343	0.036351	18397		
0.005005	44	0.020846	2616	0.036717	18838		
0.005402	47	0.021304	2915	0.037144	19280		
0.00586	49	0.02164	3220	0.037572	19721		
0.006226	52	0.022097	3534	0.037938	20158		
0.006654	56	0.022555	3869	0.038365	20597		
0.00702	61	0.022952	4215	0.038793	21034		
0.007447	69	0.023349	4564	0.03922	21455		
0.007905	70	0.002381	4946	0.03947	21869		
0.008363	73	0.024203	5338	0.040044	22259		
0.00876	81	0.0246	5736	0.040502	22682		
0.009156	96	0.025027	6127	0.040868	23092		
0.009553	110	0.025455	6570	0.041265	23506		
0.010011	131	0.025882	6989	0.041662	23913		
0.010408	156	0.02634	7432	0.042089	24312		
0.010866	180	0.026737	7874	0.042516	24713		
0.011262	204	0.027133	8303	0.042943	25113		
0.011659	235	0.027591	8758	0.043401	25511		
0.012086	266	0.028018	9217	0.043767	25900		
0.012514	299	0.028354	9649	0.044195	26296		
0.01291	336	0.028812	10119	0.044622	26645		
0.013307	371	0.029239	10573	0.045049	26927		
0.013765	412	0.029606	11029	0.045416	27277		
0.014162	458	0.030094	11493	0.045843	27629		
0.014559	516	0.03046	11954	0.04627	27970		
0.014986	566	0.030887	12419	0.046698	28283		
0.015413	635	0.031284	12888	0.047125	28612		

Table

Summary of Laboratory Measurements of the Dimensions of 2-Inch Cube Specimens for a Water/Cement Ratio of 0.40 Cured for 28 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Length	Width	Height		
28	H1	1.946	2.000	2.002		
		1.951	2.001	2.003		
		1.972	2.001	2.004		
	Average	1.956	2.001	2.003	3.914	7.840
28	H2	1.989	2.005	2.006		
		1.990	2.005	2.002		
		1.990	2.005	2.003		
	Average	1.990	2.005	2.004	3.990	7.996
28	H3	1.980	2.000	2.000		
		1.966	2.000	2.001		
		1.966	2.002	2.006		
	Average	1.971	2.001	2.002	3.944	7.896

Table

Results of Compressive Test on Specimen H.1

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015841	6078	0.03162	23495		
0.000428	6	0.016238	6513	0.032078	23927		
0.000824	9	0.016696	6973	0.032536	24345		
0.001221	11	0.017092	7421	0.032902	24761		
0.001679	15	0.017489	7887	0.033299	25171		
0.002106	25	0.017916	8365	0.033757	25585		
0.002473	38	0.018313	8616	0.034154	25994		
0.00293	49	0.018771	9277	0.034581	26393		
0.003358	66	0.019168	9749	0.035008	26793		
0.003785	90	0.019626	10226	0.035405	27190		
0.004182	121	0.020053	10701	0.035893	27590		
0.004579	160	0.02045	11162	0.036229	27982		
0.005006	211	0.020846	11638	0.036687	28368		
0.005403	267	0.021274	12108	0.037084	28739		
0.00583	327	0.02164	12586	0.037481	29116		
0.006257	394	0.022098	13054	0.037969	29485		
0.006654	481	0.022525	13529	0.038335	29836		
0.007051	569	0.022861	13996	0.038762	30151		
0.007509	681	0.023319	14464	0.03919	30409		
0.007905	804	0.023746	14925	0.039525	30323		
0.008333	934	0.024204	15397	0.040044	30494		
0.00873	1094	0.024601	15868	0.040258	30616		
0.009157	1245	0.025058	16323				
0.009615	1418	0.025455	16798				
0.009981	1589	0.025852	17261				
0.010378	1769	0.026279	17725				
0.010835	1969	0.026676	18179				
0.011232	2184	0.027103	18640				
0.01166	2433	0.0275	19087				
0.012087	2700	0.027958	19537				
0.012484	3005	0.028416	19990				
0.012941	3322	0.028813	20436				
0.013338	3678	0.029209	20883				
0.013766	4046	0.029606	21328				
0.014162	4429	0.030064	21760				
0.01459	4830	0.0304	22192				
0.015017	5235	0.030857	22627				
0.015444	5657	0.031224	23073				

Table

Results of Compressive Test on Specimen H.2

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.01578	2144	0.031651	16708	0.047522	32950
0.000366	6	0.016176	2345	0.032078	17183	0.047919	33282
0.000977	7	0.016634	2550	0.032475	17642	0.048346	33622
0.001404	9	0.017031	2771	0.032902	18117	0.048773	33936
0.001831	13	0.017458	3003	0.033299	18578	0.04917	34251
0.002228	16	0.017886	3244	0.033726	19051	0.049597	34534
0.002564	22	0.018252	3481	0.034153	19521	0.049994	34762
0.00293	26	0.01871	3735	0.034581	19990	0.050391	34917
0.003266	33	0.019167	3999	0.035008	20452	0.050971	35035
0.003724	51	0.019534	4297	0.035374	20908		
0.00409	68	0.019961	4573	0.035802	21371		
0.004578	94	0.020388	4906	0.036198	21825		
0.004975	140	0.020785	5185	0.036687	22280		
0.005402	207	0.021182	5542	0.037053	22733		
0.005769	291	0.02164	5916	0.03748	23188		
0.006196	294	0.022128	6305	0.037908	23644		
0.006593	314	0.022464	6702	0.038335	24087		
0.007051	325	0.022861	7105	0.038732	24530		
0.007478	340	0.023288	7512	0.039159	24968		
0.007875	352	0.023685	7944	0.039586	25407		
0.008271	367	0.024112	8375	0.039983	25839		
0.008699	381	0.024539	8808	0.04038	26260		
0.009157	410	0.024997	9252	0.040807	26684		
0.009553	433	0.025363	9701	0.041234	27104		
0.00992	459	0.025821	10149	0.041631	27540		
0.010408	511	0.026248	10612	0.042089	27946		
0.010805	579	0.026645	11076	0.042516	28360		
0.011232	656	0.027103	11538	0.042883	28767		
0.011629	732	0.027469	12004	0.043249	29173		
0.012026	836	0.027927	12471	0.043737	29579		
0.012483	941	0.028324	12936	0.044164	29973		
0.01288	1063	0.028721	13401	0.044592	30373		
0.013277	1179	0.029117	13872	0.044989	30757		
0.013704	1309	0.029606	14343	0.045446	31145		
0.014101	1457	0.030003	14812	0.045843	31525		
0.014559	1611	0.030369	15297	0.046209	31893		
0.014986	1777	0.030796	15770	0.046637	32242		
0.015322	1954	0.031193	16234	0.047094	32598		

Table

Results of Compressive Test on Specimen H.3

Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)	Platen Displa. (in)	Applied Load (lb.)
0	0	0.015841	5385	0.031651	22317		
0.000367	3	0.016207	5755	0.032109	22763		
0.000794	8	0.016635	6116	0.032475	23213		
0.001191	14	0.017062	6516	0.032933	23648		
0.001618	20	0.017459	6916	0.03333	24089		
0.002045	29	0.017916	7310	0.033788	24530		
0.002442	40	0.018344	7704	0.034184	24957		
0.0029	50	0.018741	8126	0.034551	25400		
0.003327	66	0.019137	8572	0.035008	25813		
0.003755	84	0.019565	8981	0.035405	26241		
0.004151	105	0.019992	9436	0.035802	26666		
0.004579	130	0.020389	9878	0.03626	27088		
0.005036	159	0.020785	10316	0.036626	27494		
0.005403	188	0.021243	10774	0.037053	27919		
0.00583	227	0.02164	11217	0.037481	28333		
0.006227	259	0.022067	11670	0.037877	28728		
0.006654	310	0.022464	12138	0.038305	29137		
0.007081	371	0.022922	12590	0.038701	29525		
0.007478	449	0.023349	13068	0.039159	29941		
0.007936	549	0.023746	13521	0.039526	30326		
0.008302	673	0.024173	13999	0.039953	30709		
0.00873	816	0.02454	14456	0.04038	31106		
0.009096	974	0.024997	14920	0.040838	31487		
0.009554	1155	0.025394	15406	0.041235	31864		
0.009981	1337	0.025791	15857	0.041632	32240		
0.010408	1547	0.026249	16337	0.042059	32592		
0.010805	1778	0.026676	16802	0.042486	32954		
0.011232	2013	0.027103	17269	0.042913	33306		
0.01166	2262	0.0275	17715	0.043341	33628		
0.012087	2524	0.027897	18203	0.043737	33987		
0.012484	2790	0.028355	18659	0.044165	34268		
0.01288	3090	0.028752	19114	0.044592	34553		
0.013308	3386	0.029148	19581	0.045264	34919		
0.013766	3701	0.029606	20039				
0.014162	4017	0.030033	20501				
0.014559	4331	0.0304	20945				
0.015017	4691	0.030796	21420				
0.015383	5027	0.031315	21865				

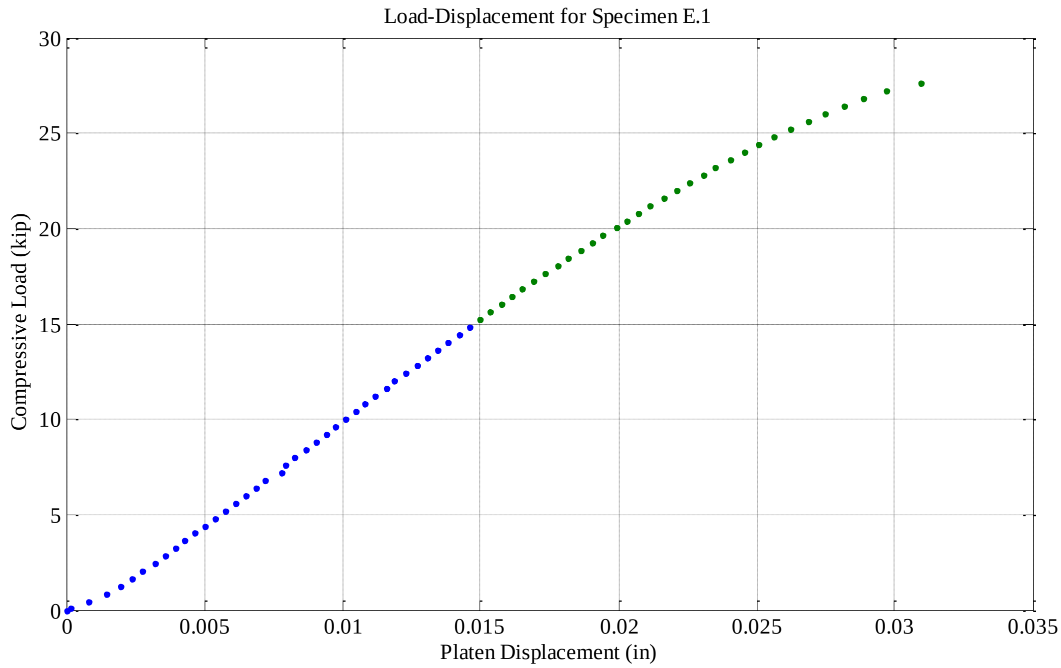

Figure Load-Displacement Curve for E.1

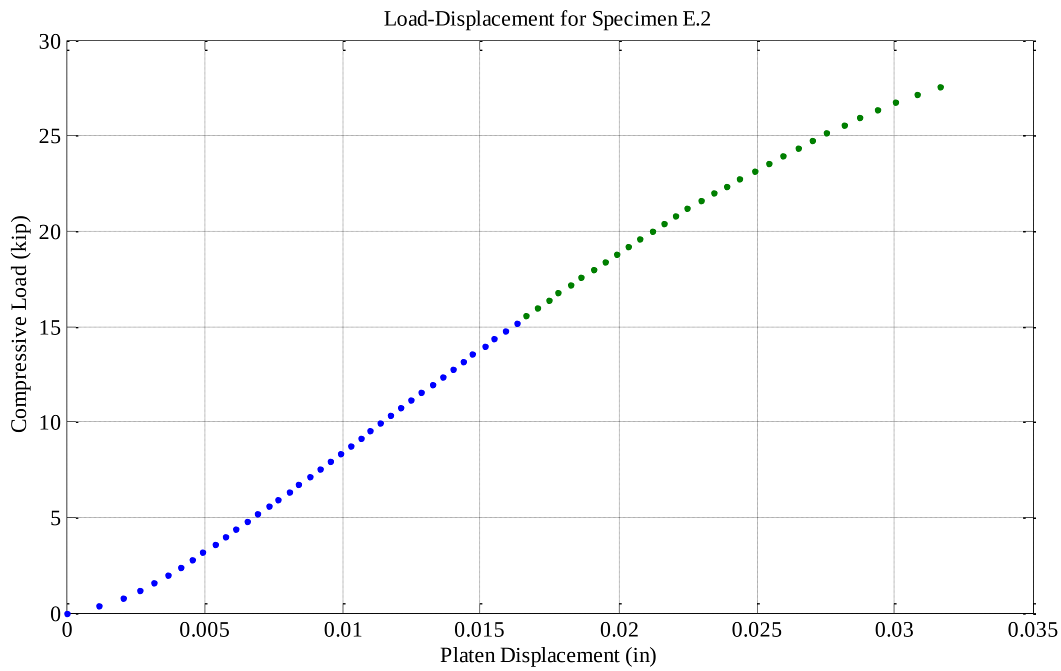

Figure Load-Displacement Curve for E.2

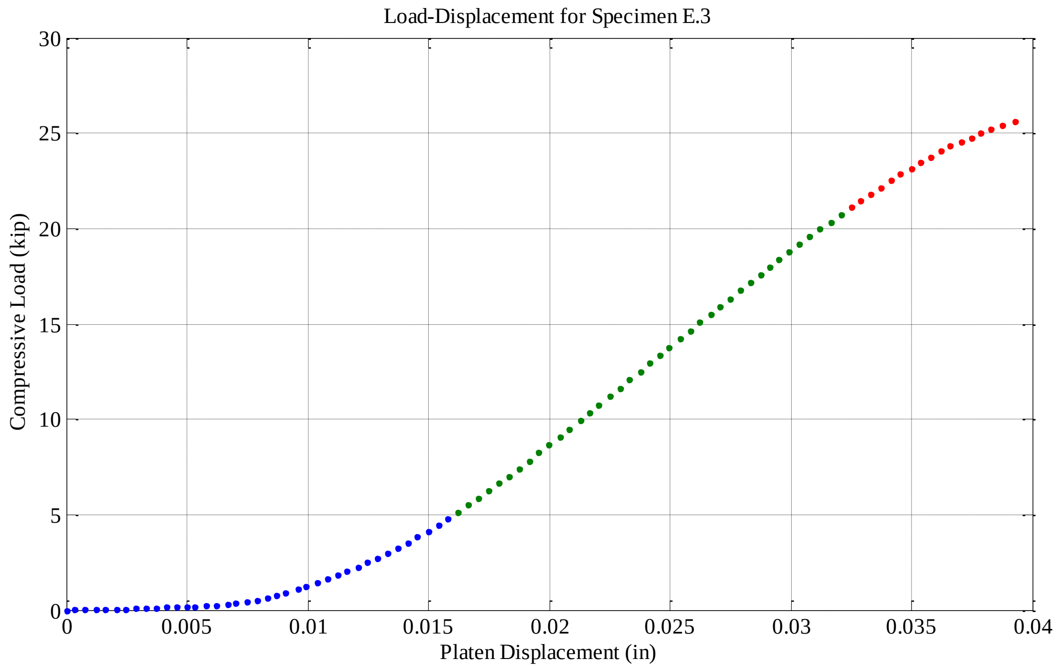

Figure Load-Displacement Curve for E.3

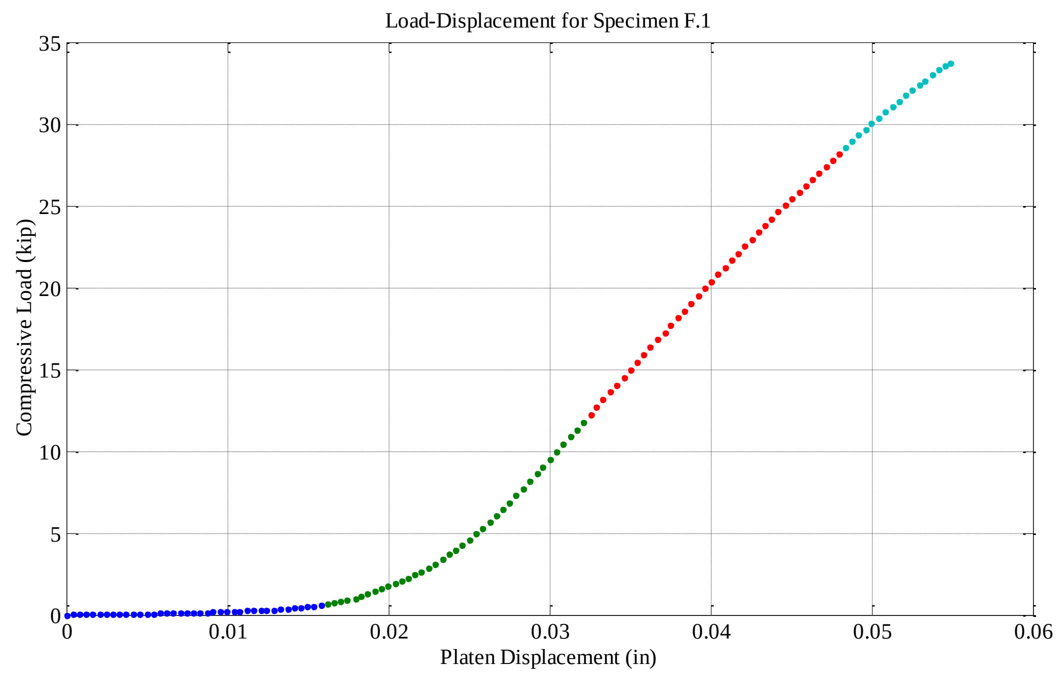

Figure Load-Displacement Curve for F.1

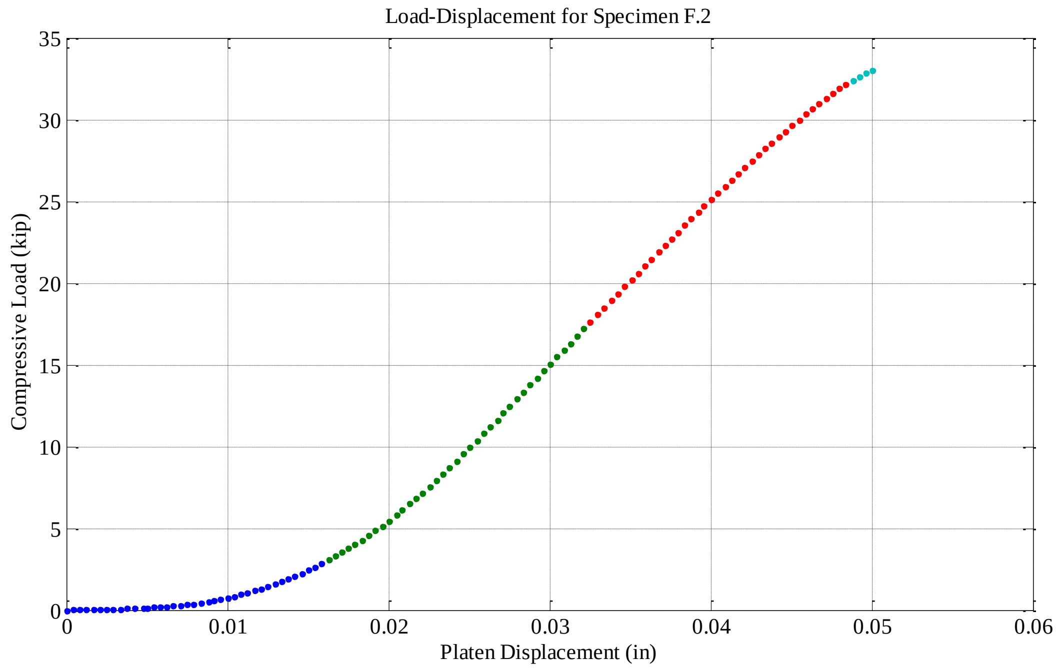

Figure Load-Displacement Curve for F.2

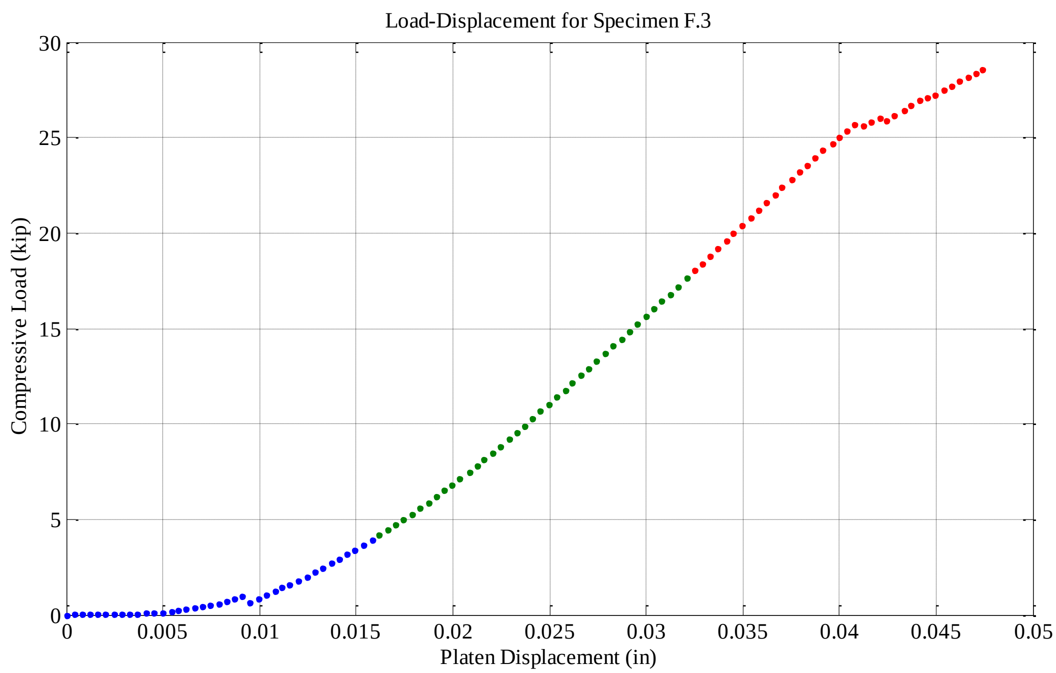

Figure Load-Displacement Curve for F.3

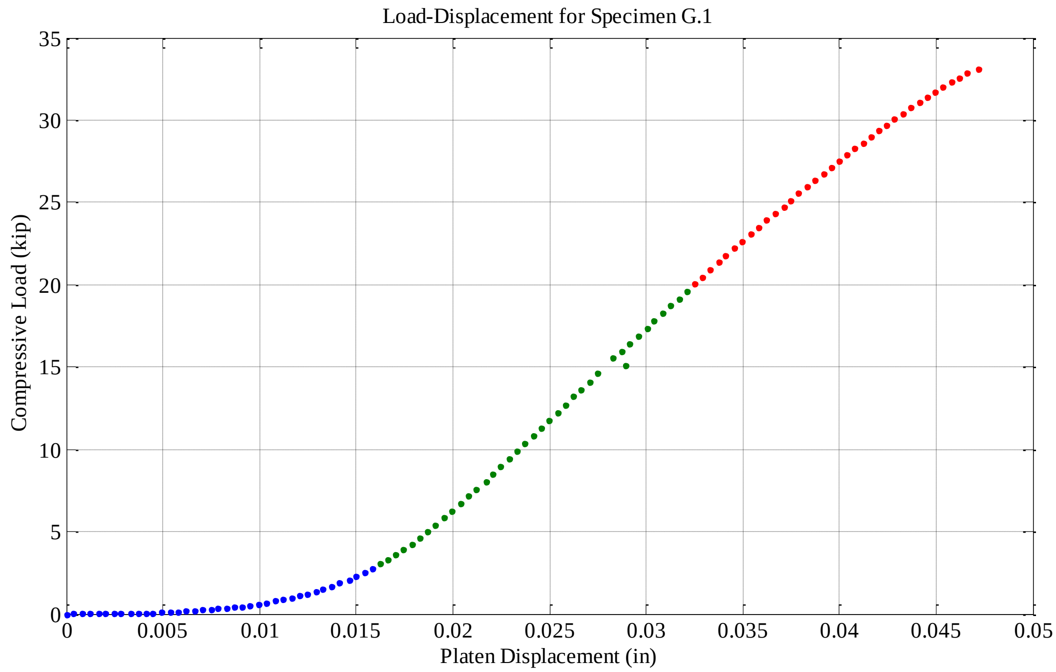

Figure Load-Displacement Curve for G.1

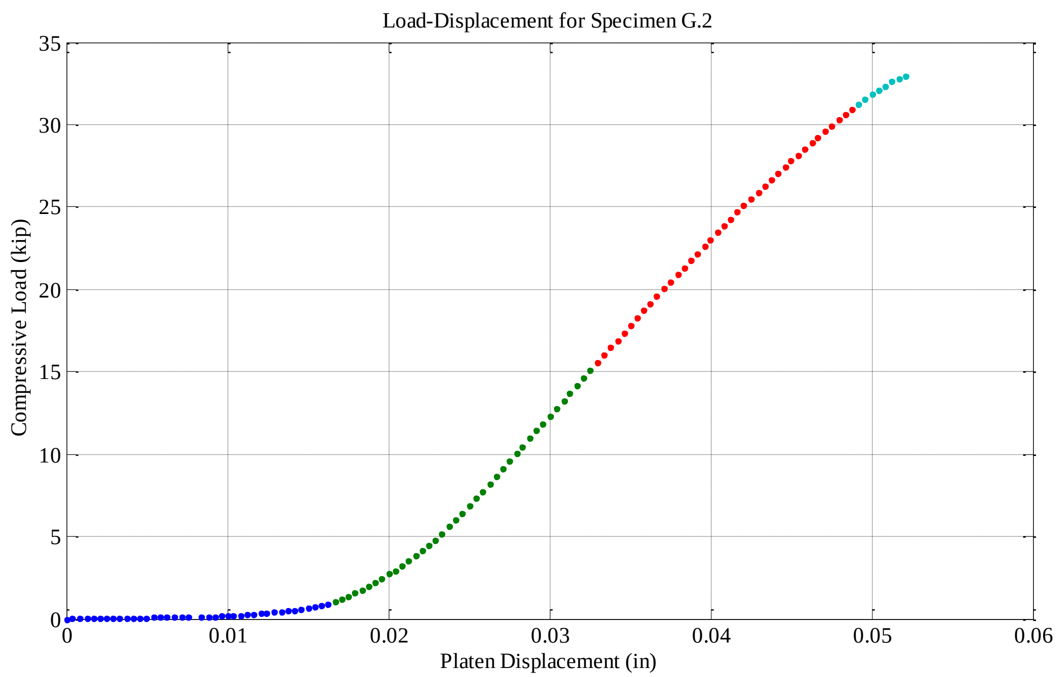

Figure Load-Displacement Curve for G.2

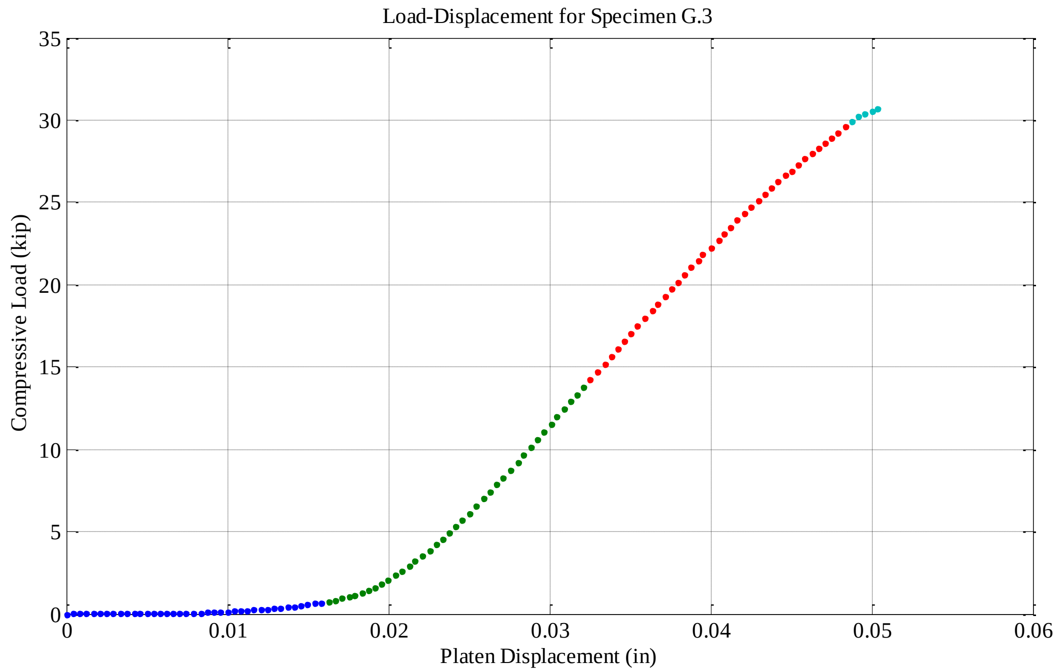

Figure Load-Displacement Curve for G.3

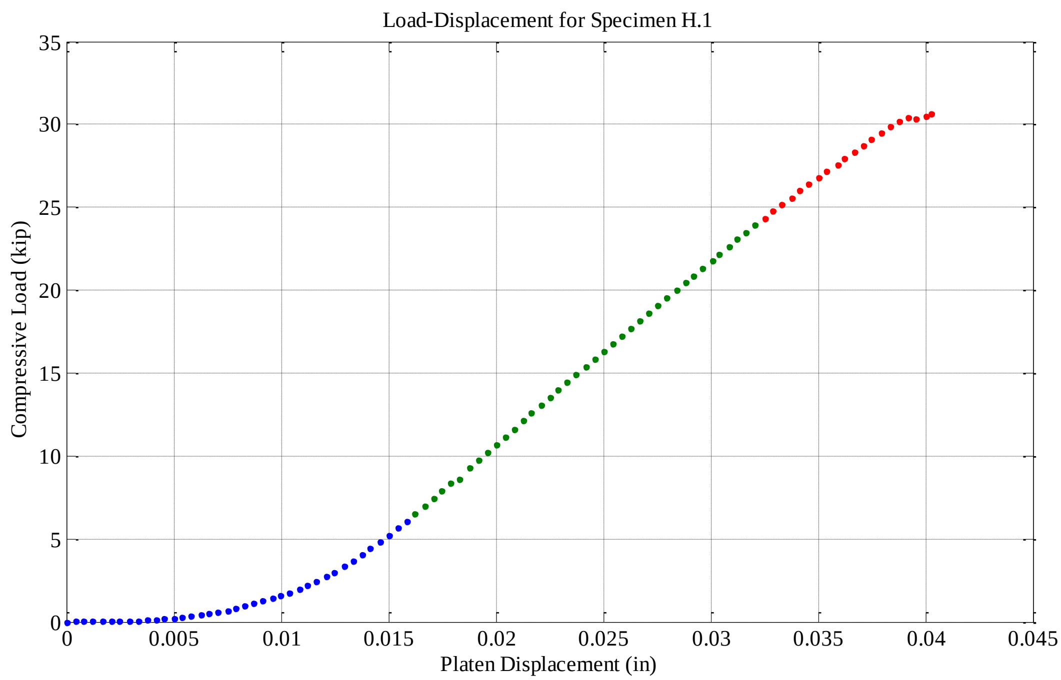

Figure Load-Displacement Curve for H.1

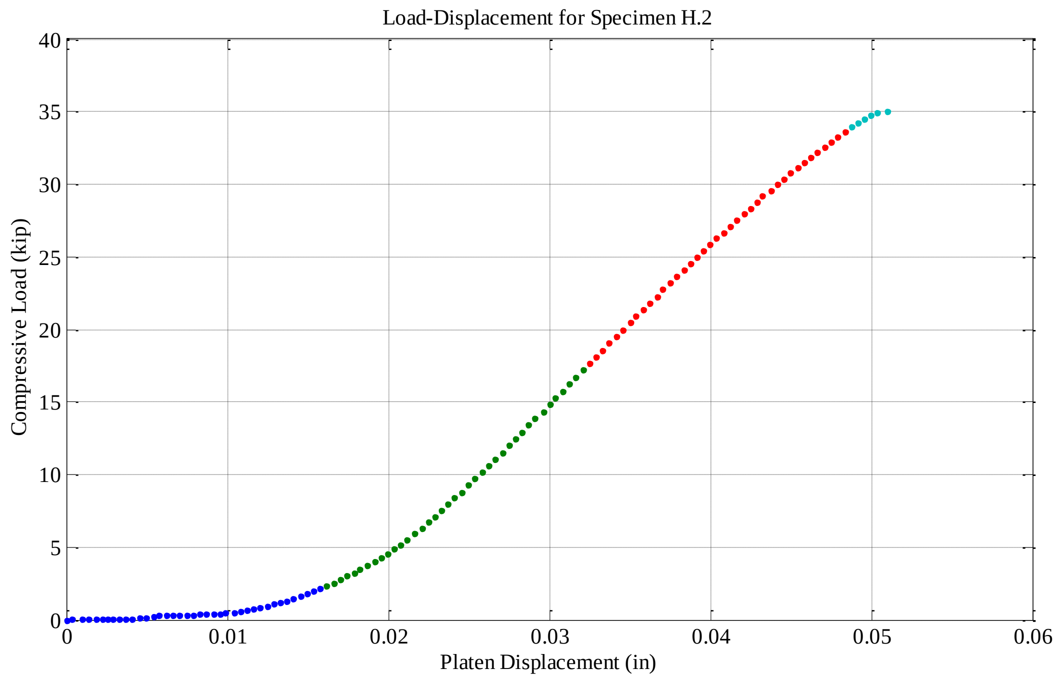

Figure Load-Displacement Curve for H.2

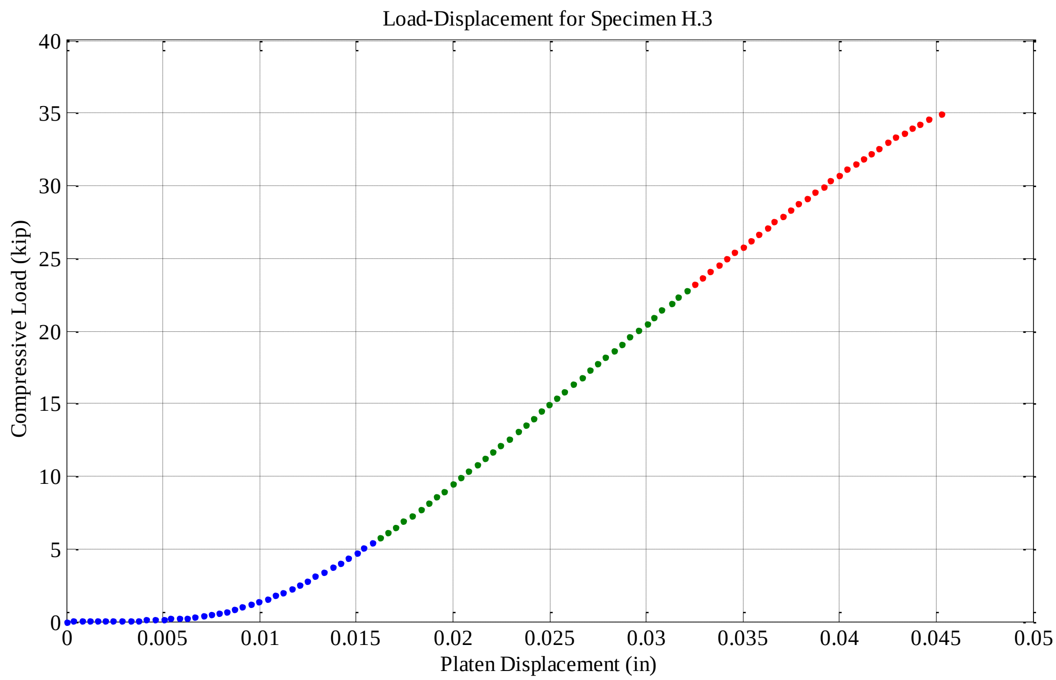

Figure Load-Displacement Curve for H.3

Table

Summary of Average Laboratory Measurements on 2- Inch Cube

Specimens for a Water/Cement Ratio of 0.40

Curing Time (days)	Specimen Designation	Average Dimensions (in)			Specimen Mass (gr)		Failure Load (lb.)
		Length	Width	Height	Before Curing	After Curing	
3	E1	2.001	2.011	2.002	258.12	257.95	26,400
	E2	2.003	2.004	2.005	257.58	257.44	26,300
	E3	2.005	1.994	2.000	256.69	256.63	24,300
7*	F1	1.970	2.011	2.002	258.82	259.35	32,000
	F2	1.985	2.008	2.013	260.35	263.38	27,700
	F3	1.977	2.009	2.001	259.46	261.42	30,600
14	G1	1.897	1.865	1.902	253.11	253.05	30,700
	G2	1.898	1.866	1.903	253.25	253.20	30,200
	G3	1.899	1.850	1.903	252.29	252.26	28,500
28	H1	1.956	2.001	2.003	251.57	251.50	29,000
	H2	1.990	2.005	2.004	254.07	253.96	33,500
	H3	1.971	2.001	2.002	252.51	252.42	33,200

*Notice that specimens “F” were the only specimens that gained mass during the curing process.

Appendix D

Table

Record of Stress/Strain for Cylinder C.2 of Neat Paste Cement for a Water/Cement Ratio of 0.35 and Cured for 14 Days

Record Number	First Loading		Second Loading	
	Stress (MPa)	Strain (%)	Stress (MPa)	Strain (%)
1	0.00263	0.52	0.00263	0.59
2	0.00958	1.44	0.00958	1.63
3	0.01916	2.69	0.01916	3.01
4	0.02874	4.16	0.02874	4.50
5	0.03832	5.66	0.03832	6.02
6	0.04790	7.41	0.04790	7.58
7	0.05749	8.84	0.05749	9.33
8	0.06707	10.45	0.06707	10.88
9	0.07665	11.99	0.07665	12.61
10	0.08623	13.45	0.08623	14.13
11	0.09581	15.17	0.09581	15.80
12	0.10060	15.82	0.10060	16.56
13	0.10539	16.74	0.10539	17.50
14	0.11018	17.36	0.11018	18.16
15	0.11497	18.25	0.11497	18.98
16	0.11976	18.91	0.11976	19.81
17	0.12455	19.76	0.12455	20.60
18	0.12934	20.57	0.12934	21.42
19	0.13413	21.37	0.13413	22.27
20	0.13892	22.15	0.13892	23.21
21	0.14371	22.84	0.14371	24.05
22	0.14850	23.57	0.14850	24.79
23	0.15329	24.35		
24	0.15808	25.05		
Elastic Modulus (MPa)	15,819.2		16,620.1	

Table

Record of Stress/Strain for Cylinder C.3 of Neat Paste Cement for a Water/Cement Ratio of 0.35 and Cured for 14 Days

Record Number	First Loading		Second Loading	
	Stress (MPa)	Strain (%)	Stress (MPa)	Strain (%)
1	0.00263	0.57	0.00263	0.80
2	0.00958	1.82	0.00958	2.01
3	0.01916	3.50	0.01916	3.83
4	0.02874	5.22	0.02874	5.64
5	0.03832	7.04	0.03832	7.37
6	0.04790	8.91	0.04790	9.15
7	0.05749	10.64	0.05749	10.83
8	0.06707	12.49	0.06707	12.78
9	0.07665	14.27	0.07665	14.67
10	0.08623	15.99	0.08623	16.25
11	0.09581	17.64	0.09581	18.14
12	0.10060	18.44	0.10060	18.88
13	0.10539	19.32	0.10539	19.69
14	0.11018	20.18	0.11018	20.60
15	0.11497	21.05	0.11497	21.59
16	0.11976	21.90	0.11976	22.32
17	0.12455	22.64	0.12455	23.32
18	0.12934	23.49	0.12934	24.03
19	0.13413	24.22	0.13413	24.86
20	0.13892	25.07		
Elastic Modulus (MPa)	17,974.9		18,273.5	

Table

Record of Stress/Strain for Cylinder D.2 of Neat Paste Cement for a Water/Cement Ratio of 0.35 and Cured for 28 days

Record Number	First Loading		Second Loading	
	Stress (MPa)	Strain (%)	Stress (MPa)	Strain (%)
1	0.00263	0.56	0.00263	0.63
2	0.00958	1.58	0.00958	1.56
3	0.01916	3.04	0.01916	2.92
4	0.02874	4.43	0.02874	4.30
5	0.03832	5.99	0.03832	5.88
6	0.04790	7.57	0.04790	7.61
7	0.05749	9.25	0.05749	9.24
8	0.06707	11.08	0.06707	11.10
9	0.07665	12.90	0.07665	12.88
10	0.08623	14.51	0.08623	14.67
11	0.09581	16.20	0.09581	16.44
12	0.00263	0.56	0.00263	0.63
Elastic Modulus (MPa)	16,833.9		17,057.6	

Table

Record of Stress/Strain for Cylinder D.3 of Neat Paste Cement for a Water/Cement Ratio of 0.35 and Cured for 28 days

Record Number	First Loading		Second Loading	
	Stress (MPa)	Strain (%)	Stress (MPa)	Strain (%)
1	0.00263	0.69	0.00263	0.80
2	0.00958	1.95	0.00958	2.02
3	0.01916	3.65	0.01916	3.69
4	0.02874	5.45	0.02874	5.42
5	0.03832	7.20	0.03832	7.20
6	0.04790	8.94	0.04790	8.89
7	0.05749	10.73	0.05749	10.74
8	0.06707	12.68	0.06707	12.69
9	0.07665	14.47	0.07665	14.69
10	0.08623	16.20	0.08623	16.28
Elastic Modulus (MPa)	18,559.1		18,550.5	

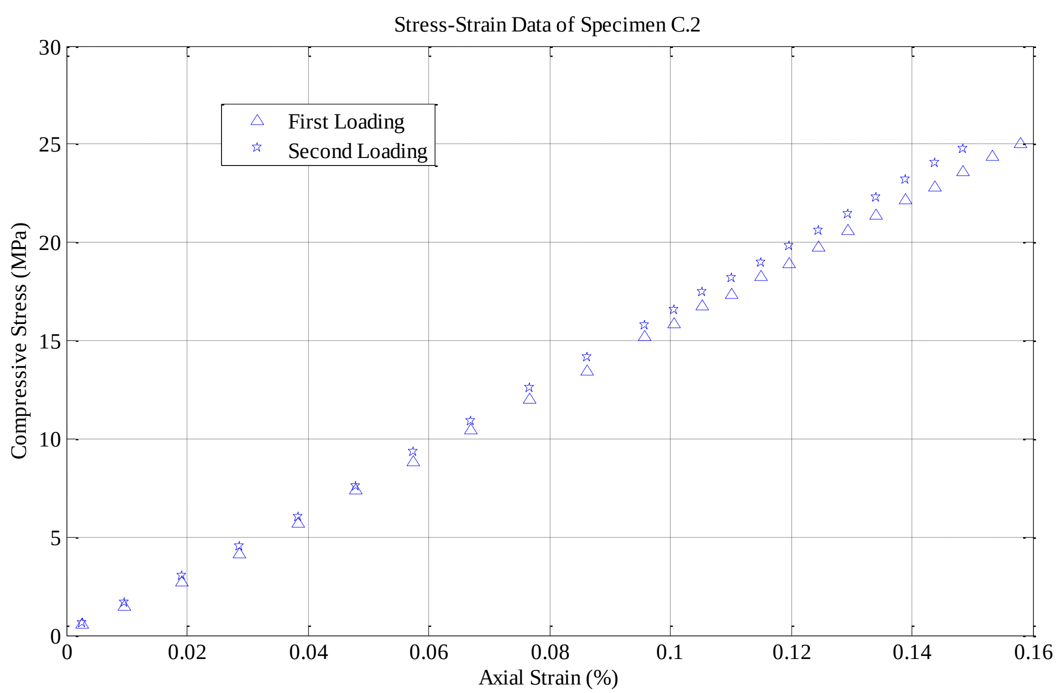

Figure Stress-Stain Plot of Elastic Modulus for Specimen C.2

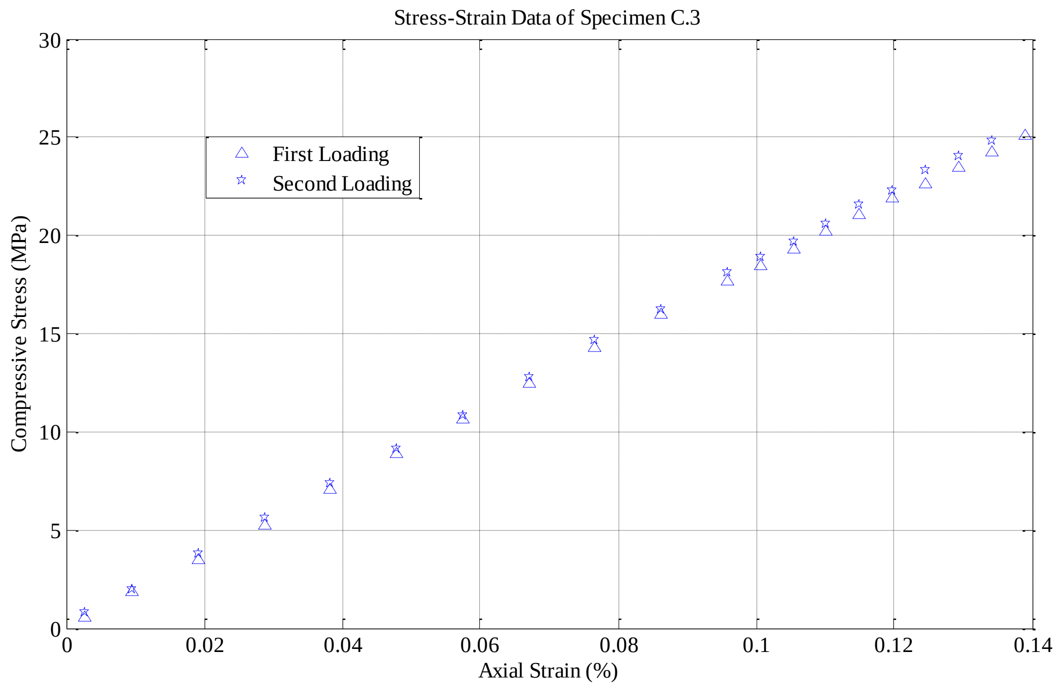

Figure Stress-Stain Plot of Elastic Modulus for Specimen C.3

Figure Stress-Stain Plot of Elastic Modulus for Specimen D.2

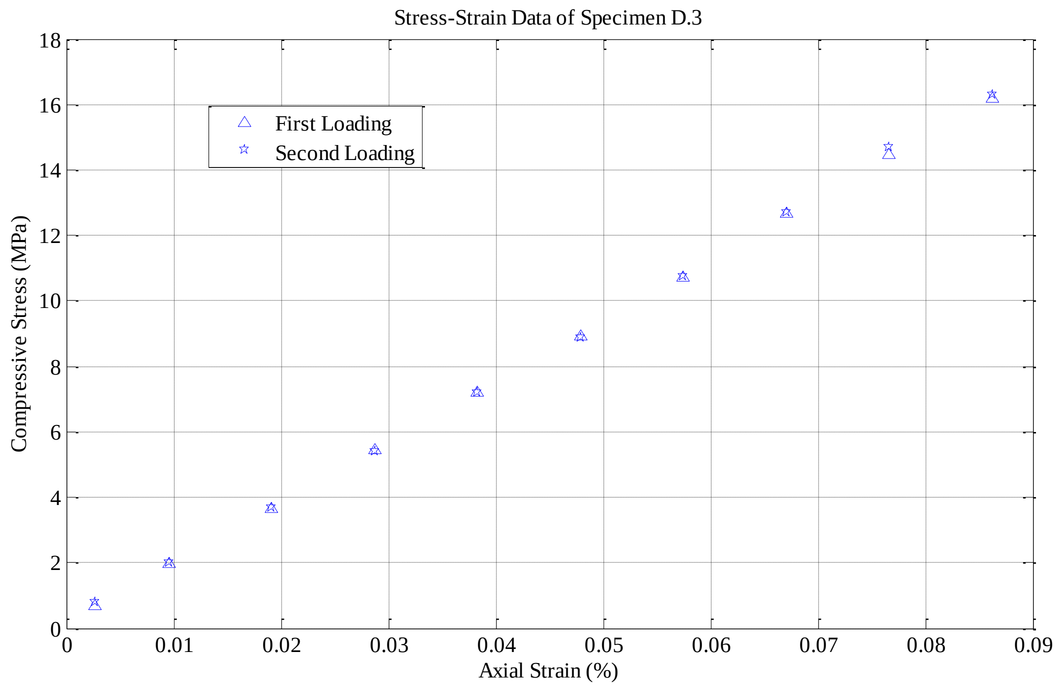

Figure Stress-Stain Plot of Elastic Modulus for Specimen D.3

Appendix E

Table

Summary of Laboratory Measurements of the Dimensions of Prismatic Flexure Specimens for a Water/Cement Ratio of 0.35 Cured During 3 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Width	Height	Length		
3	A.1	1.648	1.599	6.288		
		1.646	1.578	6.288		
		1.608	1.571	6.288		
	Average	1.634	1.583	6.288	2.587	16.265
3	A.2	1.636	1.569	6.295		
		1.661	1.580	6.295		
		1.658	1.576	6.295		
	Average	1.652	1.575	6.295	2.602	16.379
3	A.3	1.666	1.574	6.288		
		1.657	1.572	6.288		
		1.655	1.572	6.288		
	Average	1.659	1.573	6.288	2.610	16.409

Table

Results of Flexure Test on Specimen A.1

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002777	84.97				
0.000091	0.09	0.002869	90.68				
0.000183	0.09	0.002899	92.72				
0.000244	0.18	0.002991	96.17				
0.000305	0.18	0.003052	103.19				
0.000427	0.37	0.003082	112.81				
0.000519	0.43	0.003204	118.91				
0.000549	0.58	0.003296	124.28				
0.00061	0.92	0.003388	131.27				
0.000732	1.04	0.003418	134.75				
0.000793	1.37	0.00351	143.72				
0.000854	1.86	0.003571	149.04				
0.000915	2.08	0.003601	154.01				
0.000976	2.84	0.003632	157.09				
0.001068	3.11	0.003723	163.90				
0.001159	4.40	0.003784	172.93				
0.00119	5.13	0.003906	181.63				
0.001282	5.77	0.003967	187.80				
0.001343	7.69	0.003998	192.41				
0.001434	8.15	0.004028	199.91				
0.001495	11.11	0.00409	203.76				
0.001526	12.36	0.004242	208.03				
0.001648	13.28	0.004273	212.67				
0.001709	17.15	0.004303	222.62				
0.001739	18.13	0.004395	233.43				
0.0018	22.56	0.004517	239.53				
0.001922	26.71						
0.002014	30.77						
0.002075	35.40						
0.002106	37.39						
0.002197	39.74						
0.002258	42.46						
0.002319	47.31						
0.002411	55.15						
0.002533	62.69						
0.002594	64.74						
0.002624	66.81						
0.002686	77.83						

Table

Results of Flexure Test on Specimen A.2

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002686	36.35	0.005341	254.06		
0.000031	0.03	0.002808	44.84	0.005372	263.43		
0.000122	0.09	0.002869	48.10	0.005494	273.26		
0.000214	0.15	0.00293	53.26	0.005525	280.83		
0.000244	0.18	0.003022	57.11	0.005555	284.24		
0.000305	0.12	0.003083	59.88				
0.000366	0.15	0.003144	63				
0.000458	0.27	0.003174	67.54				
0.000489	0.52	0.003235	75.57				
0.00055	0.70	0.003296	81.55				
0.000641	0.89	0.003358	83.54				
0.000702	1.01	0.003449	88.02				
0.000794	1.37	0.00348	90.34				
0.000885	1.50	0.003571	98.80				
0.000916	1.92	0.003663	105.73				
0.000946	2.47	0.003693	113.54				
0.001007	2.72	0.003785	115.31				
0.001068	3.63	0.003846	124.16				
0.001129	3.88	0.003937	127.24				
0.001252	4.76	0.003998	132.83				
0.001313	5.40	0.00406	135.21				
0.001465	5.77	0.004121	144.43				
0.001496	7.57	0.004212	153.37				
0.001587	8.24	0.004334	158.44				
0.001679	9.80	0.004365	166.71				
0.00174	10.47	0.004426	171.68				
0.00177	12.06	0.004517	173.85				
0.001862	13.34	0.004578	181.30				
0.001923	14.22	0.004639	185.36				
0.002015	15.05	0.00467	193.54				
0.002045	17.31	0.004762	203.61				
0.002137	19.35	0.004792	209.01				
0.002198	21.55	0.004884	218.01				
0.002289	22.74	0.005006	220.03				
0.00235	25.88	0.005067	230.01				
0.002472	28.26	0.005128	240.02				
0.002503	30.80	0.005189	245.45				
0.002595	34.24	0.00525	249.36				

Table

Results of Flexure Test on Specimen A.3

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002777	78.07				
0.000061	0.15	0.002808	81.52				
0.000183	0.18	0.002869	83.96				
0.000244	0.18	0.0029	89.52				
0.000336	0.27	0.003022	98.43				
0.000397	0.61	0.003083	103.77				
0.000458	0.82	0.003113	111.59				
0.000549	1.40	0.003174	113.51				
0.000672	2.17	0.003266	116.16				
0.000702	2.20	0.003296	124.25				
0.000855	3.66	0.003357	133.44				
0.000885	4.70	0.003479	140.37				
0.000946	5.86	0.003541	146.07				
0.001007	6.81	0.003632	153.95				
0.001068	7.26	0.003663	160.02				
0.001129	7.87	0.003724	165.43				
0.00116	10.13	0.003815	174.89				
0.001282	11.99	0.003907	179.19				
0.001343	12.82	0.003937	182.76				
0.001404	13.49	0.004059	188.50				
0.001435	14.28	0.00412	198.66				
0.001557	16.76	0.004181	203.97				
0.001618	19.66	0.004212	211.85				
0.001648	21.85	0.004273	223.32				
0.00174	22.77	0.004365	232.27				
0.001801	23.32	0.004456	237.30				
0.001892	28.54	0.004487	247.96				
0.001984	31.16	0.004639	255.04				
0.002045	34.49	0.00467	258.48				
0.002106	36.38	0.004761	262.91				
0.002198	42.36	0.004792	269.75				
0.002259	46.21	0.004853	282.08				
0.00232	49.17	0.004945	290.72				
0.002442	53.90	0.005006	295.05				
0.002503	57.62	0.005067	301.61				
0.002533	61.47	0.005097	306.59				
0.002594	63.73	0.005189	317.21				
0.002686	69.31	0.005219	322.79				

Table

Summary of Laboratory Measurements of the Dimensions of Prismatic Flexure Specimens for a Water/Cement Ratio of 0.35 Cured During 7 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Width	Height	Length		
7	B.1	1.555	1.564	6.285		
		1.568	1.571	6.285		
		1.570	1.571	6.285		
	Average	1.564	1.569	6.285	2.454	15.423
7	B.2	1.600	1.564	6.289		
		1.560	1.565	6.289		
		1.565	1.565	6.289		
	Average	1.575	1.565	6.289	2.465	15.502
7	B.3	1.607	1.567	6.284		
		1.578	1.573	6.284		
		1.573	1.573	6.284		
	Average	1.586	1.571	6.284	2.492	15.657

Table

Results of Flexure Test on Specimen B.1

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002655	55.98				
0.000061	0.06	0.002747	62.89				
0.000152	0.18	0.002777	66.57				
0.000213	0.24	0.002869	68.40				
0.000305	0.31	0.002899	70.81				
0.000397	0.46	0.00296	77.16				
0.000458	0.64	0.003052	84.06				
0.000549	0.92	0.003143	89.64				
0.000641	1.10	0.003174	92.27				
0.000671	1.34	0.003204	97.27				
0.000763	1.89	0.003296	103.59				
0.000763	2.26	0.003357	105.60				
0.000854	2.53	0.003418	111.40				
0.000915	3.48	0.00354	117.17				
0.001007	3.75	0.003571	120.07				
0.001037	3.91	0.003632	129.32				
0.001098	4.52	0.003754	133.56				
0.00119	6.01	0.003784	136.83				
0.001221	7.81	0.003845	147.02				
0.001343	8.55	0.003906	149.80				
0.001434	8.91	0.003998	160.08				
0.001465	9.22	0.004059	163.41				
0.001526	12.18	0.00412	166.52				
0.001587	13.61	0.004212	176.02				
0.001648	15.87	0.004242	180.72				
0.001739	16.30	0.004334	183.49				
0.00177	18.50	0.004395	194.51				
0.001862	20.72	0.004486	199.79				
0.001953	21.85	0.004578	204.13				
0.002045	26.89	0.004608	208.12				
0.002106	28.63	0.004669	212.25				
0.002136	32.96	0.004731	212.67				
0.002258	35.59						
0.002319	39.53						
0.00238	43.80						
0.002441	45.32						
0.002502	47.89						
0.002564	51.43						

Table

Results of Flexure Test on Specimen B.2

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002564	24.72	0.005158	194.79		
0.000122	0.06	0.002625	26.59	0.005189	198.08		
0.000183	0.09	0.002717	29.85	0.00525	203.37		
0.000214	0.15	0.002778	32.23	0.005341	212.92		
0.00275	0.06	0.002808	34.61	0.005464	223.08		
0.000305	0.18	0.00293	38.03	0.005402	227.51		
0.000427	0.12	0.002991	40.26	0.005555	230.41		
0.000458	0.18	0.003052	44.10	0.005586	235.47		
0.000489	0.28	0.003113	45.72	0.005616	243.56		
0.00055	0.40	0.003205	47.25	0.005708	253.39		
0.00058	0.31	0.003266	50.09	0.00583	262.45		
0.000641	0.46	0.003327	55.34	0.005921	266.03		
0.000733	0.76	0.003388	60.56	0.005952	268.62		
0.000763	0.95	0.003449	64.52	0.006013	276.04		
0.000824	0.98	0.003541	66.02	0.006074	286.66		
0.000916	1.44	0.003571	73.07	0.006166	295.81		
0.000977	1.65	0.003693	76.15	0.006196	302.99		
0.001007	1.80	0.003724	79.72	0.006257	305.92		
0.001068	2.41	0.003815	84.61	0.006318	308.63		
0.001191	2.63	0.003846	87.60	0.006379	319.93		
0.001252	3.42	0.003968	91.08	0.006471	330.39		
0.001343	4	0.003998	94.01	0.006562	338.57		
0.001374	4.34	0.00409	101.42	0.006623	343.73		
0.001435	4.58	0.004151	109.76	0.006684	345.14		
0.001526	5.68	0.004212	114.36	0.006715	354.29		
0.001587	7.20	0.004243	119.61	0.006806	362.75		
0.001679	7.82	0.004365	126.15	0.006898	374.01		
0.001709	8.18	0.004456	129.11	0.006959	379.29		
0.001831	8.52	0.004487	132.13	0.00702	381.70		
0.001893	10.81	0.004517	137.62	0.007081	387.71		
0.001954	12.58	0.004639	146.23	0.007142	397.51		
0.002045	13.80	0.00467	154.41	0.007203	408.10		
0.002076	14.32	0.004762	160.30	0.007264	416.62		
0.002167	16.27	0.004823	162.50	0.007325	420.37		
0.002228	17.76	0.004853	165.12				
0.002259	19.02	0.004945	173.79				
0.002381	21.34	0.005006	183.98				
0.002472	22.10	0.005097	190.70				

Table

Results of Flexure Test on Specimen B.3

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002594	76.73	0.005158	302.47		
0.000091	0.03	0.002685	82.56	0.005249	308.51		
0.000152	0.21	0.002747	85.40	0.00531	319.99		
0.000213	0.40	0.002777	88.57	0.005371	329.66		
0.000335	0.49	0.002899	92.39	0.005402	334.55		
0.000366	0.58	0.00293	97.52	0.005493	339.12		
0.000396	0.98	0.002991	106.09	0.005554	344.43		
0.000488	1.44	0.003113	111.34	0.005616	354.54		
0.000549	1.53	0.003174	113.48	0.005677	365.77		
0.00061	1.74	0.003204	124.04	0.005799	372.03		
0.000702	2.41	0.003296	128.13	0.005829	381.18		
0.000763	3.60	0.003387	136.13	0.005921	390.52		
0.000824	5.07	0.003418	140.70	0.005951	393.51		
0.000885	5.86	0.00351	143.51				
0.000946	6.07	0.00354	151.30				
0.001037	6.81	0.003632	156.51				
0.001098	8.49	0.003662	160.27				
0.001159	11.08	0.003723	163.14				
0.00122	12.64	0.003784	169.91				
0.001312	13.34	0.003937	179.25				
0.001343	15.23	0.003937	185.33				
0.001404	16.76	0.004028	189.17				
0.001465	19.05	0.004059	192.96				
0.001556	22.19	0.004151	199.92				
0.001678	23.93	0.004212	208.31				
0.001739	28.45	0.004242	217.10				
0.001831	31.01	0.004334	224.06				
0.001892	35.19	0.004395	230.50				
0.001922	37.73	0.004456	238.07				
0.002014	40.08	0.004547	241.06				
0.002075	44.93	0.004608	244.90				
0.002136	48.71	0.004639	252.41				
0.002228	50.70	0.00473	262.51				
0.002289	52.71	0.004852	272.28				
0.00235	58.27	0.004914	275.64				
0.002441	64.68	0.004975	286.72				
0.002502	70.35	0.005036	294.10				
0.002533	71.70	0.005127	296.39				

Table

Summary of Laboratory Measurements of the Dimensions of Prismatic Flexure Specimens for a Water/Cement Ratio of 0.35 Cured During 14 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Width	Height	Length		
14	C.1	1.587	1.566	6.283		
		1.571	1.572	6.283		
		1.565	1.569	6.283		
	Average	1.574	1.569	6.283	2.470	15.517
14	C.2	1.545	1.565	6.284		
		1.572	1.570	6.284		
		1.569	1.567	6.284		
	Average	1.562	1.567	6.284	2.448	15.381
14	C.3	1.559	1.568	6.285		
		1.670	1.572	6.285		
		1.565	1.567	6.285		
	Average	1.598	1.569	6.285	2.507	15.758

Table

Results of Flexure Test on Specimen C.1

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002686	27.23				
0.000092	0.06	0.002778	29.73				
0.000122	0.06	0.002839	30.40				
0.000183	0.18	0.00293	33.24				
0.000244	0.28	0.002991	37.88				
0.000336	0.24	0.003052	40.44				
0.000427	0.37	0.003174	44.44				
0.000488	0.46	0.003205	47.16				
0.00058	0.58	0.003296	52.10				
0.000611	0.67	0.003357	58.88				
0.000672	0.86	0.003418	62.69				
0.000763	1.04	0.00348	67.24				
0.000794	1.31	0.003541	73.28				
0.000885	1.34	0.003663	77.16				
0.000916	1.74	0.003693	81.77				
0.000977	1.89	0.003754	87.96				
0.001129	2.32	0.003876	95.23				
0.00116	3.14	0.003937	99.04				
0.001282	3.17	0.004029	104.54				
0.001343	2.01	0.00409	112.84				
0.001404	2.59	0.004151	115.28				
0.001496	3.05	0.004212	117.08				
0.001526	3.42	0.004273	123.79				
0.001557	4.46	0.004334	132.68				
0.001648	5.89	0.004426	139.39				
0.001709	6.50	0.004517	143.05				
0.00177	7.57	0.004578	148.27				
0.001801	8.79	0.004609	153.37				
0.001923	9.92	0.004639	159.78				
0.002014	10.38	0.0047	162.53				
0.002045	11.90						
0.002137	13.49						
0.002228	14.44						
0.002289	16.57						
0.002411	20.05						
0.002472	22.59						
0.002564	24.30						
0.002655	25.46						

Table

Results of Flexure Test on Specimen C.2

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002564	85.95				
0.000061	0.21	0.002625	90.74				
0.000122	0.49	0.002747	98.89				
0.000184	0.55	0.002808	104.41				
0.000245	0.82	0.002869	108.69				
0.000306	2.04	0.002961	113.57				
0.000397	2.90	0.003022	118.85				
0.000428	3.69	0.003114	126.97				
0.000519	4.21	0.003175	133.38				
0.00058	5.95	0.003226	138.20				
0.000672	6.87	0.003266	143.85				
0.000733	7.23	0.003358	150.38				
0.000794	8.45	0.003388	155.51				
0.000855	10.10	0.003449	164.39				
0.000977	11.87	0.003571	171.13				
0.001008	13.09	0.003632	176.41				
0.001069	14.50	0.003724	179.04				
0.00113	16.60	0.003785	188.32				
0.001221	18.22	0.003816	192.77				
0.001282	20.08	0.003907	198.39				
0.001374	21.24	0.003968	207.73				
0.001435	22.83	0.00406	216.46				
0.001496	23.32	0.00409	222.26				
0.001587	26.74	0.004151	226.83				
0.001649	29.24	0.004243	235.35				
0.00171	32.57	0.004304	238.62				
0.001801	34.76	0.004395	244.23				
0.001832	38.52	0.004426	253.39				
0.001923	41.05	0.004487	261.35				
0.001954	44.41	0.004579	267.85				
0.002045	48.19	0.004609	273.84				
0.002137	53.38	0.004731	279.24				
0.002198	56.04	0.004792	289.62				
0.002289	61.44	0.004823	298.25				
0.002351	67.67	0.004914	305.70				
0.002412	72.82	0.005006	314.22				
0.002473	78.23	0.005036	313.55				
0.002503	80.18	0.005067	325.75				

Table

Results of Flexure Test on Specimen C.3

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002716	173.67				
0.000061	0.09	0.002747	178.34				
0.000183	0.15	0.0029	190.48				
0.000214	0.15	0.00293	195.86				
0.000305	0.70	0.002991	204.86				
0.000397	0.98	0.003083	216.67				
0.000458	2.56	0.003174	218.69				
0.000549	2.84	0.003205	226.68				
0.000641	5.16	0.003235	230.34				
0.000733	6.32	0.003296	238.16				
0.000763	13.55	0.003357	248.63				
0.000824	15.23	0.00348	256.20				
0.000885	16.33	0.003541	259.55				
0.000977	21.88	0.003632	264.25				
0.001068	28.84	0.003663	273.93				
0.001129	30.22	0.003693	281.74				
0.00116	34.61	0.003785	294.87				
0.001221	37.11	0.003876	300.12				
0.001313	43.55	0.003937	307.04				
0.001404	51.70	0.003998	312.33				
0.001435	56.98	0.004059	323.25				
0.001526	62.33	0.00412	333.72				
0.001587	65.44	0.004151	340.77				
0.001648	71.97	0.004243	344.92				
0.00174	79.72	0.004273	349.87				
0.001801	81.92	0.004365	358.66				
0.001831	91.78	0.004456	371.17				
0.001953	97.79	0.004517	377.06				
0.002015	106.92	0.004548	381.18				
0.002076	110.76						
0.002167	113.02						
0.002228	125.14						
0.002289	132.59						
0.00235	141.86						
0.002442	146.01						
0.002503	156.30						
0.002594	159.20						
0.002686	165.30						

Table

Summary of Laboratory Measurements of the Dimensions of Prismatic Flexure Specimens for a Water/Cement Ratio of 0.35 Cured During 28 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Width	Height	Length		
28	D.1	1.568	1.582	6.283		
		1.566	1.575	6.283		
		1.568	1.571	6.283		
	Average	1.567	1.576	6.283	2.470	15.516
28	D.2	1.575	1.573	6.292		
		1.581	1.570	6.292		
		1.598	1.571	6.292		
	Average	1.585	1.571	6.292	2.490	15.667
28	D.3	1.563	1.573	6.285		
		1.574	1.576	6.285		
		1.595	1.571	6.285		
	Average	1.577	1.573	6.285	2.481	15.591

Table

Results of Flexure Test on Specimen D.1

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002595	57.78				
0.000031	0.15	0.002686	63.73				
0.000122	0.21	0.002778	67.24				
0.000153	0.67	0.002869	74.08				
0.000214	0.92	0.00293	77.07				
0.000306	1.10	0.002961	84.42				
0.000367	1.43	0.003052	90.34				
0.000428	2.04	0.003113	94.28				
0.000519	2.72	0.003175	97.76				
0.00058	2.99	0.003236	101.82				
0.000611	3.33	0.003327	108.84				
0.000672	3.57	0.003388	115.37				
0.000733	4.43	0.003449	120.35				
0.000855	5.28	0.00351	122.05				
0.000885	6.04	0.003602	124.25				
0.000977	6.38	0.003663	130.30				
0.001069	7.42						
0.00116	7.91						
0.001221	8.67						
0.001282	9.68						
0.001343	10.19						
0.001404	11.48						
0.001496	11.75						
0.001526	12.34						
0.001648	14.47						
0.001709	15.35						
0.001801	16.88						
0.001862	18.01						
0.001923	20.51						
0.002015	22.37						
0.002076	23.84						
0.002137	25.30						
0.002198	29.03						
0.002228	34.28						
0.00232	40.14						
0.002411	43.52						
0.002503	46.54						
0.002534	51						

Table

Results of Flexure Test on Specimen D.2

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002625	59.85				
0.000061	0.09	0.002656	64.95				
0.000153	0.15	0.002717	72.58				
0.000244	0.18	0.002808	79.72				
0.000275	0.37	0.00293	84.51				
0.000366	0.95	0.002961	87.20				
0.000428	1.56	0.003022	91.50				
0.000489	2.11	0.003083	97.24				
0.00058	2.32	0.003144	104.54				
0.000641	2.75	0.003235	111.07				
0.00672	3.24	0.003266	114.79				
0.000733	4.21	0.003388	117.90				
0.000824	5.10	0.003449	128.25				
0.000946	5.71	0.00348	131.43				
0.000977	6.26	0.003541	135.21				
0.001038	7.63	0.003632	141.68				
0.001099	8.36	0.003724	150.81				
0.001191	8.76	0.003785	157.67				
0.001252	9.52	0.003846	160.76				
0.001313	11.20	0.003907	163.69				
0.001374	12.48	0.003937	169.49				
0.001465	13.12	0.00406	178.52				
0.001526	14.07	0.004121	184.29				
0.001618	16.33	0.004151	186.18				
0.001709	17.09						
0.00174	19.56						
0.001801	20.91						
0.001862	21.67						
0.001893	23.11						
0.001954	25.58						
0.002045	27.13						
0.002106	32.29						
0.002167	35.44						
0.002228	36.57						
0.002289	40.47						
0.00232	46.70						
0.002442	52.71						
0.002533	57.69						

Table

Results of Flexure Test on Specimen D.3

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002563	84.39				
0.000061	0.06	0.002624	89.52				
0.000091	0.12	0.002685	91.05				
0.000183	0.21	0.002716	92.42				
0.000274	0.18	0.002747	98.40				
0.000305	0.24						
0.000335	0.49						
0.000488	1.28						
0.000518	2.17						
0.00058	3.05						
0.00061	3.72						
0.000702	5.52						
0.000793	6.99						
0.000854	7.63						
0.000915	8.21						
0.000976	9.65						
0.001068	12.12						
0.001159	14.16						
0.00119	15.72						
0.00122	16.05						
0.001312	17.76						
0.001404	20.48						
0.001434	24.14						
0.001495	26.74						
0.001587	27.62						
0.001617	29.27						
0.001678	33.09						
0.00177	37.30						
0.001831	42.67						
0.001953	45.42						
0.001984	50.88						
0.002045	56.56						
0.002136	57.81						
0.002167	60.34						
0.002289	63.97						
0.00238	66.78						
0.002411	71.45						
0.002441	78.26						

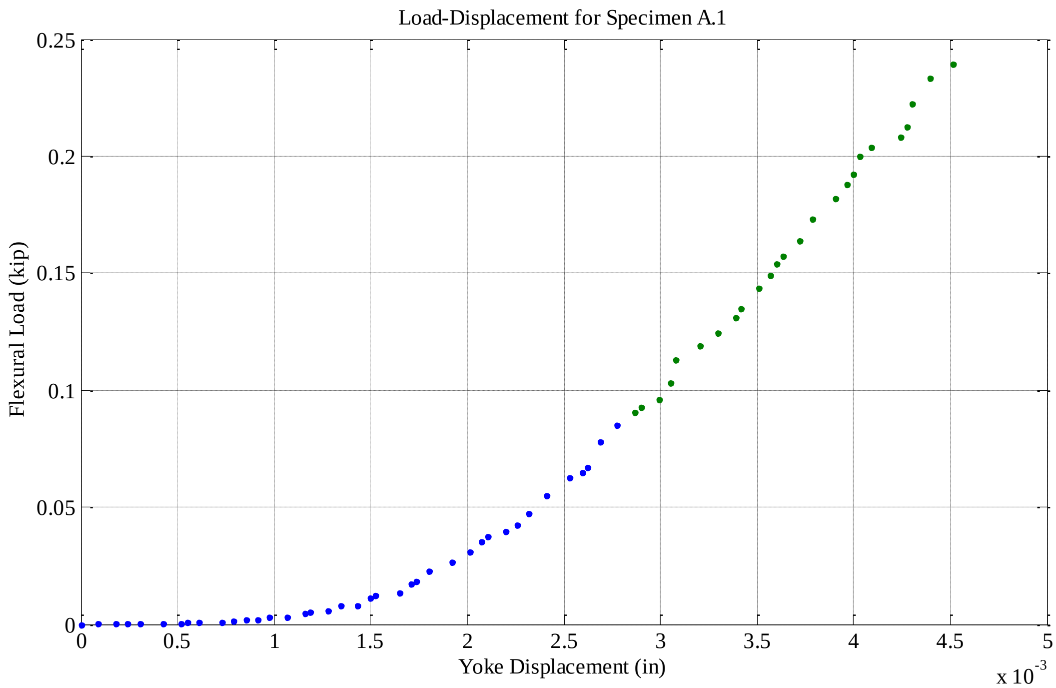

Figure Load-Displacement Curve for A.1

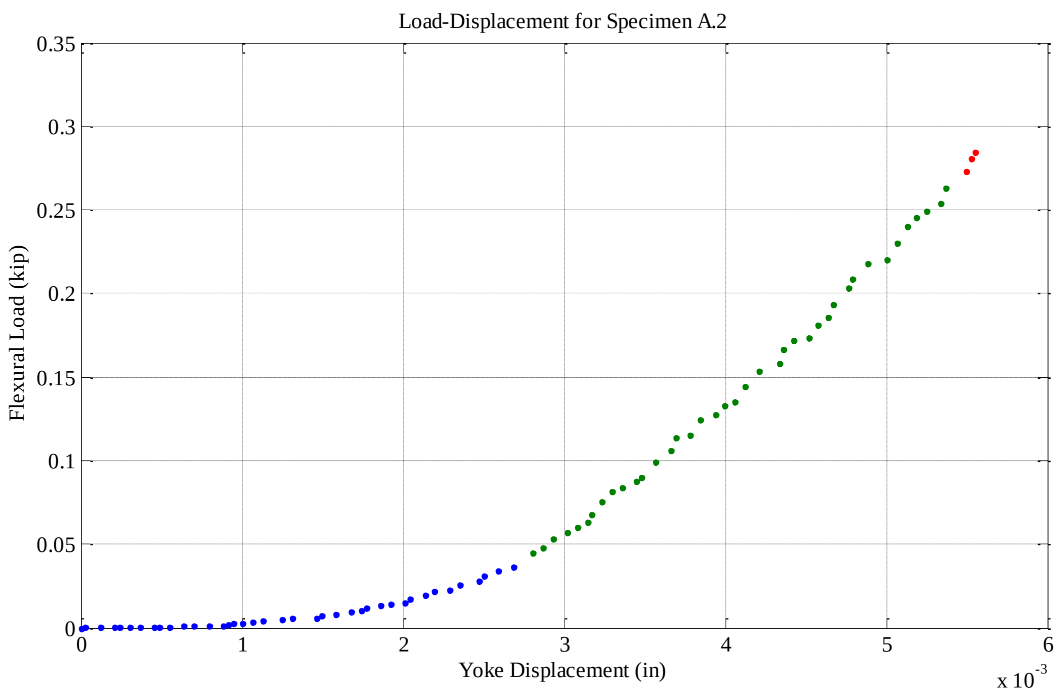

Figure Load-Displacement Curve for A.2

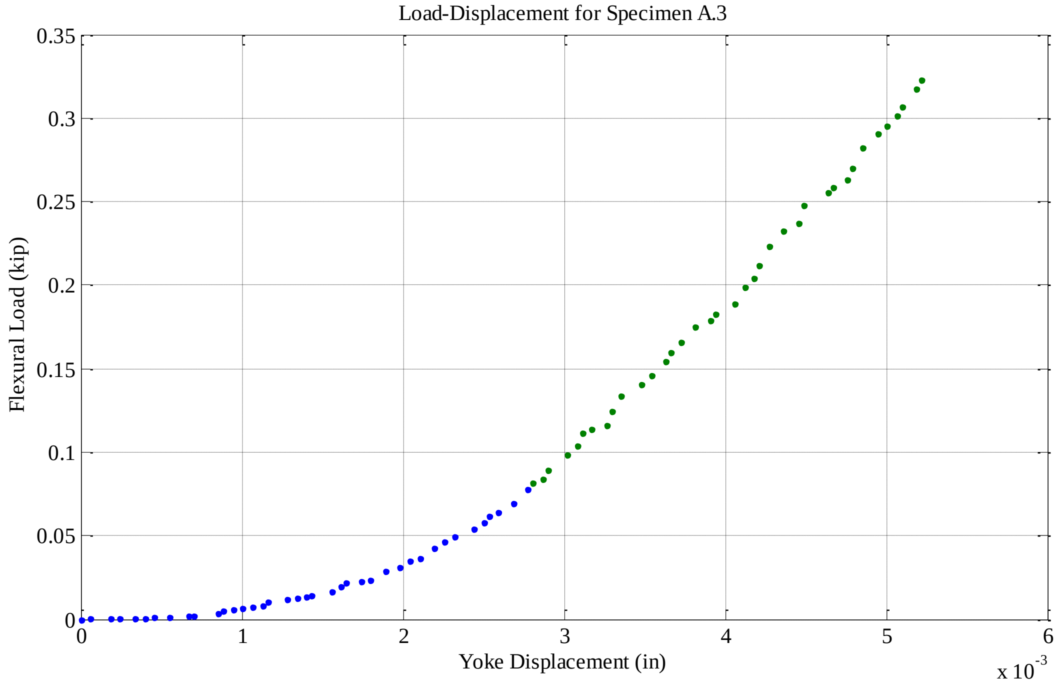

Figure Load-Displacement Curve for A.3

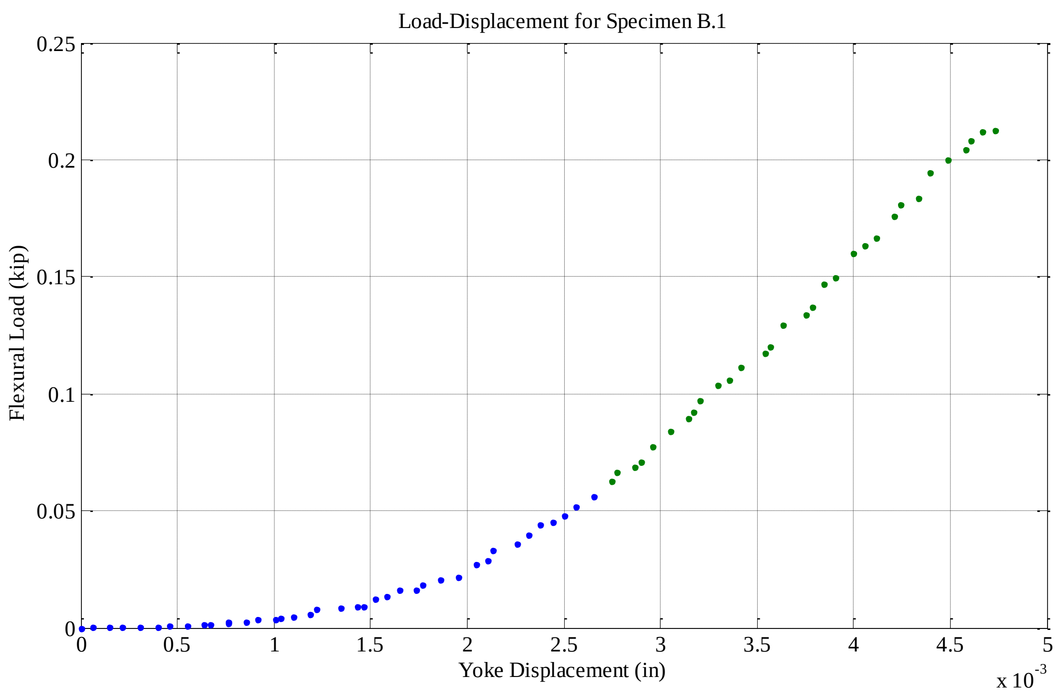

Figure Load-Displacement Curve for B.1

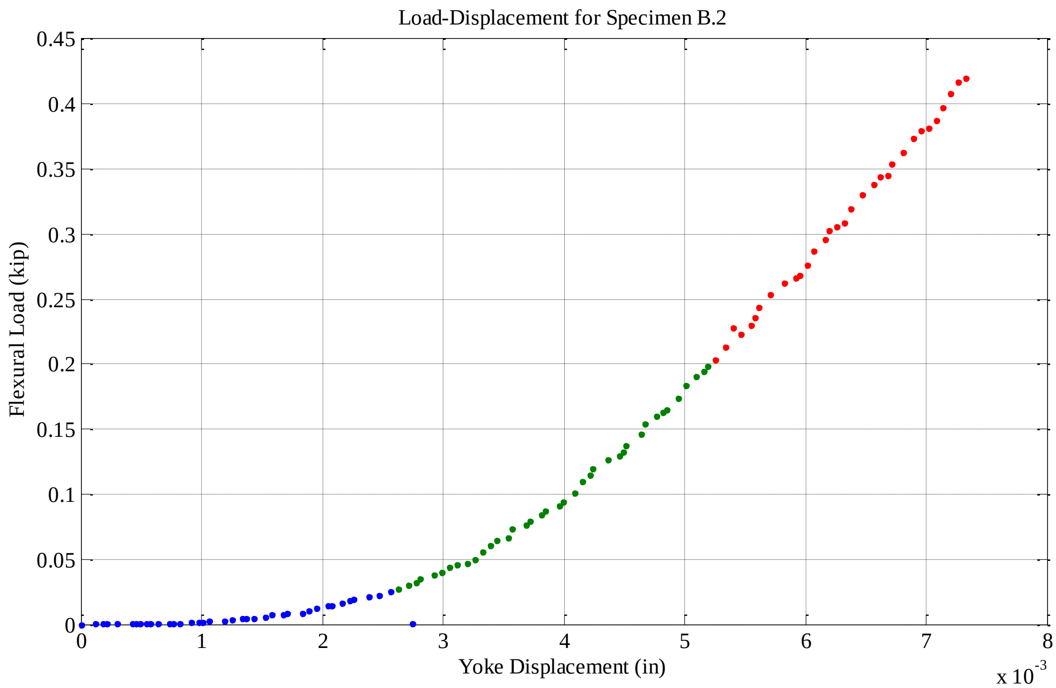

Figure Load-Displacement Curve for B.2

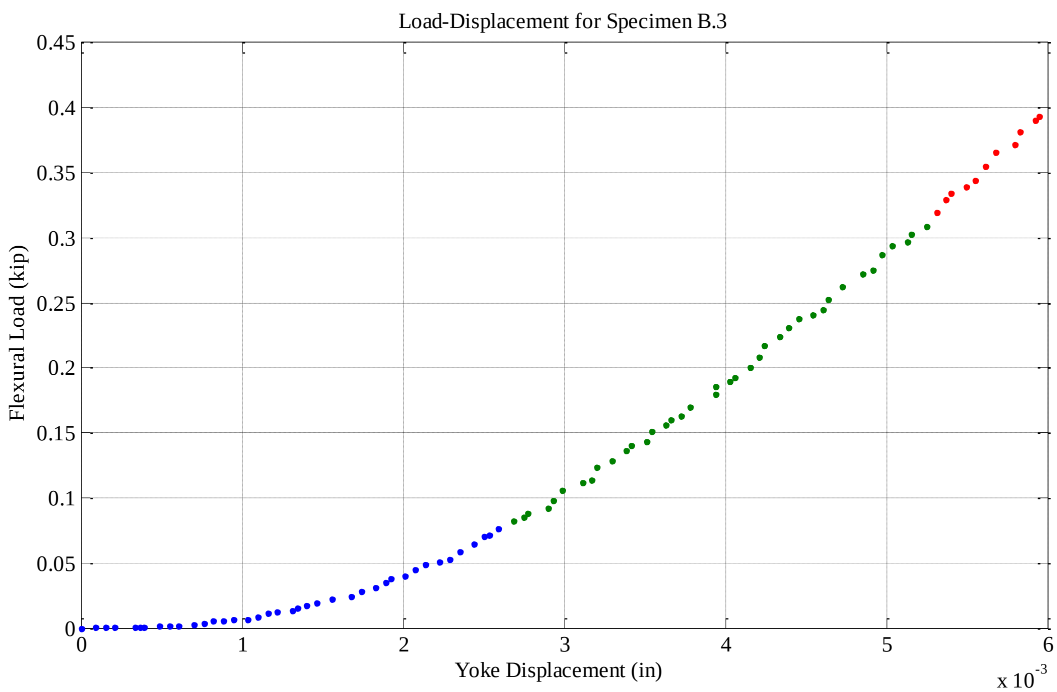

Figure Load-Displacement Curve for B.3

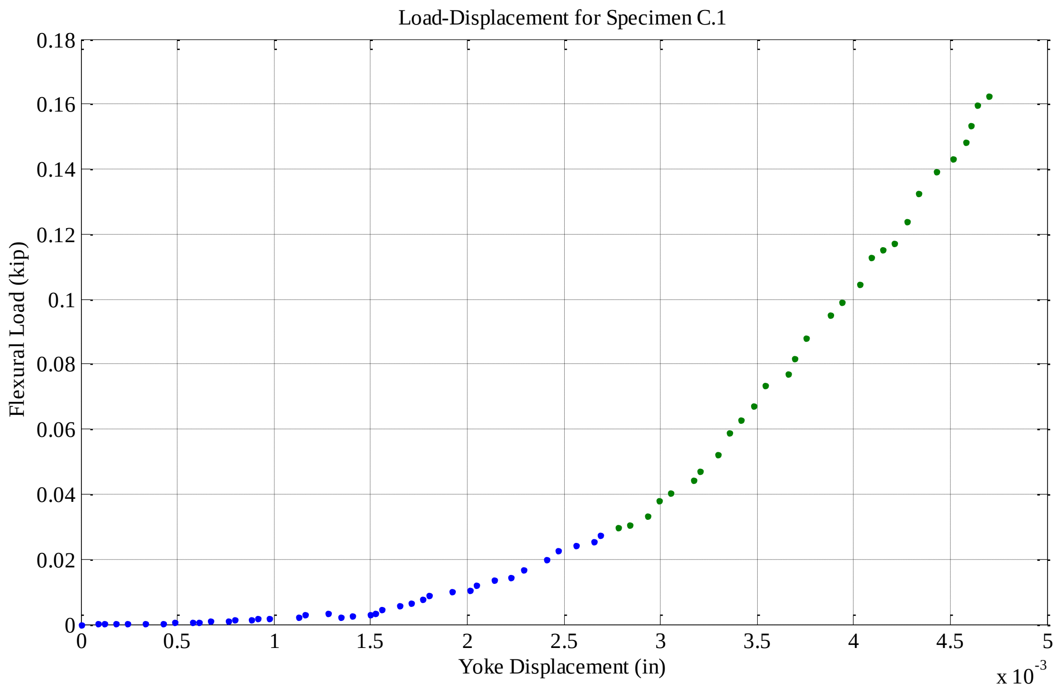

Figure Load-Displacement Curve for C.1

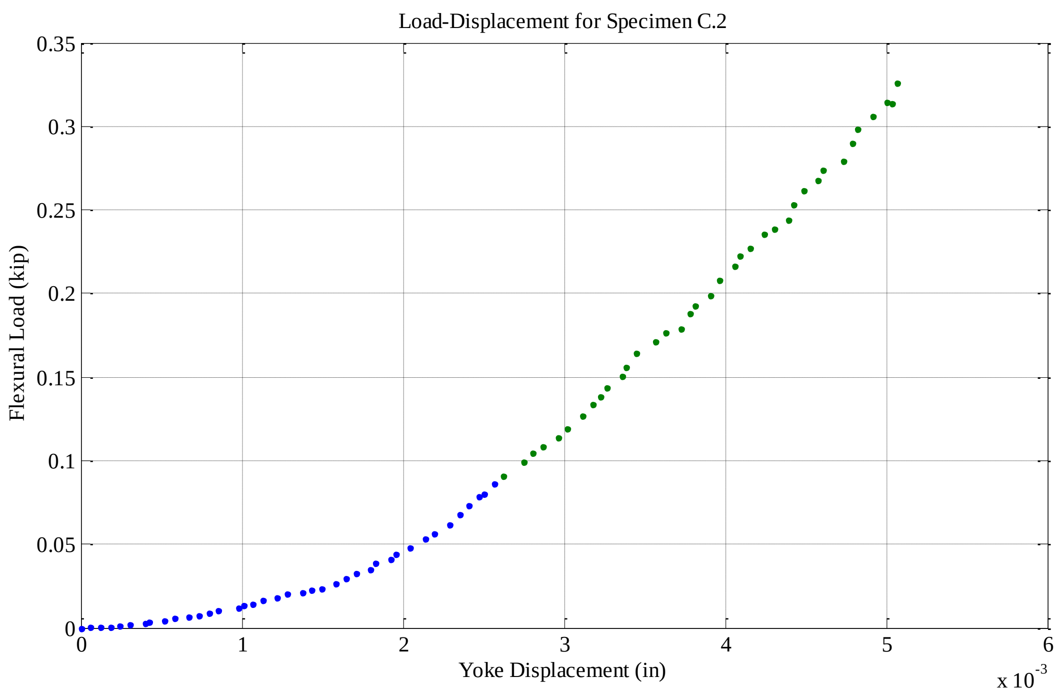

Figure Load-Displacement Curve for C.2

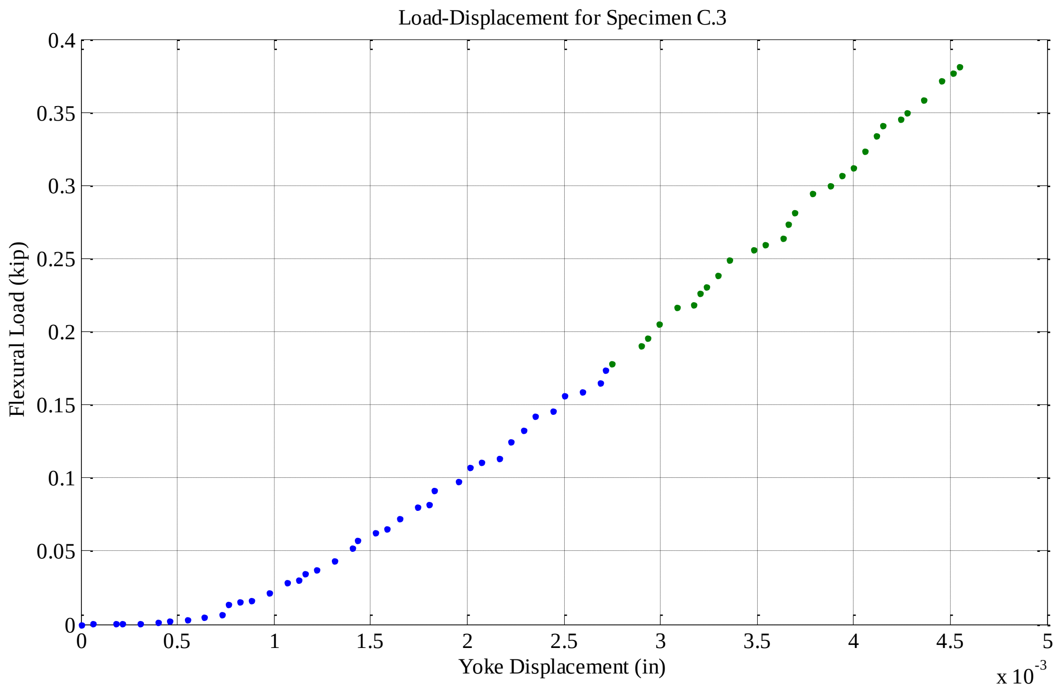

Figure Load-Displacement Curve for C.3

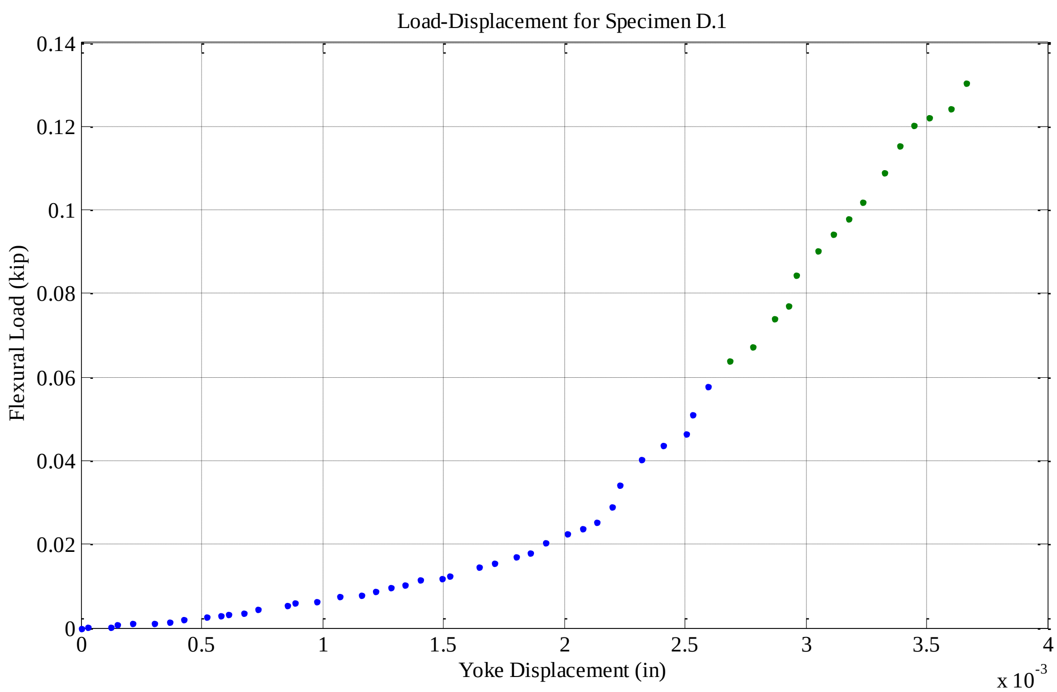

Figure Load-Displacement Curve for D.1

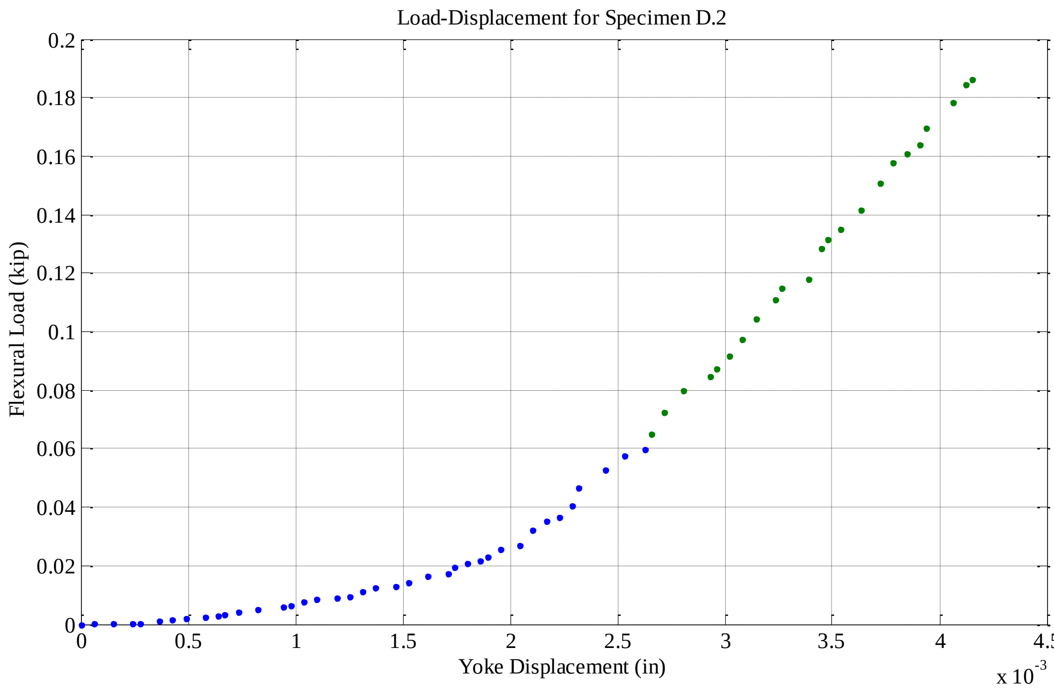

Figure Load-Displacement Curve for D.2

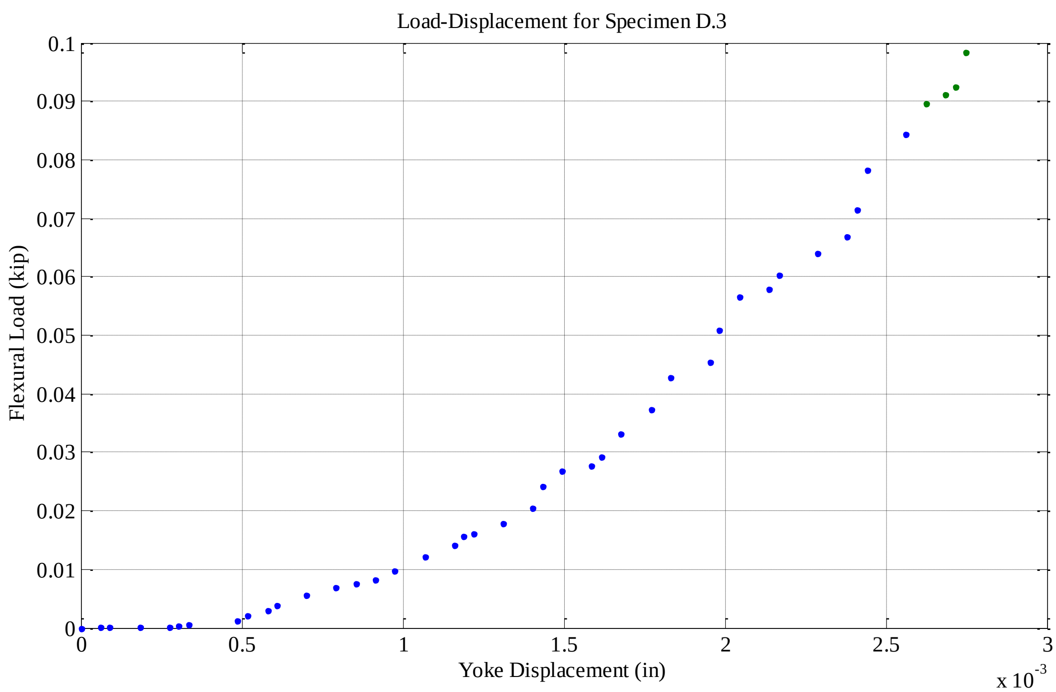

Figure Load-Displacement Curve for D.3

Table

Summary of Average Laboratory Measurements on Prismatic Flexure Specimens for a Water/Cement Ratio of 0.35

Curing Time (days)	Specimen Designation	Average Dimensions (in)			Specimen Mass (gr)		Failure Load (lb.)
		Length	Width	Height	Before Curing	After Curing	
3	A.1	1.634	1.583	6.288	542.16	542.07	230
	A.2	1.652	1.575	6.285	545.68	545.6	275
	A.3	1.655	1.573	6.288	553.18	553.09	273
7	B.1	1.564	1.569	6.285	513.56	513.67	210
	B.2	1.575	1.565	6.289	520.57	520.09	410
	B.3	1.586	1.573	6.284	525.40	524.95	385
14	C.1	1.574	1.569	6.283	517.4	517.33	160
	C.2	1.562	1.567	6.284	516.00	515.52	320
	C.3	1.598	1.569	6.285	515.49	515.43	375
28	D.1	1.567	1.576	6.283	515.77	515.48	125
	D.2	1.585	1.571	6.292	517.65	517.17	94
	D.3	1.577	1.573	6.285	514.76	514.12	133

Appendix F

Table

Summary of Laboratory Measurements of the Dimensions of Prismatic Flexure Specimens for a Water/Cement Ratio of 0.40 Cured During 3 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Width	Height	Length		
3	E.1	1.608	1.574	6.313		
		1.555	1.574	6.313		
		1.519	1.573	6.313		
	Average	1.561	1.574	6.313	2.457	15.511
3	E.2	1.558	1.575	6.300		
		1.576	1.573	6.300		
		1.584	1.574	6.300		
	Average	1.573	1.574	6.300	2.476	15.598
3	E.3	1.571	1.557	6.292		
		1.572	1.585	6.292		
		1.572	1.569	6.292		
	Average	1.572	1.570	6.292	2.468	15.529

Table

Results of Flexure Test on Specimen E.1

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002533	77.59				
0.00003	0.03	0.002563	82.56				
0.000091	0.09	0.002686	87.39				
0.000152	0.16	0.002747	90.86				
0.000183	0.25	0.002747	94.47				
0.000274	0.49	0.002838	102.95				
0.000305	0.58	0.00293	105.73				
0.000396	0.92	0.00296	109.48				
0.000457	1.44	0.003021	115.07				
0.000549	1.74	0.003113	123.10				
0.00061	2.75	0.003204	129.14				
0.00671	3.27	0.003235	134.30				
0.000732	3.48	0.003265	135.24				
0.00854	4.89	0.003326	141.84				
0.00915	5.89	0.003449	148.34				
0.001007	7.54	0.003479	156.30				
0.001068	7.76	0.003601	161.55				
0.001129	9.40	0.003693	164.88				
0.001221	9.86	0.003693	170.19				
0.001251	12.36	0.003754	176.17				
0.001312	15.32	0.003845	183.83				
0.001404	18.01	0.003906	189.91				
0.001465	18.96	0.003967	193.14				
0.001495	20.64	0.004059	198.12				
0.001587	23.53	0.00409	202.88				
0.001648	27.65	0.004151	212.43				
0.001739	31.71	0.004242	218.84				
0.0018	34.55	0.004334	225.16				
0.001831	35.07	0.004395	226.90				
0.001892	38.18	0.004425	233.03				
0.002014	43.77	0.004486	240.36				
0.002045	48.59	0.004547	247.90				
0.002136	52.77	0.004608	250.40				
0.002167	55.34						
0.002258	56.92						
0.002319	63.33						
0.00238	68.10						
0.002472	74.17						

Table

Results of Flexure Test on Specimen E.2

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002533	128.77				
0.000031	0.12	0.002564	138.14				
0.000122	0.18	0.002655	144.30				
0.000183	0.70	0.002747	149.71				
0.000244	1.65	0.002747	153.25				
0.000366	2.62	0.002839	157.76				
0.000427	3.48	0.00293	164.94				
0.00458	3.63	0.002961	173.39				
0.000519	4.88	0.003052	179.43				
0.00055	7.29	0.003113	183.83				
0.000672	9.89	0.003205	187.22				
0.000763	11.66	0.003235	192.68				
0.000794	13.92	0.003296	196.95				
0.000855	17.73						
0.000916	19.50						
0.001007	22.65						
0.001068	23.44						
0.001129	29.39						
0.00119	33.85						
0.001251	38.09						
0.001282	39.83						
0.001404	42.85						
0.001496	47						
0.001526	54.21						
0.001618	59.88						
0.001648	61.93						
0.00174	66.44						
0.00177	70.99						
0.001862	77.28						
0.001892	84.45						
0.001984	89.52						
0.002076	91.14						
0.002137	96.20						
0.002198	104.41						
0.002289	111.07						
0.002381	117.29						
0.002411	121.99						
0.002472	125.26						

Table

Results of Flexure Test on Specimen E.3

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002533	116.93				
0.000061	0.09	0.002625	123.86				
0.000122	0.12	0.002686	128.04				
0.000214	0.37	0.002777	132.40				
0.000275	0.82	0.002808	135.39				
0.000336	1.65	0.002869	144.15				
0.00427	2.17	0.00296	151.48				
0.000488	2.84	0.003021	153.64				
0.000549	3.54	0.003083	156.21				
0.00058	4.73	0.003174	156.94				
0.000641	5.92	0.003235	163.44				
0.000793	8.15						
0.000824	10.62						
0.000854	11.87						
0.000946	12.79						
0.001007	14.53						
0.001038	18.53						
0.00116	23.26						
0.001251	26.46						
0.001312	28.26						
0.001373	31.19						
0.001434	34.89						
0.001495	39.77						
0.001556	45.51						
0.001648	48.93						
0.001709	50.70						
0.00177	55.79						
0.001801	61.56						
0.001892	67.79						
0.001984	73.01						
0.002045	76.03						
0.002075	78.96						
0.002136	84.18						
0.002228	92.3						
0.002289	97.61						
0.00235	100.66						
0.002411	103.80						
0.002442	109.88						

Table

Summary of Laboratory Measurements of the Dimensions of Prismatic Flexure Specimens for a Water/Cement Ratio of 0.40 Cured During 7 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Width	Height	Length		
7	F.1	1.539	1.575	6.318		
		1.570	1.580	6.318		
		1.618	1.578	6.318		
	Average	1.576	1.578	6.318	2.487	15.712
7	F.2	1.549	1.573	6.294		
		1.577	1.571	6.294		
		1.604	1.574	6.294		
	Average	1.577	1.573	6.294	2.481	15.613
7	F.3	1.548	1.573	6.313		
		1.56	1.571	6.313		
		1.612	1.585	6.313		
	Average	1.573	1.576	6.313	2.479	15.650

Table

Results of Flexure Test on Specimen F.1

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002564	9.40	0.005158	154.10		
0.000061	0.24	0.002625	9.52	0.00525	157.76		
0.000092	0.49	0.002716	10.41	0.005341	164.54		
0.000153	0.52	0.002808	14.83	0.005402	169.42		
0.000275	0.55	0.002839	16.21	0.005463	171.68		
0.000366	0.64	0.002869	18.34	0.005524	175.89		
0.000397	0.76	0.002961	17.18				
0.000458	0.73	0.003052	18.68				
0.000519	0.79	0.003113	21.24				
0.00058	0.61	0.003144	26.25				
0.000611	0.79	0.003296	30.16				
0.00672	0.85	0.003327	32.63				
0.000733	0.98	0.003388	34.55				
0.000794	1.01	0.003449	40.32				
0.000855	1.28	0.003541	41.81				
0.000946	1.31	0.003571	42.09				
0.001038	1.34	0.003632	45.63				
0.001099	1.31	0.003724	51.52				
0.00116	1.65	0.003754	58.75				
0.001221	1.74	0.003846	59.55				
0.001282	1.89	0.003876	61.78				
0.001374	2.11	0.003998	64.22				
0.001465	2.38	0.004029	71.42				
0.001526	2.20	0.00409	79.36				
0.001587	2.53	0.004212	84.21				
0.001679	2.84	0.004243	87.87				
0.001709	2.87	0.004334	95.59				
0.00177	3.45	0.004426	96.57				
0.001862	3.14	0.004517	98.46				
0.001923	3.94	0.004548	102				
0.001984	3.75	0.004609	111.86				
0.002076	3.88	0.00467	119.09				
0.002167	3.51	0.004731	123.79				
0.002198	4.15	0.004792	124.98				
0.002259	4.91	0.004884	133.50				
0.00235	6.56	0.004975	136.06				
0.002411	7.05	0.005006	145.13				
0.002533	8.61	0.005128	149.40				

Table

Results of Flexure Test on Specimen F.2

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002717	19.29				
0.000061	0.09	0.002747	21.30				
0.000153	0.18	0.002808	25.49				
0.000214	0.27	0.0029	30.80				
0.000244	0.27	0.002961	35.68				
0.000275	0.37	0.003052	37.21				
0.000397	0.49	0.003083	39.68				
0.000489	0.46	0.003113	40.01				
0.00055	0.58	0.003205	47.92				
0.00058	0.67	0.003266	55.15				
0.000672	0.61	0.003358	59.42				
0.000702	0.92	0.003419	60.31				
0.000794	0.64	0.00348	63				
0.000885	0.92	0.003541	67.79				
0.001007	0.89	0.003632	75.85				
0.001068	0.95	0.003693	82.83				
0.001099	1.01	0.003724	83.90				
0.001252	1.07	0.003815	86.83				
0.001282	1.47	0.003907	91.11				
0.001374	1.53	0.003937	101.48				
0.001465	1.80	0.003998	108.26				
0.001496	2.11	0.00406	112.62				
0.001587	2.23	0.004121	118.21				
0.001648	2.78	0.004273	124.04				
0.001709	2.90	0.004334	126.14				
0.001801	3.33	0.004395	134.69				
0.001862	3.78	0.004487	138.78				
0.001954	3.88						
0.002076	4.70						
0.002106	5.04						
0.002198	5.37						
0.002228	6.99						
0.002289	8.06						
0.00232	8.73						
0.002442	9.28						
0.002472	12.12						
0.002564	17.52						
0.002625	18.74						

Table

Results of Flexure Test on Specimen F.3

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002838	109.97				
0.000122	0.31	0.00293	117.72				
0.000214	0.82	0.003022	121.26				
0.000275	1.04	0.003083	127.64				
0.000336	1.31	0.003174	132.58				
0.000397	1.98	0.003205	135.21				
0.000519	1.89	0.003327	142.17				
0.00058	1.43	0.003357	144.64				
0.000671	4.52	0.003449	150.47				
0.000702	3.11						
0.000763	3.54						
0.000793	5.13						
0.000855	8.67						
0.001007	10.84						
0.001099	12.61						
0.001129	15.57						
0.001221	15.72						
0.001312	20.21						
0.001404	22.59						
0.001434	24.78						
0.001495	29.12						
0.001587	29.54						
0.001648	35.71						
0.00174	38.18						
0.001801	42.39						
0.001862	47.92						
0.001923	48.74						
0.002014	56.13						
0.002075	58.08						
0.002136	63.91						
0.002259	69.65						
0.002289	71.30						
0.002381	79.20						
0.002503	82.44						
0.002533	90.98						
0.002655	94.43						
0.002716	100.75						
0.002777	106.86						

Table

Summary of Laboratory Measurements of the Dimensions of Prismatic Flexure Specimens for a Water/Cement Ratio of 0.40 Cured During 14 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Width	Height	Length		
14	G.1	1.482	1.472	6.191		
		1.489	1.473	6.191		
		1.449	1.474	6.191		
	Average	1.473	1.473	6.191	2.170	13.433
14	G.2	1.482	1.470	6.191		
		1.469	1.469	6.191		
		1.432	1.471	6.191		
	Average	1.461	1.470	6.191	2.148	13.296
14	G.3	1.445	1.472	6.193		
		1.451	1.473	6.193		
		1.439	1.472	6.193		
	Average	1.445	1.472	6.193	2.127	13.173

Table

Results of Flexure Test on Specimen G.1

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002656	72.82				
0.000122	0.06	0.002717	76.30				
0.000184	0.12	0.002747	83.66				
0.000275	0.09	0.002808	86.10				
0.000397	0.15	0.0029	90.83				
0.000428	0.18	0.00293	100.20				
0.000458	0.31	0.003022	108.23				
0.00055	0.34	0.003053	113.81				
0.000611	0.37	0.003144	116.38				
0.000672	0.70	0.003205	122.73				
0.000733	0.92	0.003266	130.42				
0.000794	0.95	0.003388	137.19				
0.000866	1.89	0.003419	144.98				
0.000947	2.11	0.00348	148.46				
0.001008	2.41	0.003541	151.94				
0.001069	2.90	0.003602	158.86				
0.00116	4.15	0.003663	168.17				
0.001221	5.49	0.003724	176.96				
0.001313	6.01	0.003877	182.79				
0.001374	6.84	0.003938	187.34				
0.001435	7.23	0.003968	190.94				
0.001465	9.34	0.003999	201.68				
0.001557	12.54	0.00406	208.64				
0.001618	13.92	0.004151	216.27				
0.001679	14.56	0.004243	220.88				
0.00174	17.85	0.004273	224.18				
0.001832	18.83	0.004365	231.57				
0.001893	24.87	0.004426	241.73				
0.001954	28.60	0.004518	249.97				
0.001984	32.17	0.004579	252.26				
0.002076	33.33	0.00464	256.81				
0.002167	36.87	0.004701	264.10				
0.002228	41.78						
0.00229	48.96						
0.002351	53.69						
0.002412	57.81						
0.002473	58.66						
0.002534	64.80						

Table

Results of Flexure Test on Specimen G.2

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002534	110.52				
0.000062	0.12	0.002595	119.28				
0.000153	0.15	0.002717	128.01				
0.000184	0.18	0.002778	133.13				
0.000275	0.15	0.002839	136.83				
0.000306	0.31	0.002931	145.65				
0.000428	0.43	0.002992	148.91				
0.000489	0.67	0.003083	159.35				
0.000519	0.92	0.003114	165.79				
0.000641	1.34	0.003144	169.64				
0.000702	1.89	0.003205	172.54				
0.000764	3.27	0.003236	180.99				
0.000855	4.40						
0.000947	6.35						
0.000977	7.42						
0.001038	8.39						
0.00113	9.80						
0.001191	13.67						
0.001252	17.03						
0.001343	19.78						
0.001404	22.56						
0.001435	24.23						
0.001496	28.17						
0.001557	34.06						
0.001618	39.62						
0.00174	42.88						
0.001771	44.29						
0.001832	47.64						
0.001923	57.35						
0.001984	63.24						
0.002045	69.10						
0.002137	70.69						
0.002167	74.53						
0.002198	83.48						
0.00229	89.67						
0.002381	95.99						
0.002442	99.84						
0.002503	104.90						

Table

Results of Flexure Test on Specimen G.3

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002778	35.19				
0.000122	0.03	0.002839	38.76				
0.000214	0.06	0.0029	46.70				
0.000336	0.09	0.002961	51.21				
0.000397	0.06	0.003022	56.46				
0.000458	0.09	0.003144	59.88				
0.000519	0.12	0.003174	63.33				
0.00058	0.12	0.003266	68.12				
0.000641	0.09	0.003327	77.68				
0.00702	0.09	0.003388	83.96				
0.000824	0.18	0.003419	87.20				
0.000885	0.21	0.003541	92.27				
0.000946	0.27	0.003571	95.53				
0.001038	0.34	0.003663	103.68				
0.001099	0.37	0.003724	112.41				
0.00116	0.61	0.003815	118.54				
0.001221	0.89	0.003846	121.54				
0.001313	1.07	0.003938	126.11				
0.001435	1.34	0.003999	133.10				
0.001435	1.68	0.00406	141.53				
0.001526	1.83	0.004151	148.33				
0.001587	2.11	0.004182	154.41				
0.001679	3.24	0.004273	161.95				
0.001771	4.06	0.004365	167.41				
0.001832	4.36	0.004426	173.27				
0.001893	5.77	0.004456	181.14				
0.001954	6.78						
0.002015	7.72						
0.002106	9.43						
0.002198	10.32						
0.002259	11.87						
0.00232	15.54						
0.002381	16.66						
0.002442	17.15						
0.002472	21.49						
0.002564	25.42						
0.002656	30.03						
0.002778	32.90						

Table

Summary of Laboratory Measurements of the Dimensions of Prismatic Flexure

Specimens for a Water/Cement Ratio of 0.40 Cured During 28 Days

Curing Time (days)	Specimen Designation	Dimensions (in)			Cross-Section Area (in^2)	Volume of Specimen (in^3)
		Width	Height	Length		
28	H.1	1.574	1.574	6.296		
		1.598	1.575	6.296		
		1.630	1.571	6.296		
	Average	1.601	1.573	6.296	2.518	15.856
28	H.2	1.554	1.571	6.300		
		1.578	1.570	6.300		
		1.618	1.571	6.300		
	Average	1.583	1.571	6.300	2.487	15.667
28	H.3	1.599	1.570	6.300		
		1.563	1.573	6.300		
		1.551	1.570	6.300		
	Average	1.571	1.571	6.300	2.468	15.549

Table

Results of Flexure Test on Specimen H.1

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.0029	1.43	0.00583	12.70		
0.000061	0.12	0.002961	1.68	0.005921	14.53		
0.000122	0.21	0.003052	1.68	0.005982	15.44		
0.000275	0.21	0.003113	1.80	0.006013	18.65		
0.000336	0.24	0.003174	1.83	0.006104	20.27		
0.000427	0.34	0.003266	1.89	0.006165	21.61		
0.000519	0.34	0.003327	2.01	0.006226	24.20		
0.000549	0.40	0.003418	2.08	0.006257	28.02		
0.000641	0.43	0.003449	2.14	0.006379	31.83		
0.000702	0.34	0.00354	2.29	0.006409	35.56		
0.000794	0.49	0.003632	2.26	0.006471	37.27		
0.000824	0.46	0.003663	2.47	0.006562	43.89		
0.000946	0.55	0.003785	2.44	0.006623	47.49		
0.001038	0.61	0.003846	2.66	0.006715	51.92		
0.001099	0.64	0.003937	2.72	0.006806	53.38		
0.00116	0.70	0.004059	2.84	0.006867	60.16		
0.001251	0.61	0.00409	2.96	0.006959	65.44		
0.001312	0.76	0.004181	3.11	0.006959	68.70		
0.001343	0.79	0.004273	3.24	0.007081	74.99		
0.001435	0.82	0.004395	3.54	0.007173	79.11		
0.001496	0.85	0.004456	3.72	0.007173	83.69		
0.001587	0.82	0.004517	3.69	0.007295	89.58		
0.001648	0.92	0.004578	4.06	0.007356	92.48		
0.00174	0.98	0.0047	4	0.007478	94.49		
0.001862	1.07	0.004731	4.52	0.007539	96.97		
0.001923	1.04	0.004853	4.58	0.0076	103.93		
0.001984	0.98	0.004914	4.79	0.007691	108.59		
0.002075	1.07	0.004975	5.34	0.007722	109.45		
0.002167	0.98	0.005036	5.07	0.007813	115.65		
0.002198	1.16	0.005097	6.04				
0.002289	1.07	0.005189	5.95				
0.00235	1.19	0.00525	6.68				
0.002442	1.28	0.005341	7.23				
0.002503	1.22	0.005433	7.14				
0.002564	1.37	0.005463	8.21				
0.002686	1.31	0.005524	8.48				
0.002777	1.53	0.005616	9.74				
0.002808	1.50	0.005707	10.74				

Table

Results of Flexure Test on Specimen H.2

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002716	36.41	0.005707	157.55		
0.000091	0.12	0.002838	37.94	0.005829	164.60		
0.000183	0.27	0.002869	40.96	0.00589	166.04		
0.000213	0.31	0.00293	42.09	0.005921	168.97		
0.000305	0.52	0.003052	45.72	0.005982	173.48		
0.000396	0.67	0.003113	46.76				
0.000458	0.76	0.003174	50.12				
0.000519	1.28	0.003296	52.65				
0.00058	1.10	0.003388	54.45				
0.00061	1.31	0.003418	59.03				
0.000671	2.01	0.00354	61.07				
0.000763	2.26	0.003601	65.77				
0.000854	3.02	0.003693	67.06				
0.000946	3.45	0.003784	72.37				
0.001007	3.91	0.003845	74.29				
0.001068	5.16	0.003906	78.26				
0.001129	5.62	0.004029	82.07				
0.00119	6.53	0.00412	85.52				
0.001282	7.54	0.004181	88.48				
0.001343	8.18	0.004242	91.53				
0.001404	9.52	0.004334	95.17				
0.001465	10.04	0.004395	97.18				
0.001556	11.41	0.004456	100.69				
0.001648	12.51	0.004578	104.05				
0.001709	12.45	0.004639	106.58				
0.0018	14.89	0.0047	111.16				
0.001831	15.60	0.004792	114.27				
0.001953	17.43	0.004883	119.80				
0.001984	18.80	0.004975	124.34				
0.002075	20.08	0.005066	128.49				
0.002167	21.76	0.005097	130.14				
0.002228	22.13	0.005219	135.36				
0.002289	24.87	0.005249	138.66				
0.00238	26.43	0.005371	141.99				
0.002411	28.42	0.005433	146.17				
0.002533	30.46	0.005494	148.21				
0.002594	31.99	0.005585	153.49				
0.002686	34.31	0.005646	156.91				

Table

Results of Flexure Test on Specimen H.3

Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)	Yoke Displa. (in)	Applied Load (lb.)
0	0	0.002747	19.23				
0.000031	0.15	0.002808	21.40				
0.000092	0.27	0.002839	24.91				
0.000183	0.34	0.002961	26.98				
0.000244	0.24	0.003022	31.28				
0.000305	0.40	0.003052	34.98				
0.000397	0.52	0.003113	38.40				
0.000458	0.27	0.003235	42.79				
0.000549	0.55	0.003296	45.23				
0.000641	0.79	0.003357	48.35				
0.000733	0.82	0.003418	53.60				
0.000855	0.64	0.003479	56.16				
0.000946	0.73	0.003571	62.51				
0.000977	0.98	0.003632	65.71				
0.001038	1.04	0.003724	67.57				
0.001099	1.13	0.003754	71.88				
0.00116	1.34	0.003876	77.74				
0.001251	1.43	0.003968	83.87				
0.001282	1.80	0.003998	87.78				
0.001374	2.20	0.004059	93.24				
0.001435	2.32	0.004151	97.52				
0.001496	2.41	0.004181	100.42				
0.001557	2.90	0.004273	102.09				
0.001679	3.05	0.004334	106.67				
0.001709	3.54	0.004395	113.26				
0.00174	3.97	0.004456	118.70				
0.001862	4.09	0.004548	121.41				
0.001892	4.64	0.004609	126.05				
0.001984	5.10	0.0047	129.93				
0.002076	5.40	0.004792	130.88				
0.002167	6.38	0.004822	132.71				
0.002259	6.71						
0.00232	6.96						
0.002381	9.58						
0.002442	10.01						
0.002533	11.08						
0.002564	13.70						
0.002625	17.24						

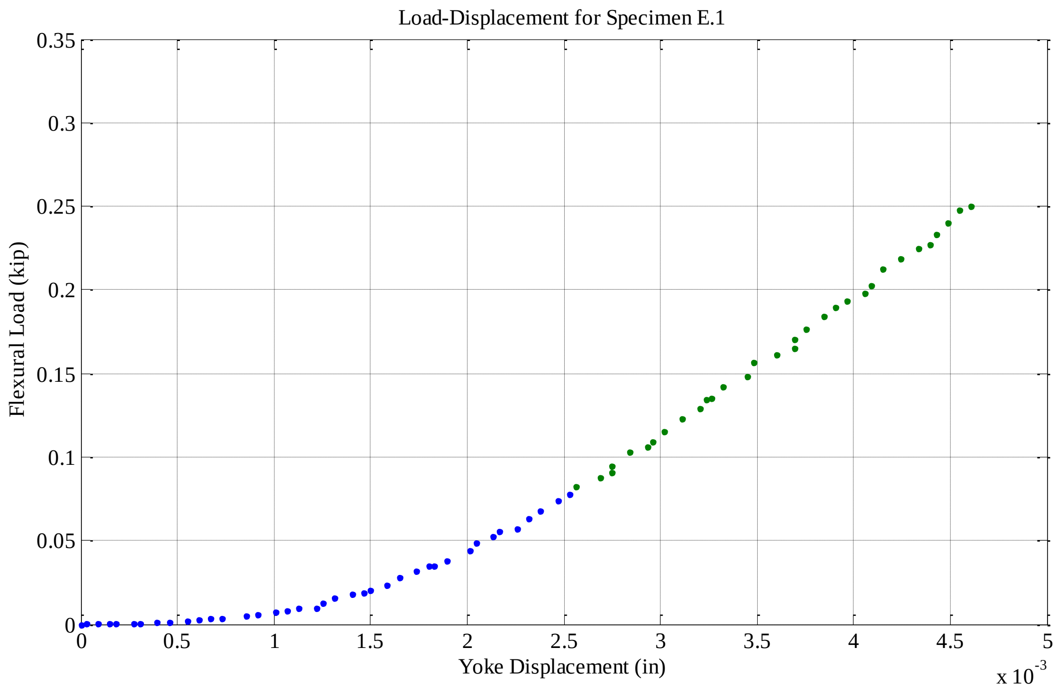

Figure Load-Displacement Curve for E.1

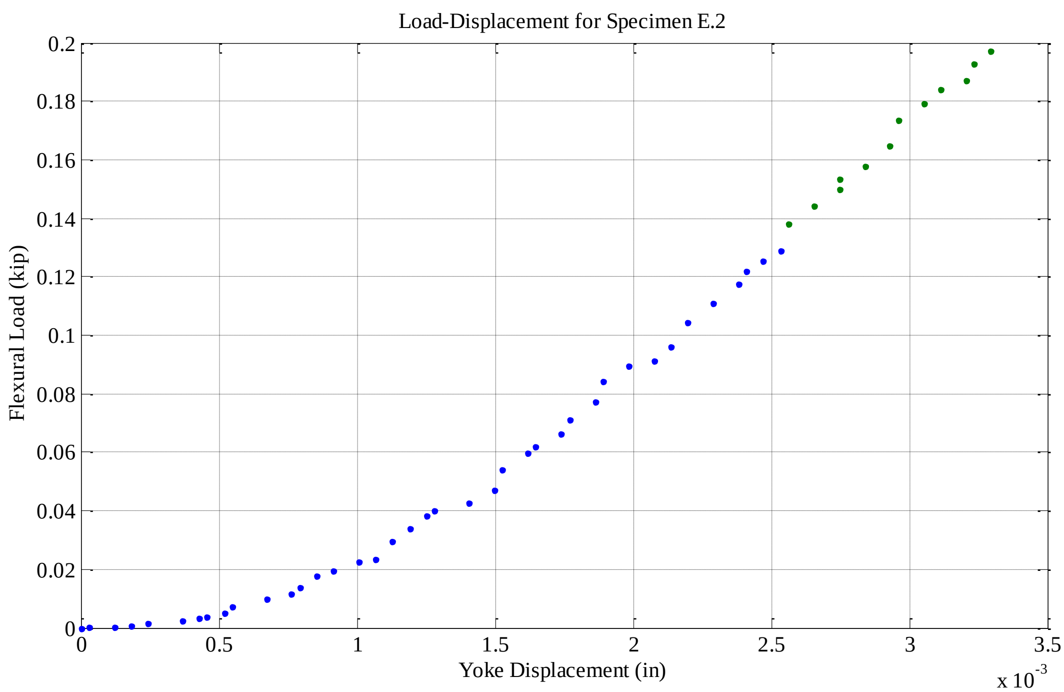

Figure Load-Displacement Curve for E.2

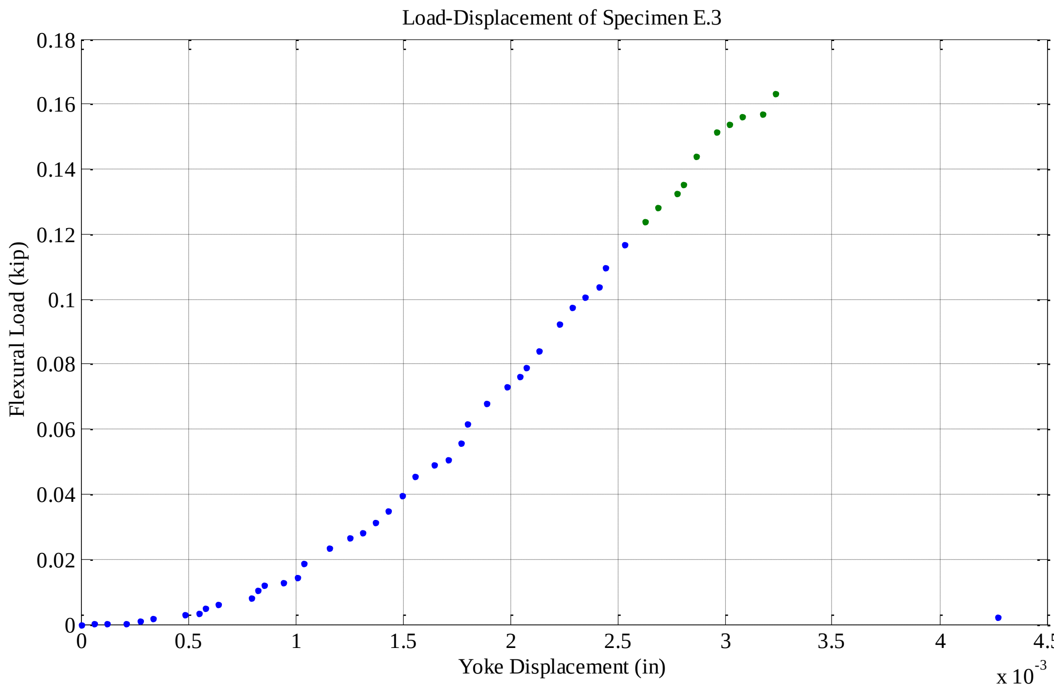

Figure Load-Displacement Curve for E.3

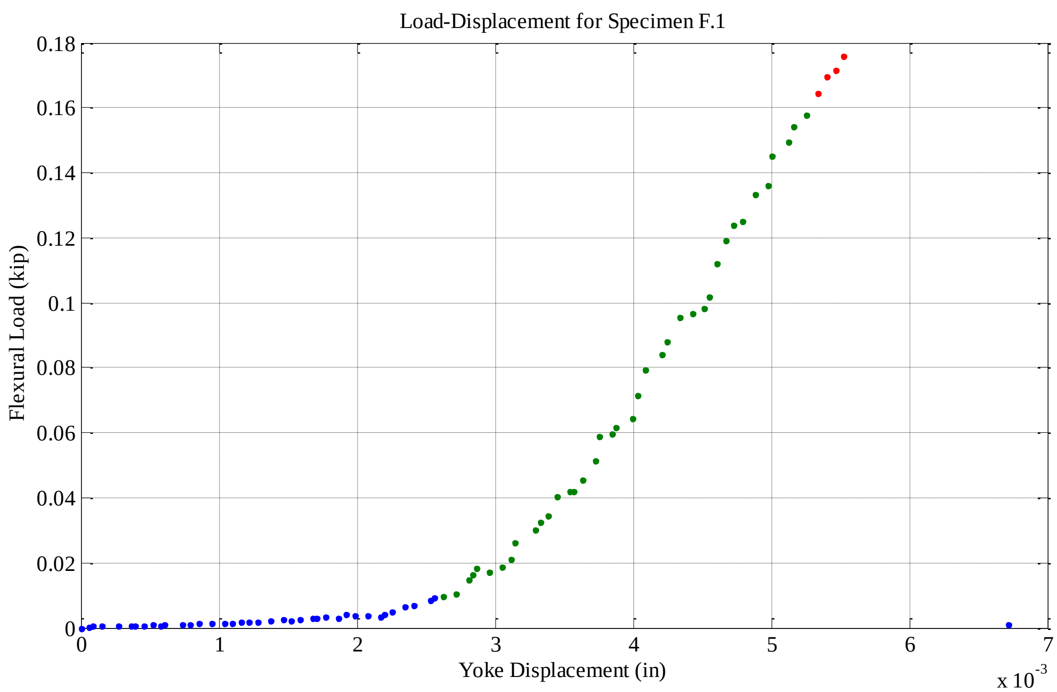

Figure Load-Displacement Curve for F.1

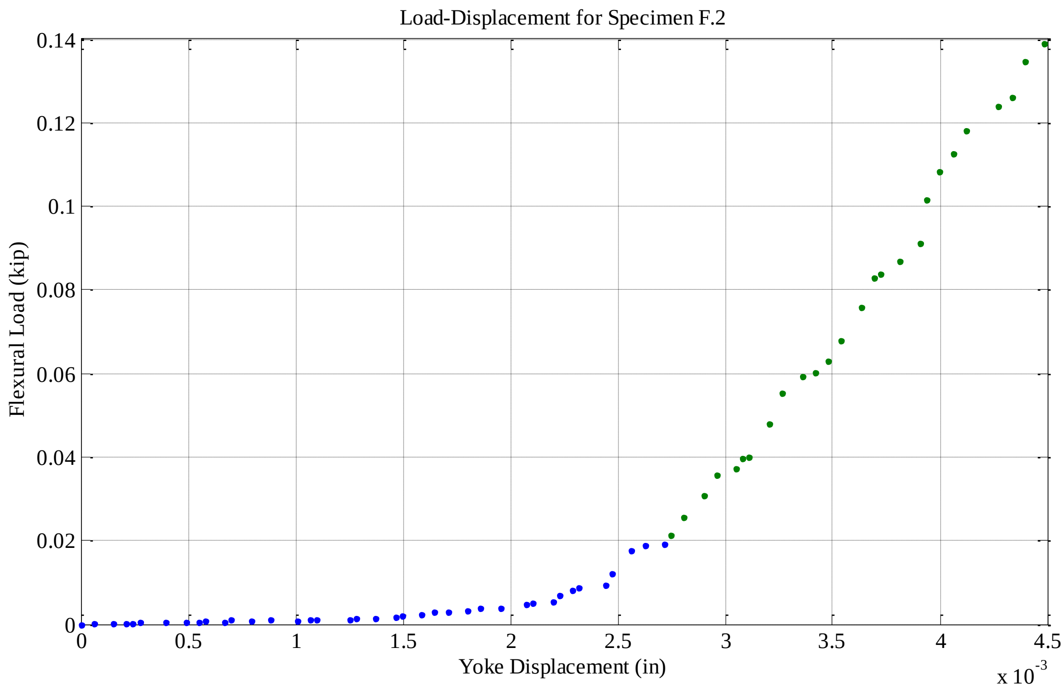

Figure Load-Displacement Curve for F.2

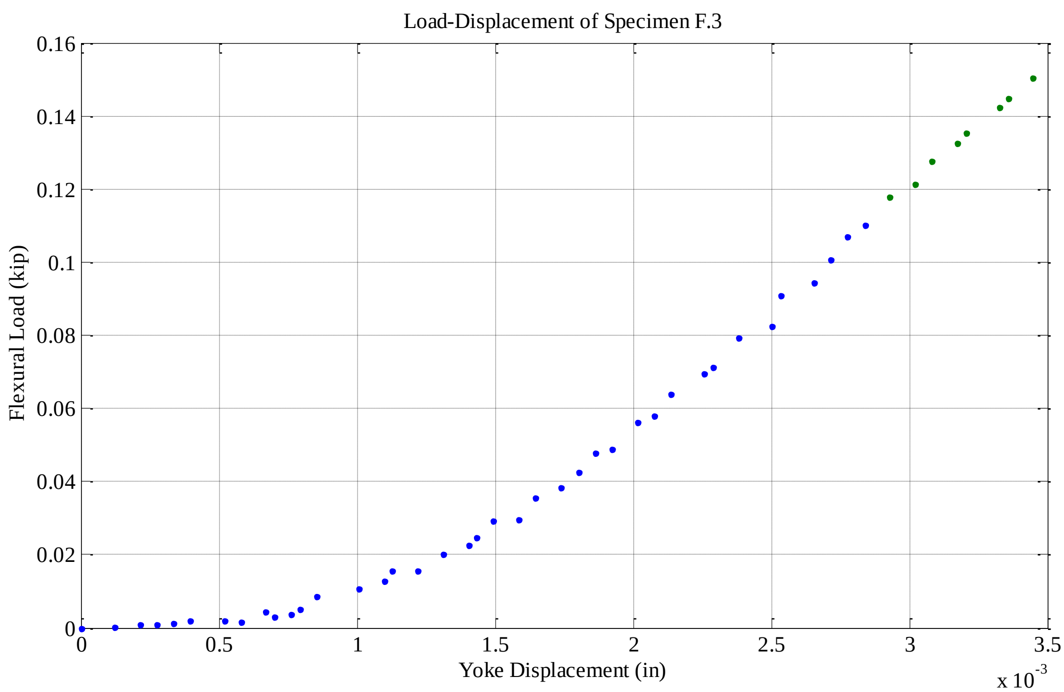

Figure Load-Displacement Curve for F.3

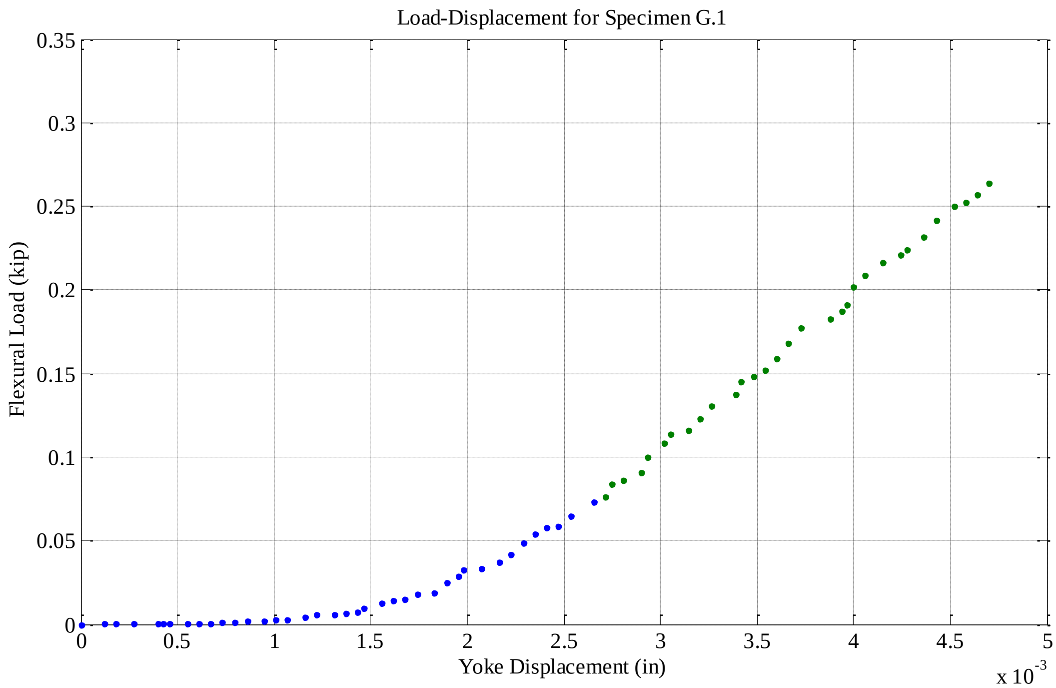

Figure Load-Displacement Curve for G.1

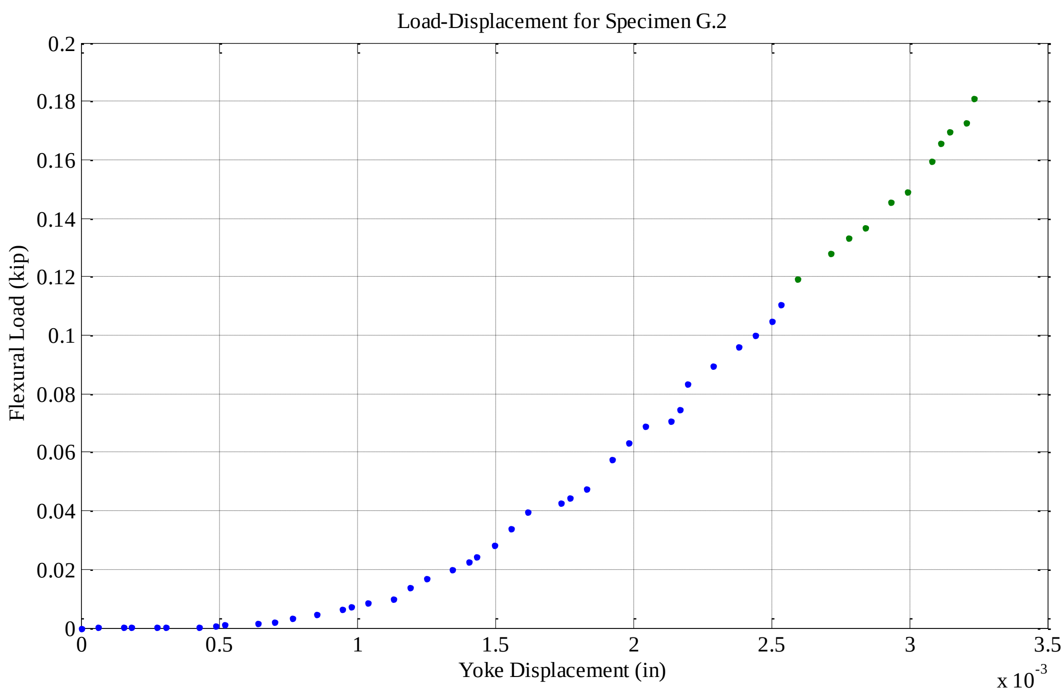

Figure Load-Displacement Curve for G.2

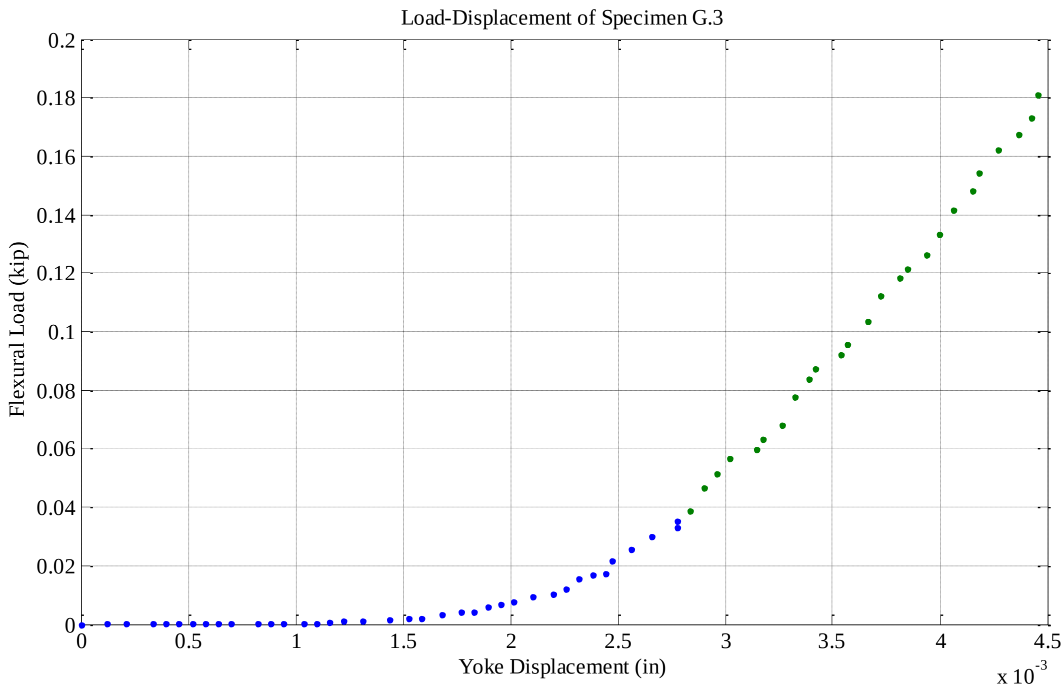

Figure Load-Displacement Curve for G.3

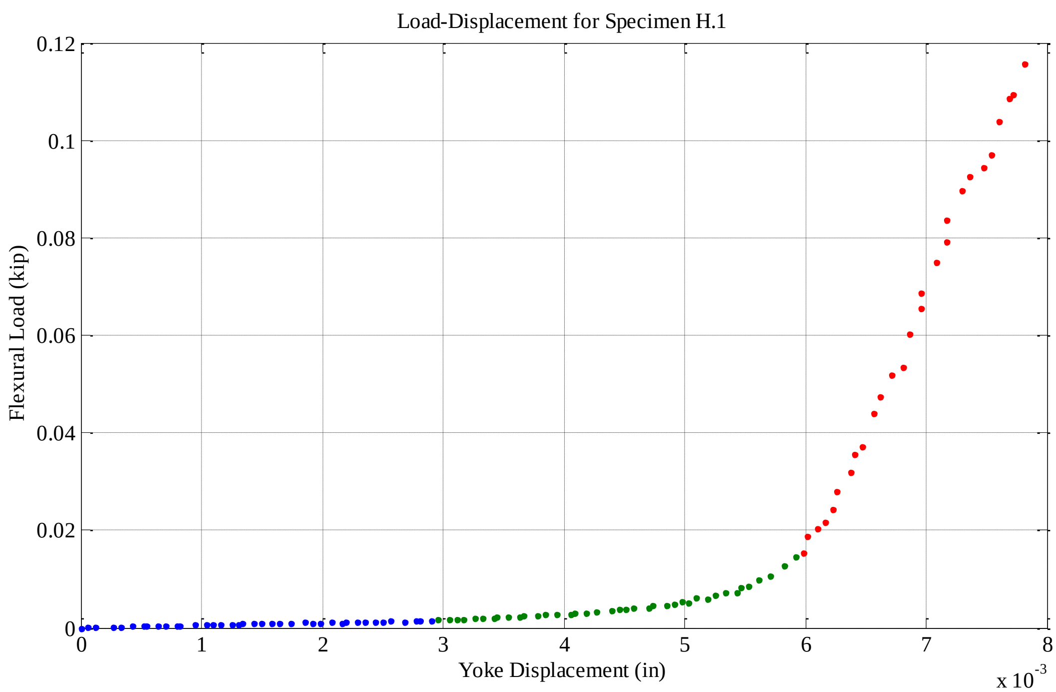

Figure Load-Displacement Curve for H.1

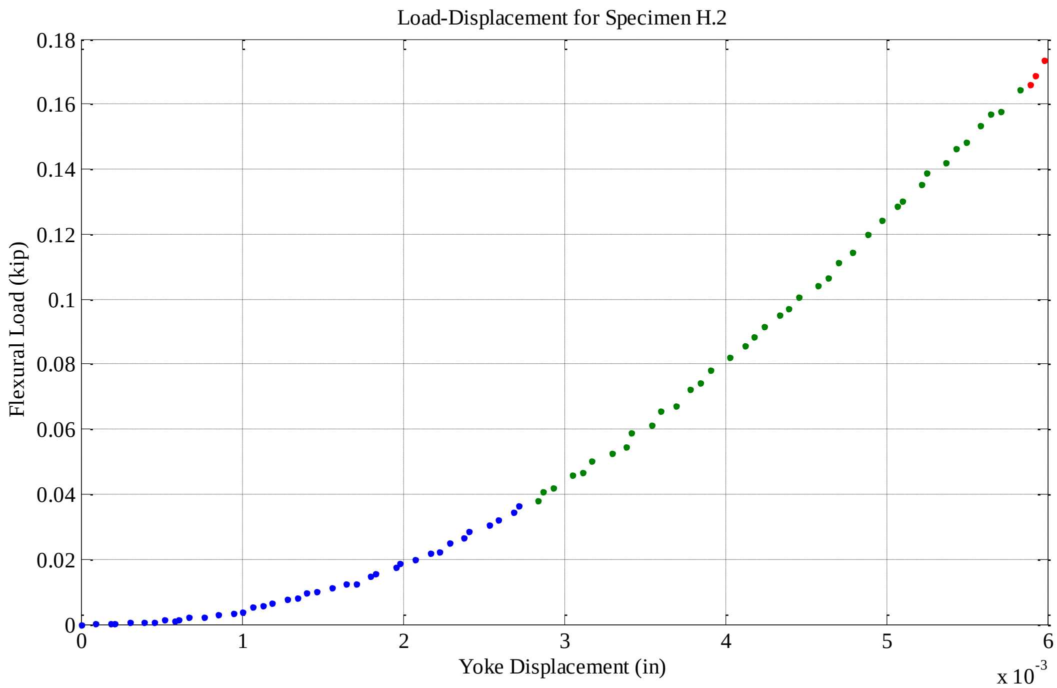

Figure Load-Displacement Curve for H.2

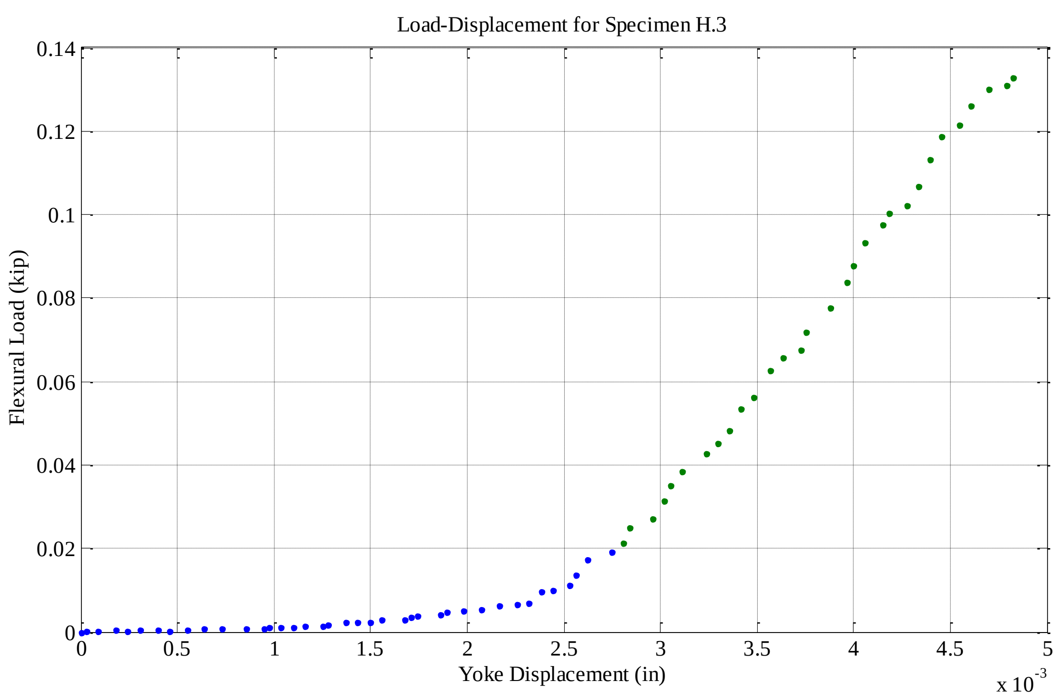

Figure Load-Displacement Curve for H.3

Table

Summary of Average Laboratory Measurements on Prismatic Flexure

Specimens for a Water/Cement Ratio of 0.40

Curing Time (days)	Specimen Designation	Average Dimensions (in)			Specimen Mass (gr)		Failure Load (lb.)
		Length	Width	Height	Before Curing	After Curing	
3*	E.1	1.561	1.574	6.313	496.00	500.33	160
	E.2	1.573	1.574	6.300	497.35	499.25	190
	E.3	1.572	1.570	6.292	500.44	500.66	240
7*	F.1	1.576	1.578	6.318	500.13	511.44	170
	F.2	1.577	1.573	6.294	499.31	502.20	140
	F.3	1.573	1.576	6.313	499.45	506.21	135
14	G.1	1.473	1.473	6.191	495.10	494.99	175
	G.2	1.461	1.470	6.191	491.40	491.32	175
	G.3	1.445	1.472	6.193	488.53	488.23	255
28	H.1	1.601	1.573	6.296	505.10	504.92	110
	H.2	1.583	1.571	6.300	499.37	499.30	130
	H.3	1.571	1.571	6.300	495.77	495.51	170

*Notice that specimens “E” and “F” were the only specimens that gained mass during the curing process.

Appendix G

Table

Properties of Briquette Specimens of Neat Cement Paste for a Water/Cement Ratio of 0.35

Curing Time (days)	Specimen Designation	Neck Dimension (in)		Specimen Mass (gr)		Failure Load (lb.)
		Width	Depth	Before Curing	After Curing	
3	A.1	0.998	0.846	135.76	135.72	265
	A.2	1.042	0.971	133.75	133.69	260
	A.3	0.943	0.981	134.49	134.46	275
7	B.1	1.095	0.926	134.16	134.09	315
	B.2	1.065	0.938	133.05	132.99	320
	B.3	1.012	0.904	129.64	129.61	280
14	C.1	0.967	0.884	131.93	131.85	275
	C.2	0.962	0.867	130.38	130.23	210
	C.3	0.976	0.762	132.57	132.55	240
28	D.1	1.033	0.958	128.36	128.25	155
	D.2	1.067	0.996	130.94	130.75	145
	D.3	1.057	0.986	130.04	129.91	135

Table

Results of Direct Tension Test on Specimen A.1

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012727	49.32				
0.000366	0.15	0.013033	55.79				
0.000733	0.15	0.013368	62.75				
0.001068	0.12	0.013704	70.01				
0.001404	0.18	0.01404	77.49				
0.001648	0.33	0.014406	85.52				
0.002076	0.58	0.014711	93.76				
0.00235	0.82	0.015047	102.21				
0.002655	0.97	0.015413	110.97				
0.003052	1.16	0.015719	120.13				
0.003388	1.40	0.016024	129.38				
0.003693	1.70	0.016421	139.17				
0.004059	2.07	0.016695	149.06				
0.004365	2.50	0.017031	159.29				
0.004761	3.08	0.017428	169.75				
0.005006	3.72	0.017702	180.47				
0.005372	4.54	0.018069	191.73				
0.005677	5.55	0.018404	203.21				
0.006043	6.65	0.01874	214.80				
0.006379	7.81	0.019076	226.46				
0.006715	9.18	0.019381	238.55				
0.007051	10.68	0.019717	250.70				
0.007356	12.26	0.020083	262.78				
0.007722	13.94	0.020388	275.33				
0.008058	15.47	0.020663	285.80				
0.008424	16.14						
0.008699	17						
0.009034	17.91						
0.009401	19.35						
0.009736	20.78						
0.010042	22.46						
0.010377	24.14						
0.010744	25.51						
0.011079	27.40						
0.011385	30.27						
0.01172	33.90						
0.012056	38.18						
0.012392	43.43						

Table

Results of Direct Tension Test on Specimen A.2

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012666	204.12				
0.000305	0.06	0.013002	215.20				
0.000641	0.03	0.013338	225.97				
0.001007	0.12	0.013674	237.18				
0.001313	0.21	0.014009	248.59				
0.001679	0.24	0.014315	259.52				
0.001984	0.61	0.01462	267.18				
0.00232	1.16						
0.002656	2.07						
0.00293	3.35						
0.003327	5						
0.003663	7.20						
0.003937	9.88						
0.004304	12.94						
0.004639	16.26						
0.005006	20.02						
0.005341	24.29						
0.005677	28.99						
0.006043	34.12						
0.006349	39.64						
0.006623	45.53						
0.00702	51.79						
0.007325	58.38						
0.007661	65.43						
0.008027	72.79						
0.008363	80.42						
0.008638	88.35						
0.009004	96.75						
0.00937	105.23						
0.009706	114.08						
0.010011	123.06						
0.010316	132.64						
0.010652	142.10						
0.010988	151.90						
0.011324	161.88						
0.011659	172.38						
0.012026	182.54						
0.012331	193.23						

Table

Results of Direct Tension Test on Specimen A.3

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0						
0.000305	0.12						
0.000702	0.36						
0.000976	1						
0.001312	2.07						
0.001678	3.69						
0.001922	5.73						
0.002319	8.48						
0.002655	11.84						
0.003021	15.59						
0.003357	19.99						
0.003662	24.87						
0.003967	30.21						
0.004334	36.01						
0.004669	42.36						
0.004975	49.13						
0.00531	56.34						
0.005677	64.09						
0.006012	72.27						
0.006318	80.72						
0.006623	89.85						
0.006958	99.40						
0.007325	109.41						
0.00763	119.55						
0.007966	130.02						
0.008332	140.76						
0.008668	151.99						
0.009003	163.50						
0.009339	175.28						
0.009644	187.61						
0.00998	200.18						
0.010316	212.91						
0.010682	225.88						
0.011018	239.31						
0.011292	252.56						
0.011689	266.26						
0.011933	278.56						

Table

Results of Direct Tension Test on Specimen B.1

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012697	95.25				
0.000336	0.03	0.013002	104.10				
0.000671	0.09	0.013338	113.29				
0.001038	0.15	0.013673	122.69				
0.001343	0.30	0.01404	132.55				
0.001678	0.42	0.014345	142.68				
0.002014	0.67	0.01465	153.24				
0.002289	1	0.015047	163.83				
0.002655	1.55	0.015383	174.88				
0.002991	2.01	0.015657	186.11				
0.003357	2.71	0.016023	197.56				
0.003632	3.51	0.016359	209.19				
0.003968	4.39	0.016695	220.97				
0.004364	5.31	0.017031	232.90				
0.00467	6.37	0.017336	245.08				
0.005005	7.56	0.017702	257.29				
0.005341	9.06	0.018038	269.56				
0.005707	10.77	0.018343	282.07				
0.006043	12.63	0.018679	294.68				
0.006348	14.49	0.019076	307.16				
0.006653	16.54	0.01932	319.71				
0.00702	18.52	0.019411	320.87				
0.007325	20.20						
0.007661	21.57						
0.008027	21.73						
0.008332	22.61						
0.008668	24.50						
0.009004	26.64						
0.009339	29.39						
0.009706	33.11						
0.010041	38.02						
0.010347	43.73						
0.010682	49.96						
0.011049	56.67						
0.011384	63.63						
0.011689	70.96						
0.011995	78.80						
0.012422	86.89						

Table

Results of Direct Tension Test on Specimen B.2

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0						
0.000336	2.17						
0.000672	4.94						
0.000977	8.45						
0.001282	12.54						
0.001679	17.09						
0.001984	22.19						
0.00235	27.74						
0.002655	33.82						
0.002991	40.26						
0.003296	47.15						
0.003632	54.54						
0.003998	62.26						
0.004365	70.32						
0.00467	78.84						
0.005006	87.72						
0.005341	96.90						
0.005677	106.37						
0.006013	116.29						
0.006288	126.45						
0.006654	136.83						
0.006959	147.33						
0.007325	158.22						
0.007692	169.61						
0.007997	180.93						
0.008332	192.56						
0.008638	204.71						
0.008973	216.82						
0.00937	229.09						
0.009675	241.67						
0.009981	254.64						
0.010347	267.49						
0.010652	280.55						
0.011018	293.95						
0.011324	307.20						
0.01169	320.26						
0.011659	320.72						

Table

Results of Direct Tension Test on Specimen B.3

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012697	193.87				
0.000336	0.06	0.013063	205.31				
0.000702	0.06	0.013338	216.57				
0.001007	0.18	0.013735	228.05				
0.001404	0.21	0.013979	239.68				
0.001679	0.30	0.014315	251.58				
0.002045	0.33	0.014681	263.52				
0.00232	0.39	0.015047	275.79				
0.002686	0.58	0.015383	288.21				
0.002991	0.88	0.015414	289.58				
0.003358	1.31						
0.003663	1.98						
0.00406	2.93						
0.004304	4.54						
0.00467	6.65						
0.005036	9.52						
0.005403	13						
0.005708	17.03						
0.006013	21.70						
0.006349	26.95						
0.006715	32.74						
0.007051	38.85						
0.007325	45.50						
0.007692	52.52						
0.007997	59.97						
0.008363	67.66						
0.008699	75.63						
0.009035	83.93						
0.00937	92.57						
0.009706	101.42						
0.010011	110.70						
0.010316	120.37						
0.010683	130.14						
0.011018	140.27						
0.011354	150.65						
0.01172	161.27						
0.012026	172.10						
0.012361	182.79						

Table

Results of Direct Tension Test on Specimen C.1

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012696	82.92				
0.000335	0.09	0.013002	92.63				
0.000702	0.06	0.013368	102.55				
0.001037	0.21	0.013704	112.59				
0.001342	0.24	0.014039	122.78				
0.001648	0.21	0.014375	133.44				
0.002044	0.42	0.01468	144.70				
0.00235	0.82	0.015047	155.59				
0.002685	1.31	0.015352	167.04				
0.003021	1.89	0.015718	178.85				
0.003357	2.65	0.016023	190.97				
0.003693	3.45	0.016359	203.42				
0.003998	4.42	0.016695	215.63				
0.004334	5.46	0.01703	228.48				
0.0047	6.53	0.017336	241.66				
0.005005	7.81	0.017671	254.42				
0.005371	9.09	0.018038	267.79				
0.005646	10.53	0.018404	280.49				
0.006012	11.96						
0.006348	13.61						
0.006684	15.32						
0.00705	17.06						
0.007355	18.92						
0.00766	20.99						
0.008027	23.10						
0.008393	25.30						
0.008698	27.59						
0.009034	30.03						
0.009339	32.59						
0.009675	35.31						
0.010011	38.15						
0.010346	41.29						
0.010682	44.65						
0.011048	48.37						
0.011353	52.65						
0.011689	58.23						
0.011964	65.56						
0.012361	73.86						

Table

Results of Direct Tension Test on Specimen C.2

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0						
0.000366	0.06						
0.000702	0.12						
0.001007	0.21						
0.001373	0.45						
0.001678	0.67						
0.002014	1.06						
0.00235	1.98						
0.002716	2.93						
0.003021	4.66						
0.003357	6.89						
0.003693	9.67						
0.004059	13.06						
0.004334	16.78						
0.0047	20.96						
0.005005	25.79						
0.005341	31.04						
0.005707	36.86						
0.006043	43.06						
0.006379	49.78						
0.006714	56.73						
0.00702	64.12						
0.007355	72.15						
0.007691	81.09						
0.008057	90						
0.008393	99.25						
0.008698	109.11						
0.009004	119.27						
0.00937	129.71						
0.009706	140.79						
0.010041	152.24						
0.010316	163.93						
0.010682	175.80						
0.011018	188.56						
0.011354	200.70						
0.011689	211.45						
0.011934	218.96						

Table

Results of Direct Tension Test on Specimen C.3

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012636	174.22				
0.000305	0.07	0.012972	186.52				
0.000641	0.10	0.013307	199.25				
0.000946	0.16	0.013643	212.13				
0.001312	0.28	0.013979	225.37				
0.001618	0.40	0.014254	238.96				
0.001923	0.43	0.014589	248.72				
0.00232	0.74						
0.002625	1.26						
0.00293	1.84						
0.003327	2.35						
0.003632	3.15						
0.003968	3.94						
0.004304	4.86						
0.004609	5.96						
0.005006	7.18						
0.005311	8.73						
0.005647	10.63						
0.005982	12.92						
0.006287	15.30						
0.006593	18.26						
0.006959	22.07						
0.007325	26.47						
0.00763	31.44						
0.007936	36.94						
0.008271	43.68						
0.008668	51.13						
0.008973	59.09						
0.009279	67.82						
0.009645	77.07						
0.00995	86.93						
0.010316	96.45						
0.010652	106.59						
0.010957	116.87						
0.011232	127.64						
0.011598	138.69						
0.011903	150.26						
0.0123	161.95						

Table

Results of Direct Tension Test on Specimen D.1

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.011964	109.61				
0.000305	0.03	0.01233	115.53				
0.000671	0.13	0.012605	121.30				
0.000976	0.16	0.013002	126.97				
0.001312	0.19	0.013276	132.74				
0.001648	0.28	0.013643	138.36				
0.002014	0.34	0.013978	143.70				
0.002319	0.31	0.014314	148.28				
0.002685	0.55	0.01465	152.98				
0.00296	0.86	0.014985	154.72				
0.003326	1.23	0.015352	156.91				
0.003632	1.93	0.015626	161.25				
0.003937	2.87	0.015749	162.41				
0.004364	4.09						
0.004608	5.47						
0.004944	7.33						
0.005249	9.68						
0.005646	12.30						
0.005982	15.45						
0.006317	18.90						
0.006653	22.68						
0.006958	26.65						
0.007325	31.04						
0.00763	35.56						
0.007996	40.48						
0.008332	45.57						
0.008668	50.85						
0.008973	56.35						
0.009309	61.96						
0.009675	67.67						
0.01001	73.53						
0.010285	79.57						
0.010621	85.62						
0.010957	91.66						
0.011323	97.70						
0.011659	103.62						

Table

Results of Direct Tension Test on Specimen D.2

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012636	27.19				
0.000397	0.03	0.013033	30.64				
0.000672	0.18	0.013369	34.70				
0.001038	0.36	0.013705	39.25				
0.001374	0.45	0.01404	44.04				
0.001679	0.52	0.014376	49.17				
0.002015	0.61	0.014681	54.57				
0.002381	0.70	0.015047	60.31				
0.002686	0.70	0.015353	66.32				
0.003022	0.82	0.015749	72.58				
0.003358	0.79	0.015994	79.02				
0.003694	0.82	0.01639	85.73				
0.004029	0.91	0.016665	92.63				
0.004365	0.91	0.017031	99.80				
0.00464	0.94	0.017367	107.16				
0.004975	1.06	0.017672	114.57				
0.005342	1.13	0.018008	121.47				
0.005708	1.13	0.018283	127.82				
0.006044	1.22	0.01868	133.95				
0.006349	1.25	0.019015	140.36				
0.006654	1.37	0.019381	146.93				
0.00702	1.64	0.019656	150.07				
0.007356	2.01						
0.007722	2.29						
0.007997	2.77						
0.008333	3.17						
0.008699	3.75						
0.009035	4.60						
0.00934	5.52						
0.009676	6.68						
0.010042	8.05						
0.010286	9.64						
0.010713	11.44						
0.011019	13.52						
0.011354	15.78						
0.01169	18.16						
0.012026	20.93						
0.012362	23.99						

Table

Results of Direct Tension Test on Specimen D.3

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0						
0.000275	0.07						
0.00061	0.31						
0.000977	0.92						
0.001312	1.68						
0.001648	2.90						
0.001953	4.55						
0.002259	6.57						
0.002655	9.01						
0.003052	11.79						
0.003327	14.87						
0.003632	18.26						
0.003968	22.19						
0.004334	26.44						
0.00467	30.95						
0.004945	35.75						
0.005311	40.87						
0.005646	46.15						
0.005952	51.77						
0.006318	57.38						
0.006654	63.18						
0.006989	69.26						
0.007325	75.45						
0.007661	81.92						
0.007997	88.36						
0.008302	94.74						
0.008638	100.97						
0.008943	107.65						
0.009309	114.06						
0.009706	120.50						
0.010042	126.94						
0.010347	133.05						
0.010683	139.18						
0.010835	141.81						

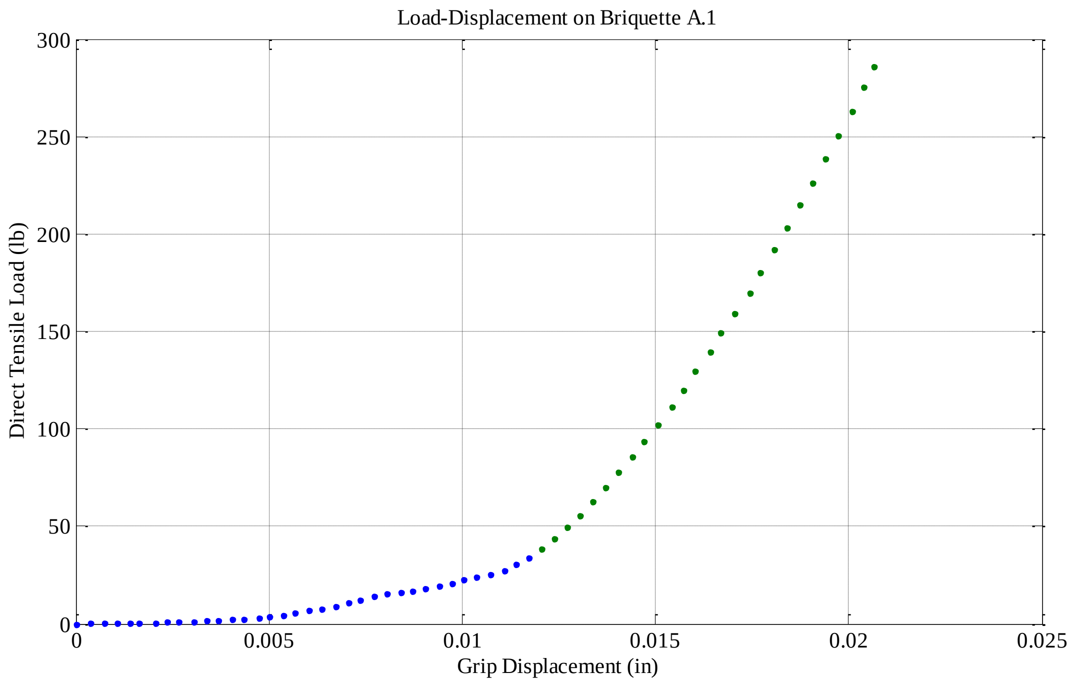

Figure Load-Displacement Curve for A.1

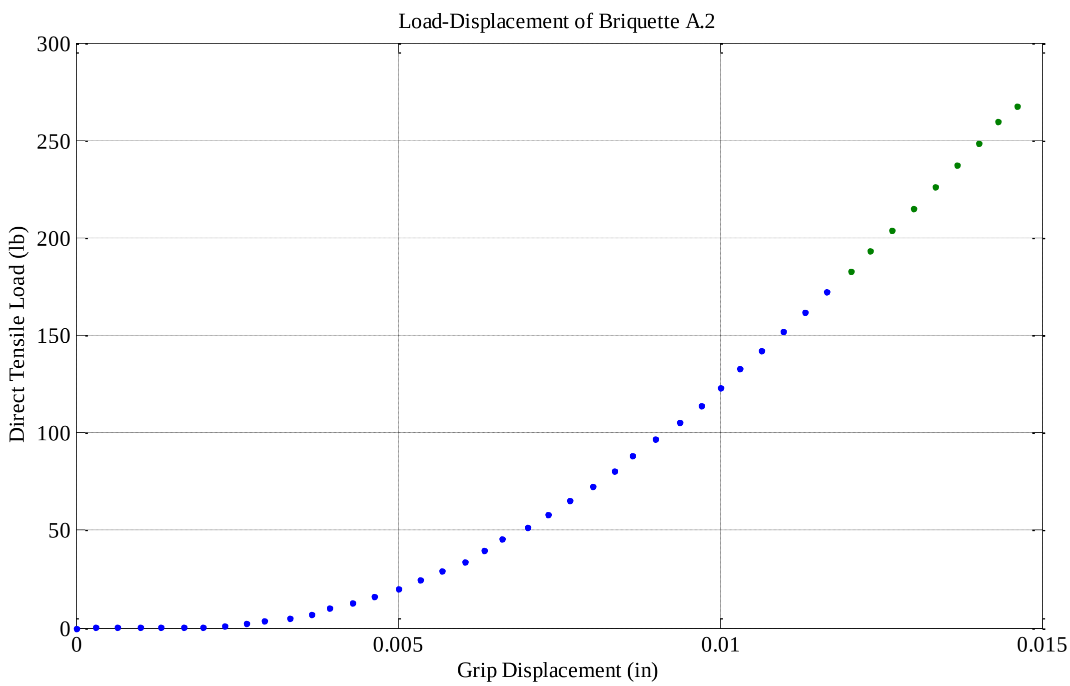

Figure Load-Displacement Curve for A.2

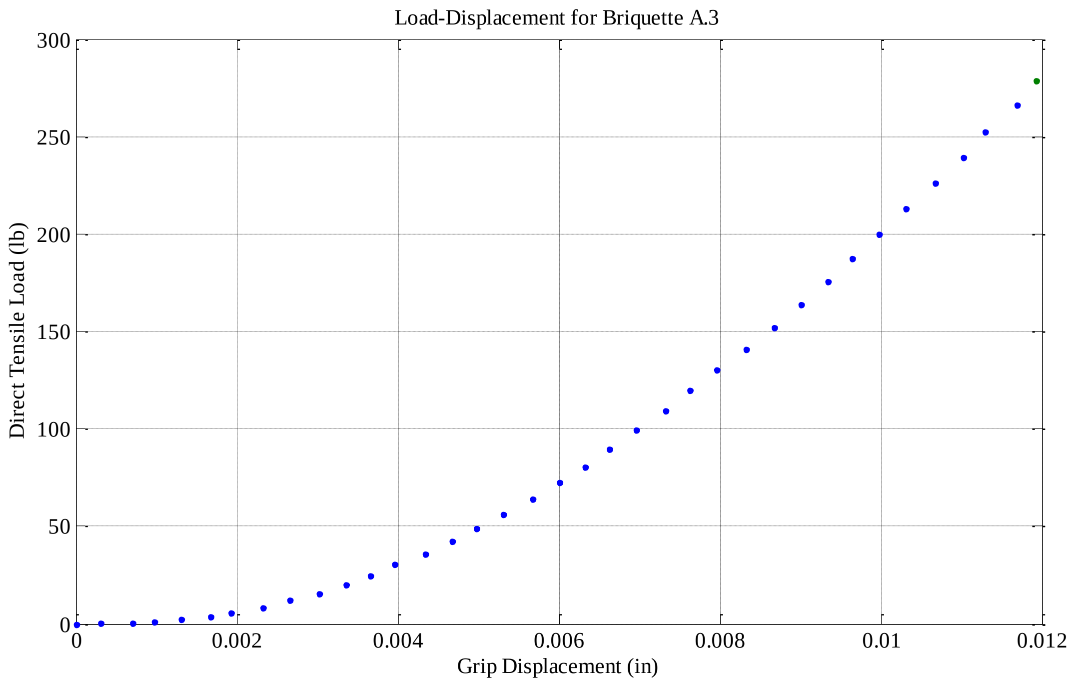

Figure Load-Displacement Curve for A.3

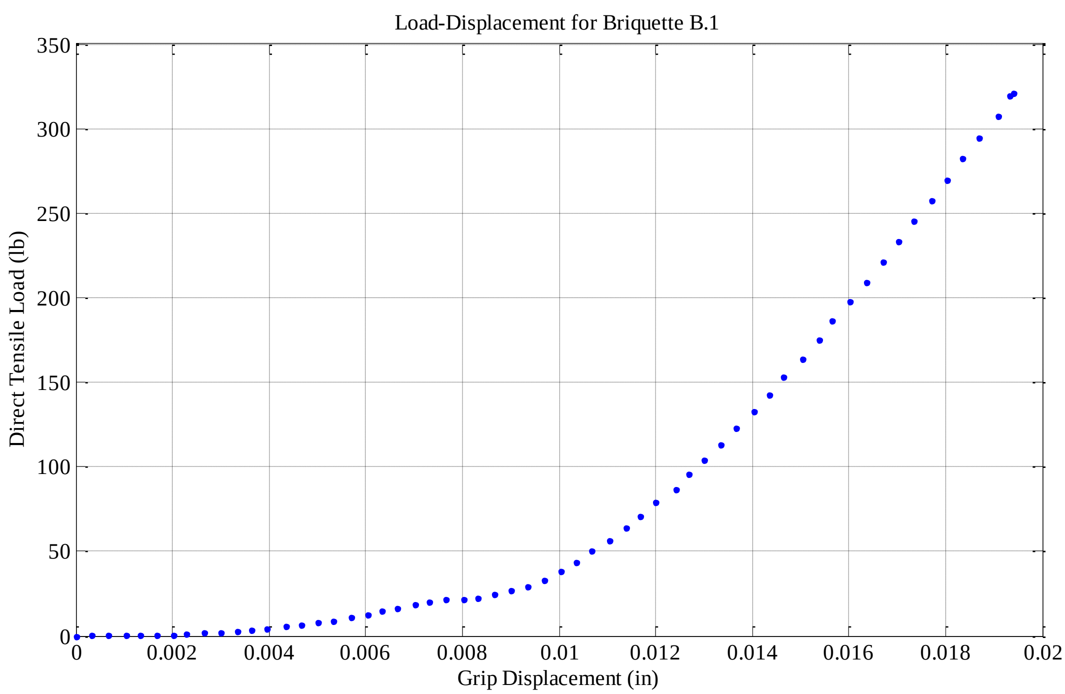

Figure Load-Displacement Curve for B.1

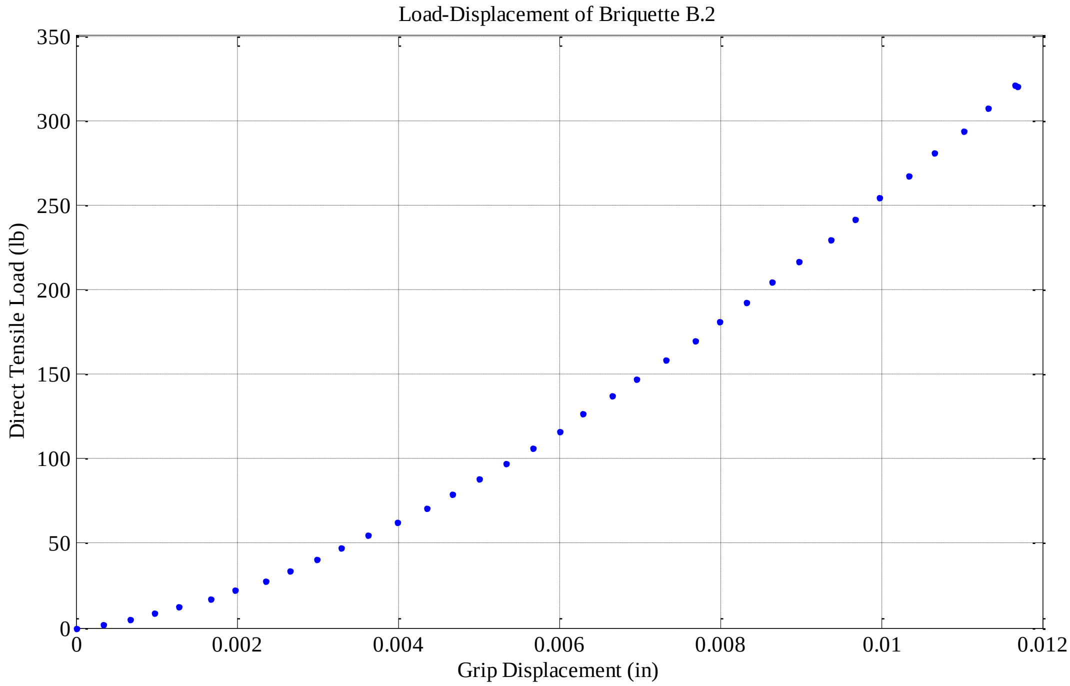

Figure Load-Displacement Curve for B.2

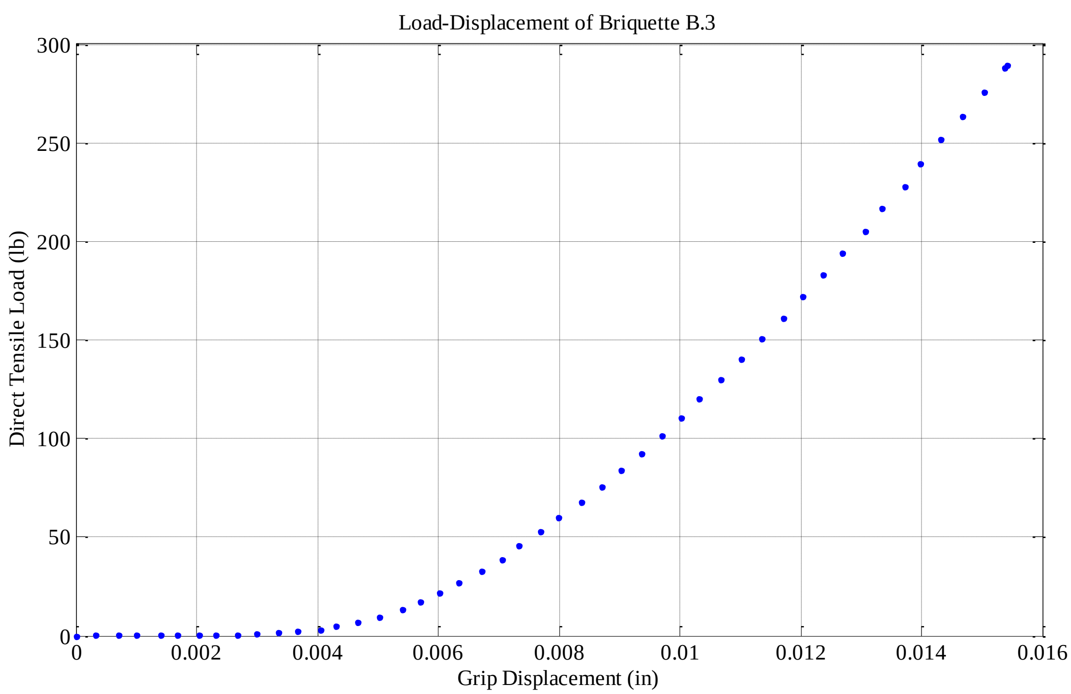

Figure Load-Displacement Curve for B.3

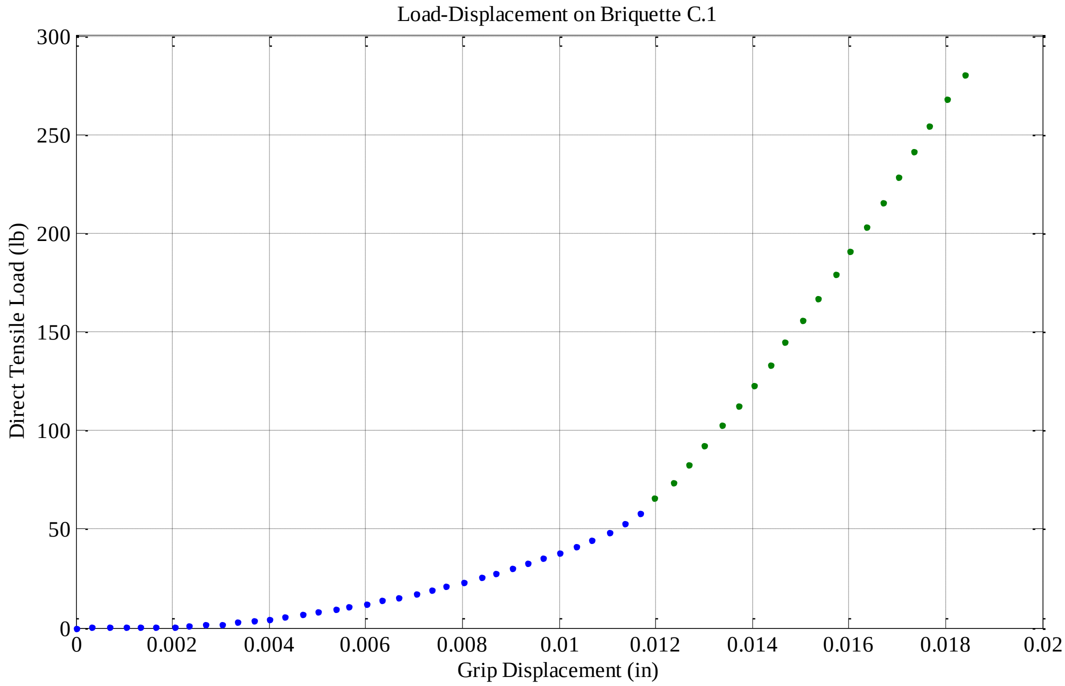

Figure Load-Displacement Curve for C.1

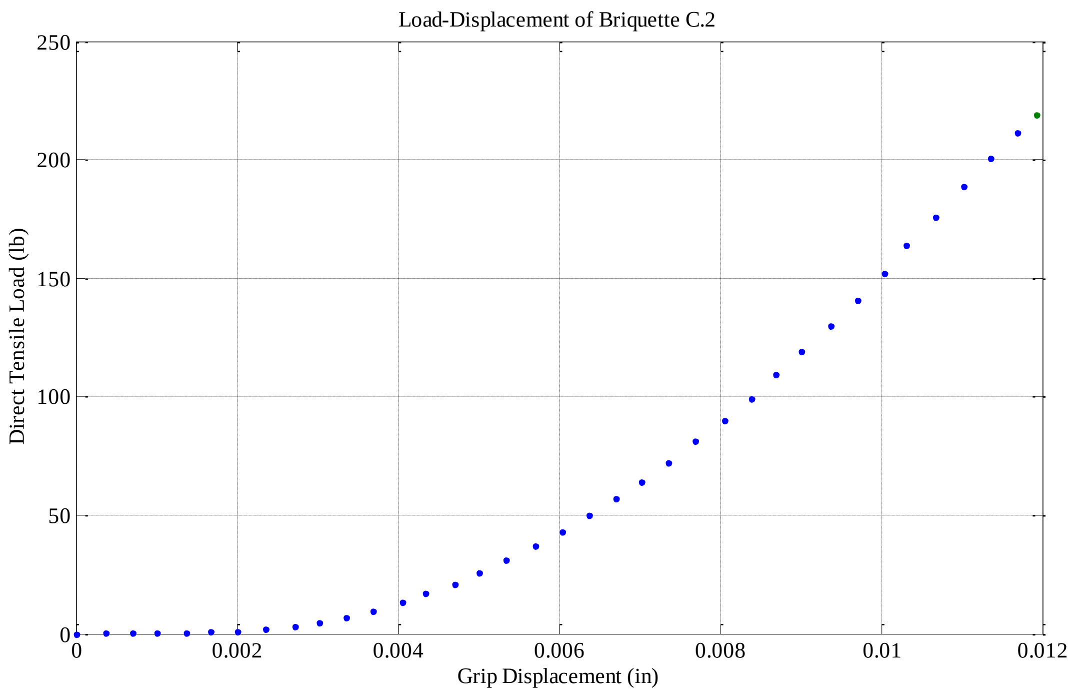

Figure Load-Displacement Curve for C.2

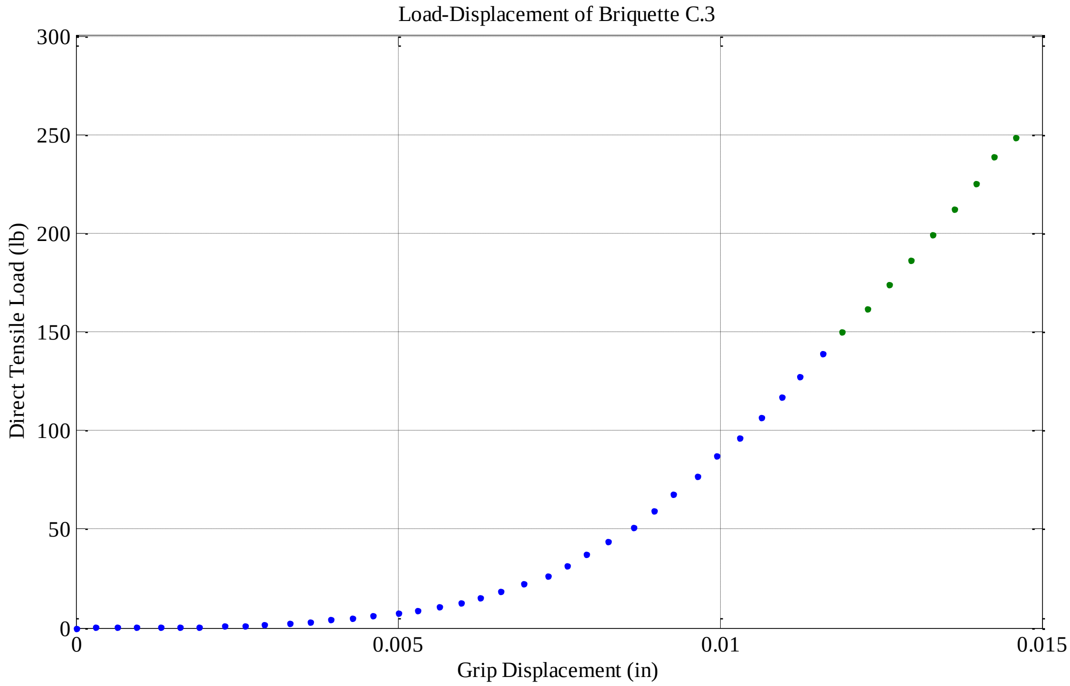

Figure Load-Displacement Curve for C.3

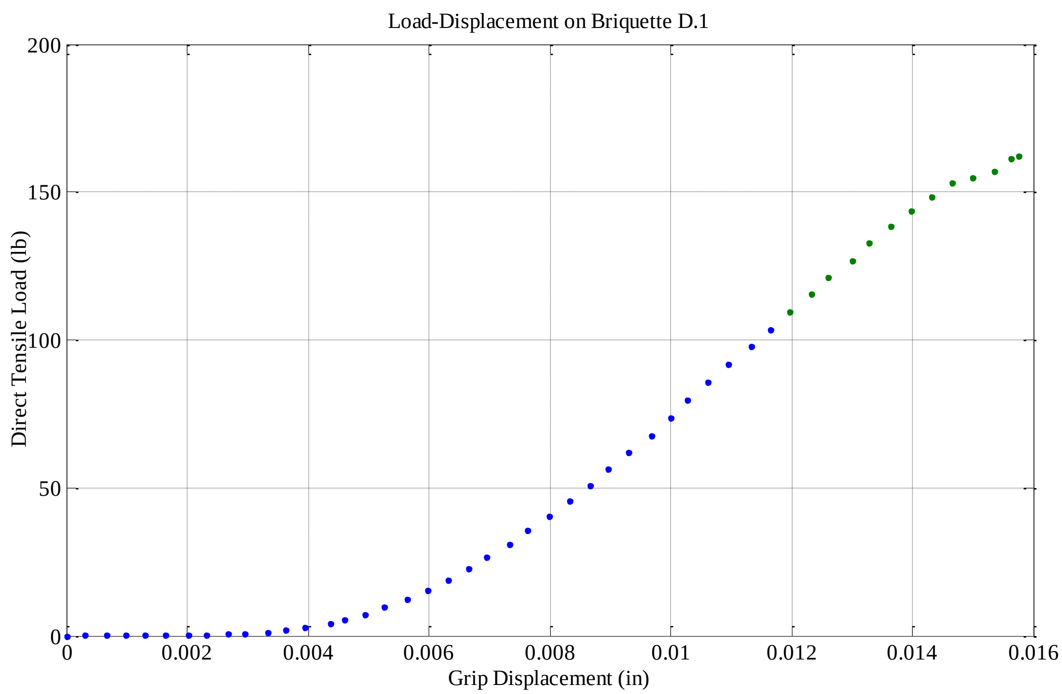

Figure Load-Displacement Curve for D.1

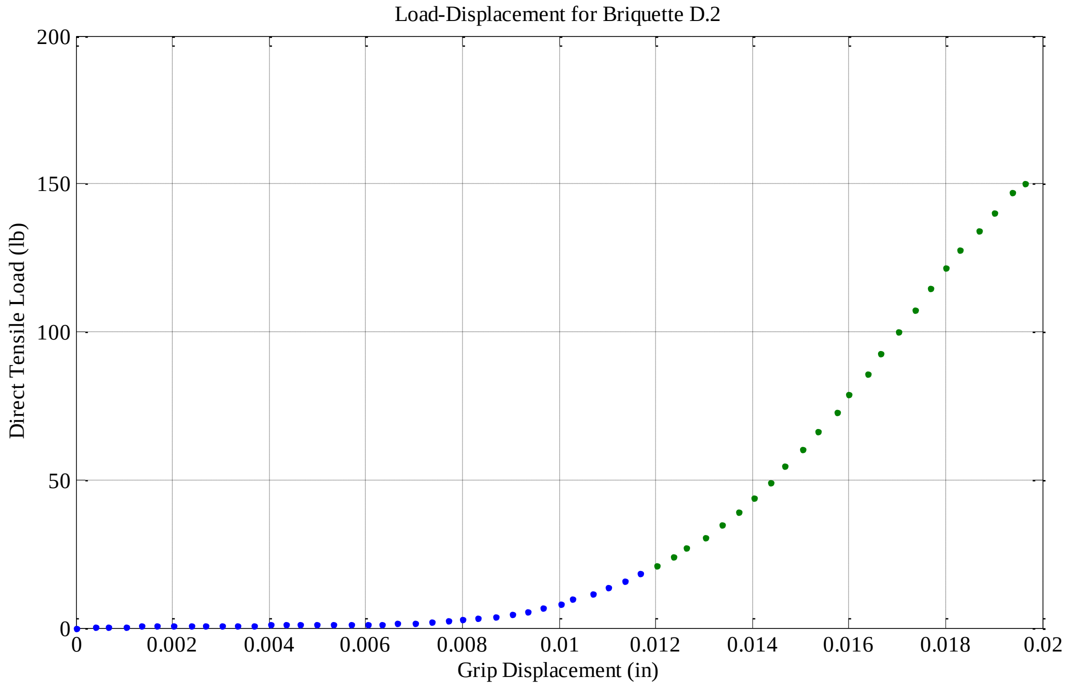

Figure Load-Displacement Curve for D.2

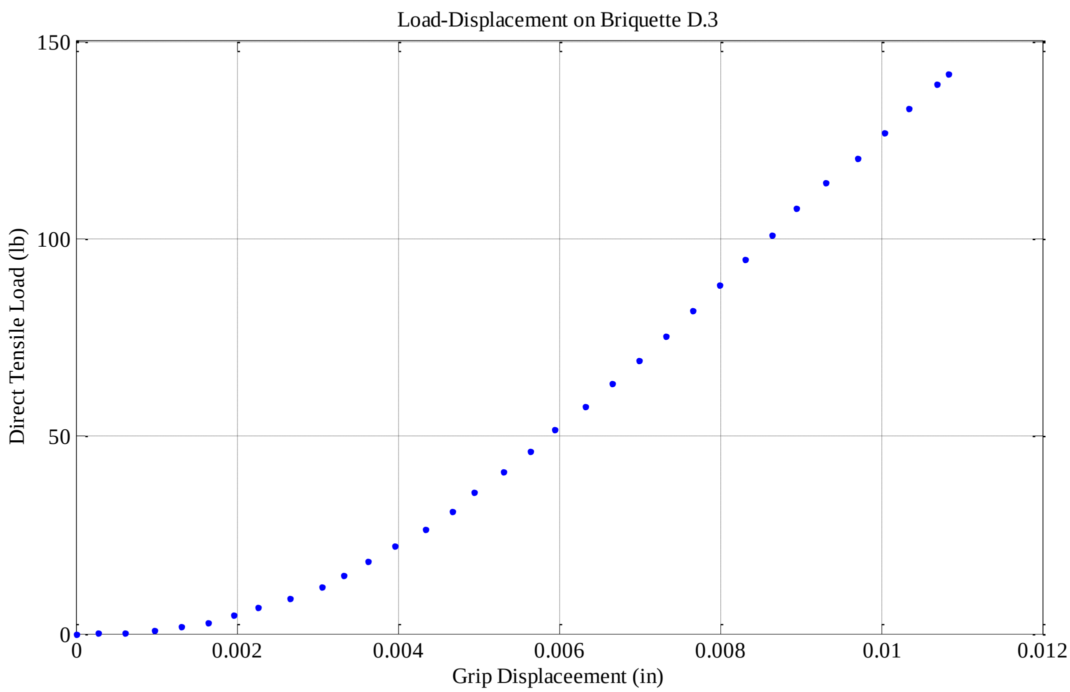

Figure Load-Displacement Curve for D.3

Appendix H

Table

Properties of Briquette Specimens of Neat Cement Paste for a Water/Cement Ratio of 0.40

Curing Time (days)	Specimen Designation	Neck Dimension (in)		Specimen Mass (gr)		Failure Load (lb.)
		Width	Depth	Before Curing	After Curing	
3	E.1	0.998	0.864	104.40	104.26	215
	E.2	1.042	0.971	117.63	117.49	160
	E.3	0.943	0.981	120.69	120.57	85
7	F.1	1.095	0.926	115.06	115.00	240
	F.2	1.065	0.938	113.69	113.65	125
	F.3	1.012	0.904	109.76	109.74	95
14	G.1	0.967	0.884	119.98	119.92	190
	G.2	0.962	0.867	118.39	118.35	130
	G.3	0.976	0.762	104.57	104.53	105
28	H.1	1.033	0.958	114.40	114.35	160
	H.2	1.067	0.996	114.32	114.28	115
	H.3	1.057	0.986	118.54	118.5	100

Table

Results of Direct Tension Test on Specimen E.1

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012697	8.95	0.025394	100.05		
0.000336	0.13	0.013094	9.65	0.02576	104.66		
0.000733	0.19	0.013399	10.29	0.026126	109.15		
0.001007	0.22	0.013735	10.93	0.026401	113.76		
0.001343	0.28	0.01404	11.51	0.026737	118.43		
0.001679	0.4	0.014406	12.09	0.027042	123.01		
0.002045	0.52	0.014711	12.67	0.027408	127.67		
0.002381	0.65	0.015047	12.91	0.027713	132.68		
0.002686	0.83	0.015383	11.30	0.02808	137.59		
0.003052	1.01	0.015719	11.05	0.028385	142.63		
0.003388	1.29	0.016085	12.33	0.028721	147.27		
0.003693	1.62	0.01639	14.26	0.029056	152.34		
0.004029	1.96	0.016695	16.06	0.029392	157.34		
0.004365	2.35	0.017062	17.61	0.029758	162.32		
0.0047	2.69	0.017397	19.17	0.030094	167.11		
0.005006	3.06	0.017764	20.91	0.030399	171.63		
0.005372	3.45	0.018008	22.77	0.030705	175.84		
0.005738	3.76	0.018374	24.82	0.030918	177.82		
0.006013	4.19	0.01871	27.17				
0.006379	4.61	0.019045	29.76				
0.006715	5.01	0.019381	32.60				
0.00702	5.38	0.019686	35.74				
0.007356	5.77	0.020022	39.04				
0.007692	6.23	0.020388	42.46				
0.008027	6.63	0.020694	45.91				
0.008393	7.09	0.02106	49.33				
0.008699	7.54	0.021365	52.90				
0.009004	7.91	0.021731	56.65				
0.00934	7.73	0.022037	60.31				
0.009706	6.84	0.022372	63.89				
0.010011	6.75	0.022739	67.67				
0.010377	6.66	0.023013	71.30				
0.010744	6.57	0.023379	75.09				
0.011079	6.69	0.023715	78.93				
0.011385	6.87	0.024051	82.81				
0.011659	7.24	0.024417	86.96				
0.012056	7.51	0.024722	91.17				
0.012422	8.15	0.025058	95.54				

Table

Results of Direct Tension Test on Specimen E.2

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012697	89.40				
0.000367	0.07	0.013033	94.10				
0.000702	0.07	0.013369	98.68				
0.001038	0.22	0.013674	103.32				
0.001313	0.16	0.01404	109.21				
0.001679	0.16	0.014376	115.41				
0.002015	0.22	0.014712	121.88				
0.00232	0.37	0.015047	128.41				
0.002686	0.61	0.015353	135.40				
0.002991	1.07	0.015719	142.36				
0.003358	1.93	0.016055	149.53				
0.003724	3.09	0.016421	156.88				
0.004029	4.37	0.016665	164.39				
0.004334	5.89	0.017062	171.81				
0.00467	7.67	0.017398	179.44				
0.005006	9.53	0.017703	186.92				
0.005372	11.48	0.018008	194.36				
0.005708	13.59	0.018374	201.96				
0.006044	15.81	0.01871	209.66				
0.006349	18.23	0.019076	217.22				
0.006685	20.73	0.019381	224.82				
0.00702	23.41	0.019412	226.04				
0.007325	26.25						
0.007661	29.30						
0.007997	32.45						
0.008363	35.87						
0.008668	39.32						
0.008974	43.01						
0.00937	46.67						
0.009706	50.52						
0.010011	54.52						
0.010347	58.54						
0.010683	62.73						
0.011049	66.94						
0.011354	71.27						
0.01169	75.67						
0.012056	80.06						
0.012392	84.70						

Table

Results of Direct Tension Test on Specimen E.3

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012727	12.09	0.025363	95.44		
0.000305	0.10	0.013002	13.28	0.025485	96.05		
0.000702	0.16	0.013338	14.53				
0.001037	0.13	0.013673	15.88				
0.001343	0.22	0.013978	17.31				
0.001678	0.22	0.014284	18.74				
0.002014	0.31	0.01465	20.39				
0.002319	0.37	0.015047	22.04				
0.002625	0.46	0.015321	23.87				
0.003021	0.58	0.015657	25.73				
0.003357	0.65	0.015993	27.66				
0.003662	0.80	0.01642	29.61				
0.003967	1.01	0.016664	31.69				
0.004334	1.16	0.017031	33.64				
0.004669	1.41	0.017336	35.68				
0.004975	1.62	0.017641	37.76				
0.005341	1.87	0.018038	39.86				
0.005677	2.11	0.018343	42.06				
0.006073	2.32	0.018709	44.38				
0.006379	2.60	0.018984	46.70				
0.006623	2.87	0.019381	48.99				
0.006989	3.18	0.019686	51.43				
0.007325	3.45	0.019991	53.90				
0.007691	3.73	0.020357	56.41				
0.007996	4	0.020693	58.79				
0.008363	4.28	0.021029	61.32				
0.008668	4.58	0.021334	63.89				
0.009004	4.92	0.021731	66.45				
0.009309	5.22	0.022036	69.13				
0.009675	5.59	0.022372	71.70				
0.010011	5.96	0.022677	74.35				
0.010346	6.51	0.023013	77.01				
0.010682	7.12	0.023349	79.30				
0.010987	7.70	0.023715	81.92				
0.011323	8.46	0.02402	84.82				
0.011689	9.19	0.024325	87.57				
0.011995	10.08	0.024722	90.29				
0.012361	11.02	0.025027	93.06				

Table

Results of Direct Tension Test on Specimen F.1

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012696	27.77	0.025393	95.96		
0.000366	0.06	0.013032	29.67	0.025698	100.14		
0.000702	0.09	0.013398	31.59	0.026004	104.63		
0.001037	0.15	0.013704	33.57	0.02637	109.48		
0.001373	0.18	0.014039	35.62	0.026706	114.42		
0.001678	0.27	0.014375	37.75	0.027011	119.52		
0.002014	0.40	0.014711	39.95	0.027347	124.50		
0.00238	0.49	0.015016	42.15	0.027713	129.78		
0.002716	0.67	0.015352	44.35	0.028018	135.21		
0.002991	0.85	0.015688	46.48	0.028415	140.67		
0.003357	1.07	0.016023	48.83	0.02872	146.26		
0.003693	1.25	0.016359	51.12	0.029025	152		
0.004028	1.59	0.016695	53.41	0.029331	157.86		
0.004395	1.86	0.01703	55.85	0.029727	163.66		
0.004669	2.14	0.017427	58.05	0.030063	169.76		
0.005036	2.53	0.017732	60.37	0.030368	175.96		
0.005341	2.84	0.018038	62.51	0.030735	182.15		
0.005677	3.30	0.018404	62.36	0.03107	188.50		
0.006043	3.78	0.018679	56.49	0.031375	194.82		
0.006409	4.30	0.019014	51.46	0.031742	201.53		
0.006714	4.91	0.01935	50.45	0.032047	208.06		
0.00705	5.52	0.019747	51	0.032352	214.75		
0.007355	6.23	0.020052	52.83	0.032749	221.49		
0.007721	6.96	0.020388	54.82	0.033054	228.42		
0.008027	7.78	0.020693	56.86	0.03339	235.29		
0.008332	8.73	0.021029	59.09	0.033695	242.34		
0.008668	9.68	0.021395	61.47	0.034031	249.60		
0.009064	10.77	0.0217	63.82	0.034214	252.38		
0.0094	11.93	0.022036	66.14				
0.009705	13.22	0.022372	68.31				
0.010041	14.56	0.022707	70.53				
0.010377	15.96	0.023074	73.04				
0.010651	17.43	0.023348	75.81				
0.011018	19.01	0.023745	78.62				
0.011384	20.66	0.02402	81.71				
0.011689	22.34	0.024356	84.97				
0.012025	24.08	0.024691	88.24				
0.01233	25.88	0.024997	91.93				

Table

Results of Direct Tension Test on Specimen F.2

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.005097	18.22	0.010469	61.04		
0.000153	0.03	0.005189	19.11	0.010683	63.18		
0.000275	0.12	0.005341	19.96	0.010927	65.04		
0.000397	0.09	0.005494	20.94	0.01111	67.21		
0.000488	0.18	0.005616	21.85	0.011323	69.31		
0.000641	0.24	0.005738	22.77	0.011598	71.48		
0.000794	0.27	0.00586	23.72	0.011842	73.40		
0.000916	0.34	0.006013	24.63	0.012056	75.45		
0.001099	0.52	0.006135	25.61	0.01227	77.55		
0.001221	0.67	0.006257	26.52	0.012544	79.75		
0.001343	0.92	0.00644	27.53	0.012727	81.98		
0.001435	1.19	0.006593	28.57	0.013002	84.12		
0.001618	1.50	0.006684	29.54	0.013246	86.34		
0.001709	1.80	0.006837	30.58	0.01346	88.51		
0.001892	2.17	0.006928	31.62	0.013674	90.71		
0.002014	2.53	0.007081	32.60	0.013918	92.85		
0.002137	3.02	0.007234	33.66	0.014162	95.26		
0.002289	3.45	0.007325	34.70	0.014376	97.21		
0.002411	3.97	0.007508	35.74				
0.002533	4.46	0.00763	36.84				
0.002686	5.04	0.007722	37.85				
0.002778	5.62	0.007875	38.95				
0.0029	6.20	0.007997	40.07				
0.003083	6.84	0.008149	41.23				
0.003205	7.45	0.008302	42.36				
0.003327	8.09	0.008424	43.46				
0.003479	8.79	0.008516	44.56				
0.003571	9.49	0.008668	45.66				
0.003754	10.19	0.008821	46.79				
0.003876	10.99	0.008973	47.92				
0.003968	11.69	0.009126	49.05				
0.004151	12.48	0.009279	50.21				
0.004243	13.25	0.00934	51.34				
0.004426	14.07	0.009492	52.47				
0.004548	14.86	0.009645	53.96				
0.004731	15.69	0.009828	55.40				
0.004822	16.51	0.010042	57.14				
0.005006	17.37	0.010255	59.24				

Table

Results of Direct Tension Test on Specimen F.3

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012727	81.10				
0.000396	0.12	0.013032	86.68				
0.000702	0.15	0.013429	92.69				
0.001068	0.18	0.013704	98.74				
0.001373	0.31	0.014039	104.81				
0.001739	0.40	0.014375	111.19				
0.002044	0.49	0.014711	117.66				
0.00238	0.67	0.015077	124.10				
0.002655	0.82	0.015382	130.23				
0.003052	1.10						
0.003387	1.40						
0.003693	1.74						
0.004089	2.23						
0.004364	2.75						
0.00473	3.42						
0.005066	4.09						
0.005402	4.91						
0.005707	6.04						
0.006043	7.23						
0.006348	8.55						
0.006714	10.07						
0.007081	11.87						
0.007416	13.89						
0.007721	16.24						
0.008057	18.80						
0.008362	21.55						
0.008698	24.72						
0.009064	28.02						
0.00937	31.74						
0.009736	35.62						
0.010011	39.77						
0.010407	44.07						
0.010682	48.86						
0.011018	53.75						
0.011384	58.78						
0.011659	64.06						
0.012086	69.56						
0.012391	75.27						

Table

Results of Direct Tension Test on Specimen G.1

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012636	121.63				
0.000336	0.24	0.013033	127.61				
0.000641	0.34	0.013338	133.47				
0.000946	0.37	0.013643	139.39				
0.001312	0.31	0.014009	145.13				
0.001648	0.37	0.014345	150.90				
0.001953	0.52	0.01465	156.73				
0.00235	0.85	0.014986	162.43				
0.002655	1.16	0.015322	168.20				
0.002961	1.71	0.015627	174.67				
0.003327	2.84	0.016024	179.71				
0.003663	4.09	0.016359	185.42				
0.003998	5.83	0.016665	191.58				
0.004334	7.94						
0.00467	10.35						
0.004975	13.12						
0.005341	16.02						
0.005646	19.23						
0.005952	22.56						
0.006318	26.07						
0.006654	29.73						
0.006989	33.66						
0.007325	37.85						
0.00763	42.12						
0.007997	46.58						
0.008302	51.21						
0.008637	56.01						
0.008973	60.80						
0.009278	65.93						
0.009614	71.08						
0.00998	76.39						
0.010316	81.74						
0.010652	87.26						
0.010988	92.82						
0.011323	98.52						
0.011659	104.20						
0.011995	109.94						
0.012331	115.83						

Table

Results of Direct Tension Test on Specimen G.2

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012727	69.22				
0.000366	0.12	0.013063	72.34				
0.000702	0.24	0.013399	74.87				
0.001007	0.34	0.013734	77.07				
0.001373	0.82	0.01404	80.09				
0.001678	1.43	0.014406	83.17				
0.002014	2.08	0.014681	85.73				
0.00238	2.90	0.015047	88.97				
0.002716	3.94	0.015382	92.75				
0.003082	5.04	0.015718	96.36				
0.003388	6.17	0.016023	99.93				
0.003723	7.45	0.016359	102.40				
0.003998	8.76	0.016573	103.04				
0.004395	10.16						
0.00467	11.51						
0.005036	13.06						
0.005341	14.59						
0.005707	16.24						
0.006043	17.89						
0.006348	19.59						
0.006684	21.52						
0.00705	23.47						
0.007386	25.49						
0.007752	27.71						
0.008057	30.16						
0.008332	32.78						
0.008729	35.62						
0.009065	38.43						
0.0094	41.45						
0.009736	44.50						
0.010041	47.55						
0.010377	50.79						
0.010774	54.05						
0.011079	57.26						
0.011354	60.04						
0.01175	60.77						
0.012056	62.84						
0.012391	66.14						

Table

Results of Direct Tension Test on Specimen G.3

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012422	141.25				
0.000275	0.09						
0.000641	0.21						
0.000946	0.31						
0.001312	0.40						
0.001618	0.52						
0.001953	0.82						
0.002289	1.53						
0.002625	2.53						
0.002961	4.09						
0.003357	6.07						
0.003663	8.45						
0.003968	11.17						
0.004273	13.98						
0.00467	17.18						
0.004975	20.63						
0.005341	24.33						
0.005647	28.38						
0.005982	32.44						
0.006287	36.84						
0.006654	41.48						
0.006959	46.24						
0.007295	51						
0.007661	55.88						
0.007966	61.07						
0.008302	66.41						
0.008638	71.69						
0.008973	77.31						
0.009309	83.11						
0.009645	88.88						
0.009981	94.89						
0.010255	100.96						
0.010652	107.16						
0.010927	112.81						
0.011323	120.28						
0.011659	126.39						
0.011964	133.19						
0.0123	140.15						

Table

Results of Direct Tension Test on Specimen H.1

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012392	57.35				
0.000367	0.37	0.012728	60.16				
0.000733	0.49	0.013064	63.27				
0.001038	0.67	0.013399	66.38				
0.001374	0.85	0.013704	69.47				
0.00171	1.16	0.014071	72.73				
0.002045	1.43	0.014276	75.94				
0.002412	1.56	0.014742	79.14				
0.002747	1.71	0.015047	82.25				
0.003053	2.11	0.015383	85.73				
0.003388	2.47	0.01578	89.24				
0.003693	3.02	0.016055	92.69				
0.004029	3.72	0.016421	95.96				
0.004426	4.61	0.016757	99.65				
0.004731	5.59	0.017092	103.28				
0.005006	6.84	0.017398	106.82				
0.005403	8.15	0.017489	107.68				
0.005708	9.61						
0.006044	11.20						
0.00641	12.91						
0.006715	14.74						
0.007051	16.66						
0.007387	18.62						
0.007692	20.69						
0.008089	22.83						
0.008394	25.03						
0.008699	27.26						
0.009096	29.64						
0.009401	32.14						
0.009706	34.67						
0.010072	37.36						
0.010378	40.14						
0.010744	42.94						
0.01108	45.90						
0.011415	48.80						
0.01169	51.67						
0.011782	51.98						
0.012087	54.51						

Table

Results of Direct Tension Test on Specimen H.2

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012727	56.01				
0.000335	0.49	0.013032	58.66				
0.000671	0.89	0.013307	61.29				
0.001037	1.34	0.013704	63.88				
0.001343	1.77	0.01404	66.29				
0.001709	2.26	0.014345	68.80				
0.001984	2.78	0.014681	71.45				
0.00235	3.36	0.014986	74.26				
0.002686	4.03	0.015352	77.16				
0.002991	4.79	0.015688	79.87				
0.003388	5.46	0.016023	82.83				
0.003693	6.17	0.016359	85.73				
0.004029	6.90	0.016664	88.79				
0.004364	7.75	0.017031	91.75				
0.00467	8.52	0.017305	94.71				
0.005005	9.43	0.017641	97.64				
0.005402	10.47	0.017977	100.35				
0.005707	11.41	0.018313	103.16				
0.005982	12.57	0.018648	106.12				
0.006318	13.77	0.019015	109.02				
0.006684	14.99	0.01935	111.68				
0.006989	16.27	0.019655	114.52				
0.000733	17.95	0.019991	117.38				
0.007722	19.84	0.020357	119.95				
0.008027	21.76	0.020419	120.28				
0.008363	23.68						
0.008607	25.70						
0.009004	28.11						
0.009339	30.12						
0.009644	32.44						
0.010011	34.86						
0.010377	37.45						
0.010682	40.04						
0.011018	42.67						
0.011384	45.48						
0.01172	48.10						
0.012025	50.42						
0.0123	53.23						

Table

Results of Direct Tension Test on Specimen H.3

Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)	Grip Displa. (in)	Tension Load (lb.)
0	0	0.012666	53.60				
0.000274	0.58	0.012941	56.28				
0.000671	0.76	0.013277	58.97				
0.000946	1.10	0.013612	61.71				
0.001312	1.50	0.013979	64.61				
0.001587	2.11	0.014314	67.51				
0.001984	2.81	0.01468	70.38				
0.002258	3.66	0.014986	73.25				
0.002655	4.52	0.015291	76.21				
0.00296	5.43	0.015627	79.17				
0.003327	6.38	0.015962	82.56				
0.003632	7.26	0.016298	86.77				
0.003998	8.24	0.016695	91.99				
0.004303	9.22	0.016939	97.70				
0.00467	10.29	0.017305	103.74				
0.004975	11.38	0.017672	110.15				
0.00528	12.51	0.018007	116.77				
0.005646	13.67	0.018313	123.58				
0.005982	14.96	0.018648	130.60				
0.006257	16.12	0.018984	137.80				
0.006653	17.40	0.01932	145.04				
0.006989	18.80	0.019655	152.21				
0.007325	19.59	0.019991	159.53				
0.0076	21.09	0.020296	166.65				
0.007935	22.74	0.020632	172.60				
0.008332	24.42						
0.008637	26.28						
0.008942	28.14						
0.009248	30.09						
0.009614	32.17						
0.009919	34.28						
0.010285	36.50						
0.010652	38.67						
0.010987	40.99						
0.011293	43.40						
0.011659	45.87						
0.011964	48.38						
0.0123	50.97						

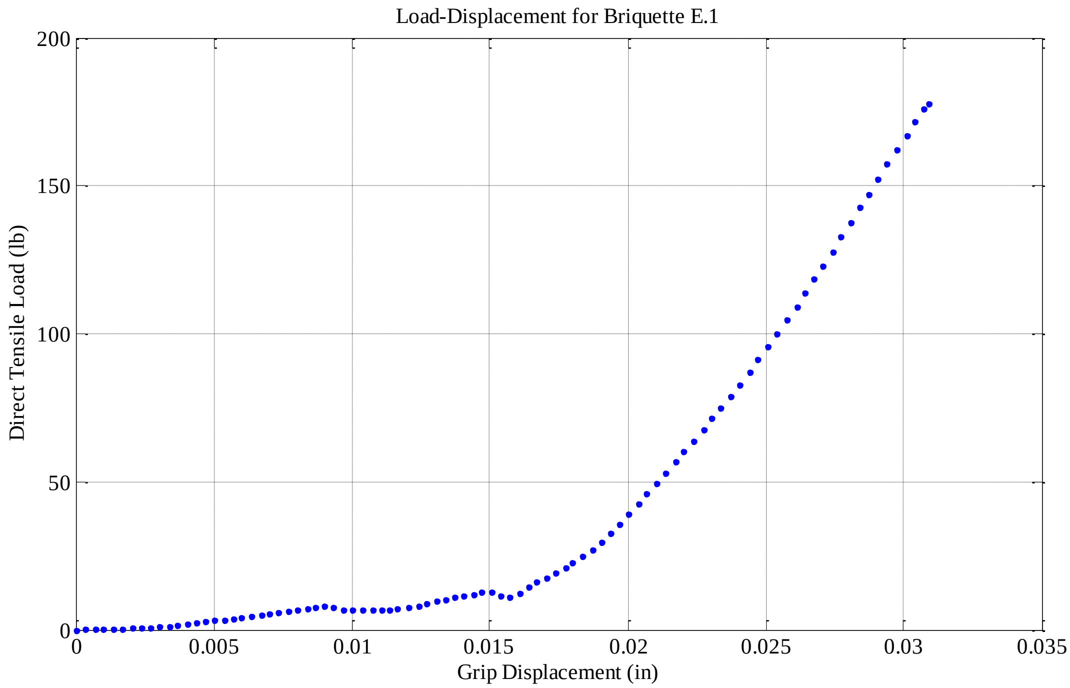

Figure Load-Displacement Curve for E.1

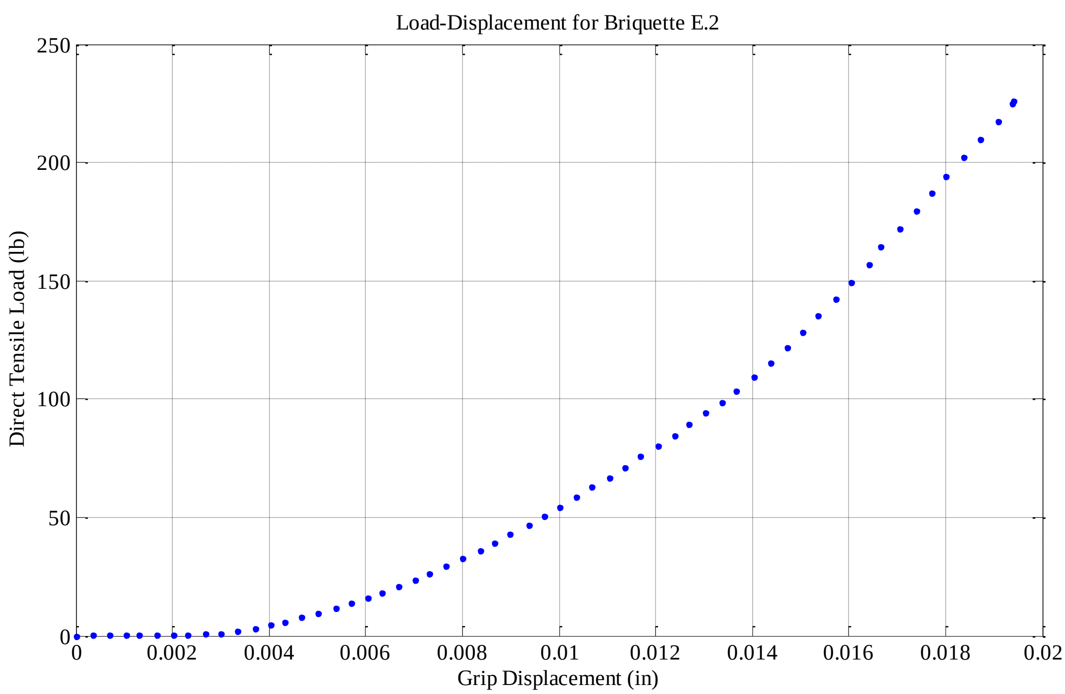

Figure Load-Displacement Curve for E.2

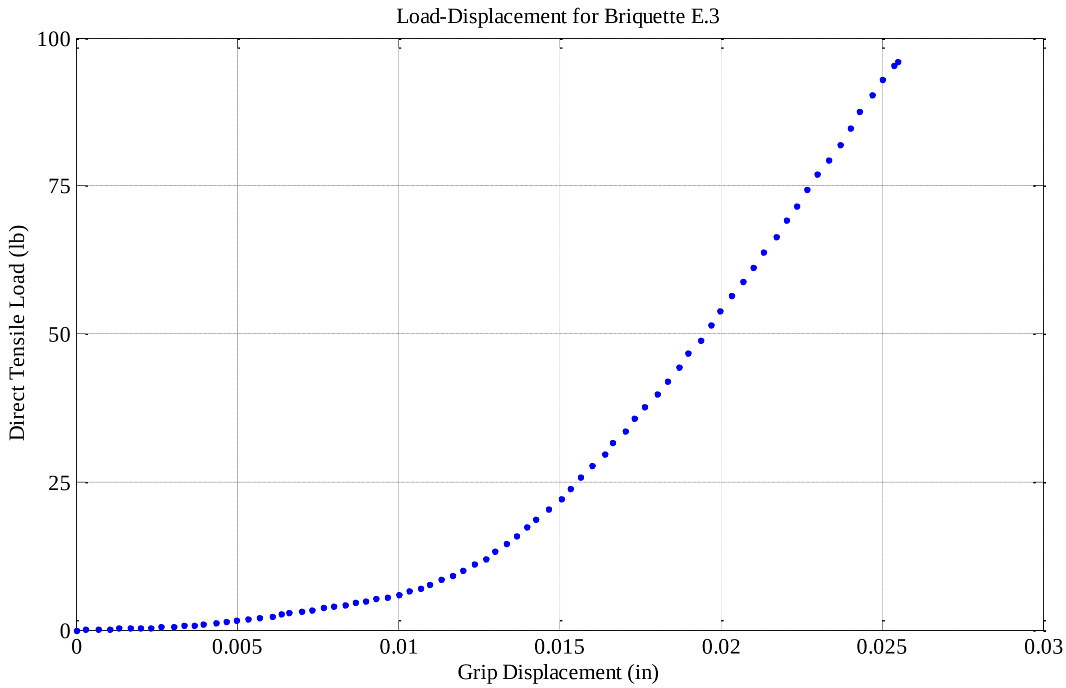

Figure Load-Displacement Curve for E.3

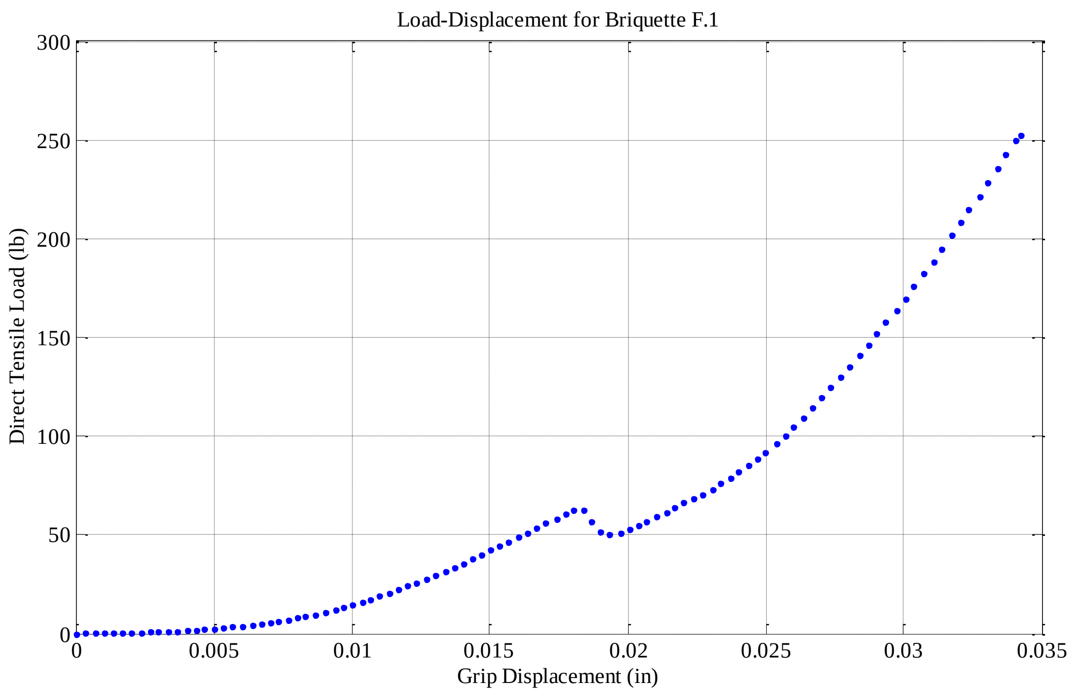

Figure Load-Displacement Curve for F.1

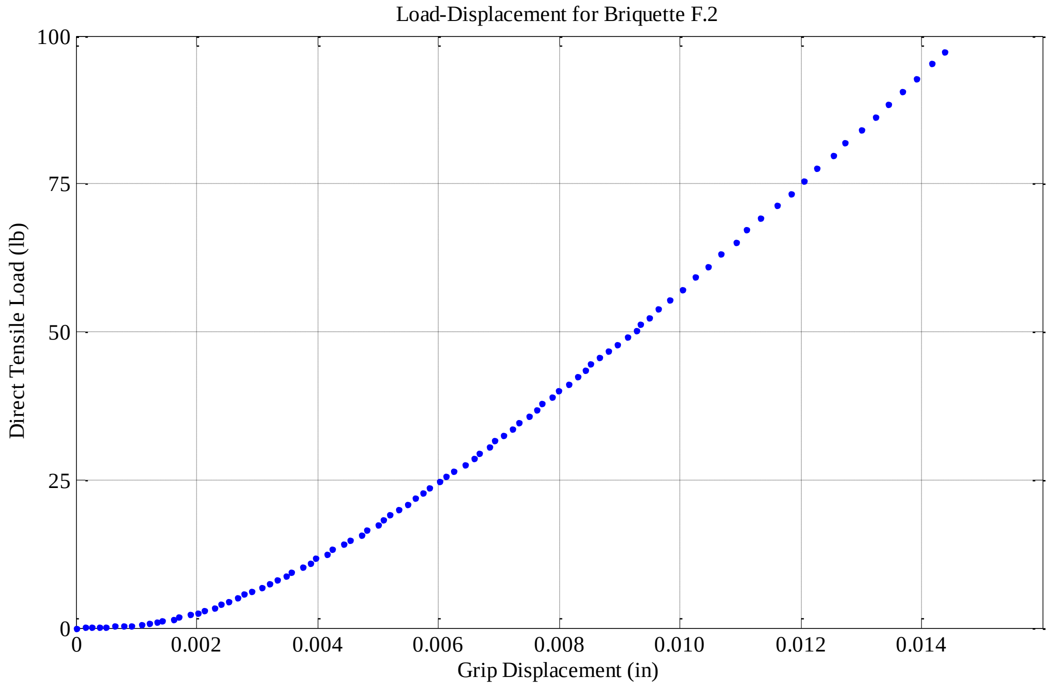

Figure Load-Displacement Curve for F.2

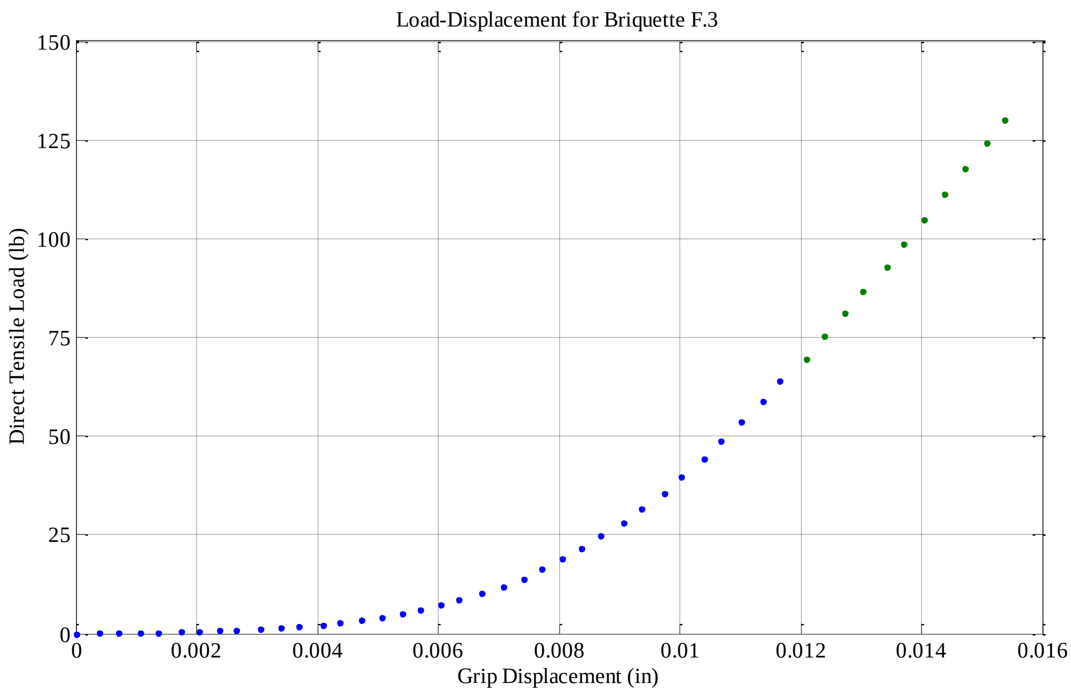

Figure Load-Displacement Curve for F.3

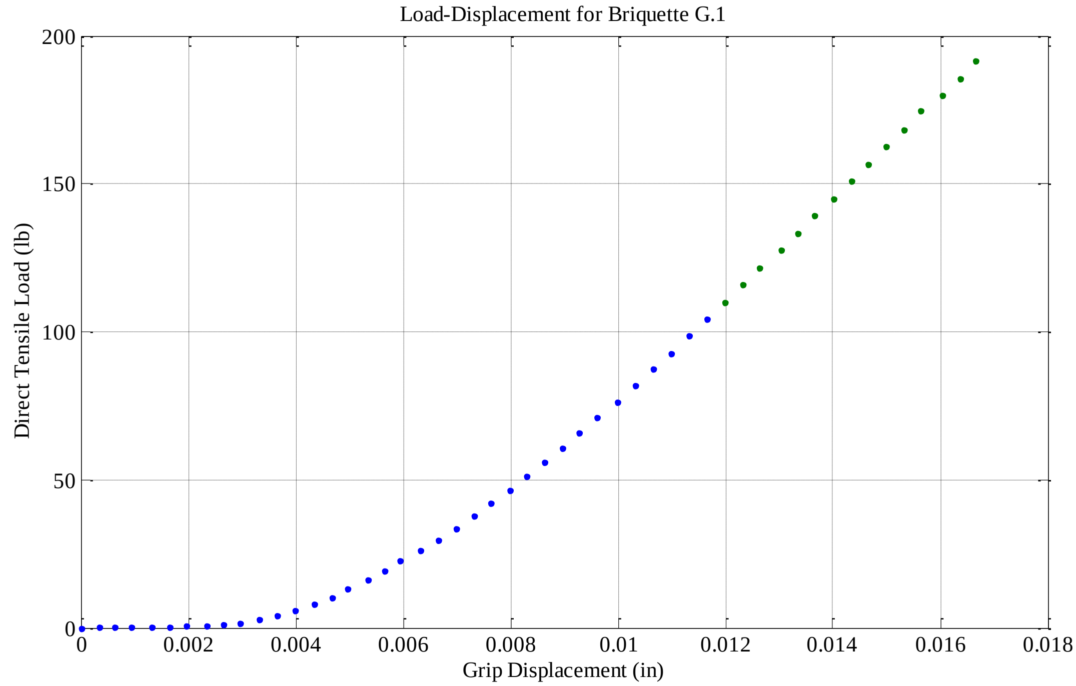

Figure Load-Displacement Curve for G.1

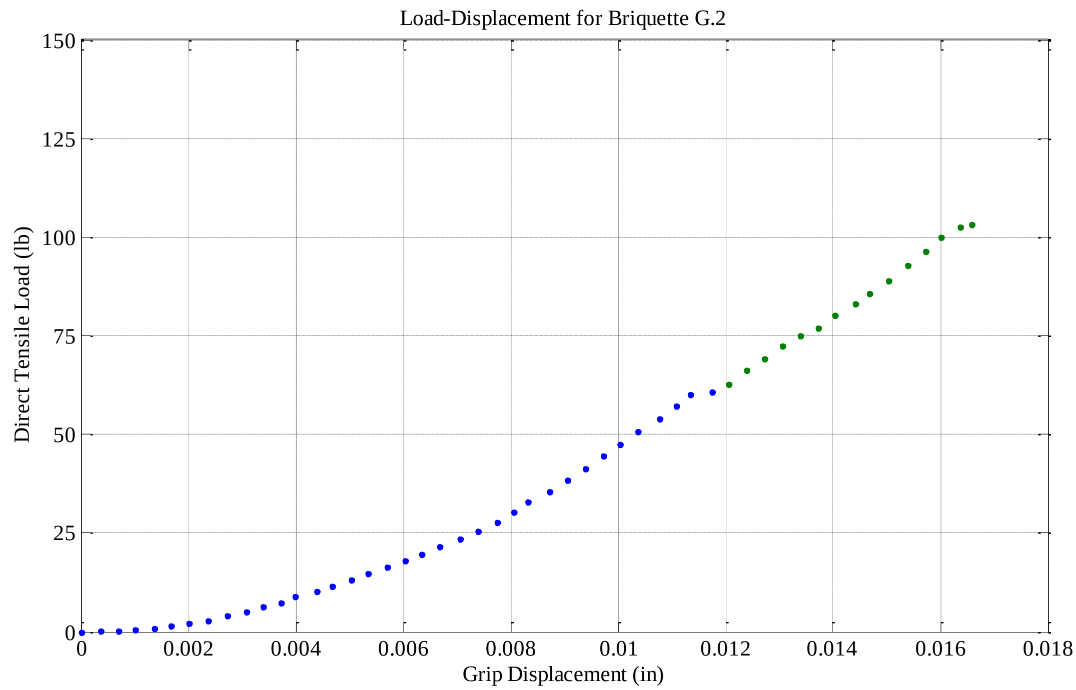

Figure Load-Displacement Curve for G.2

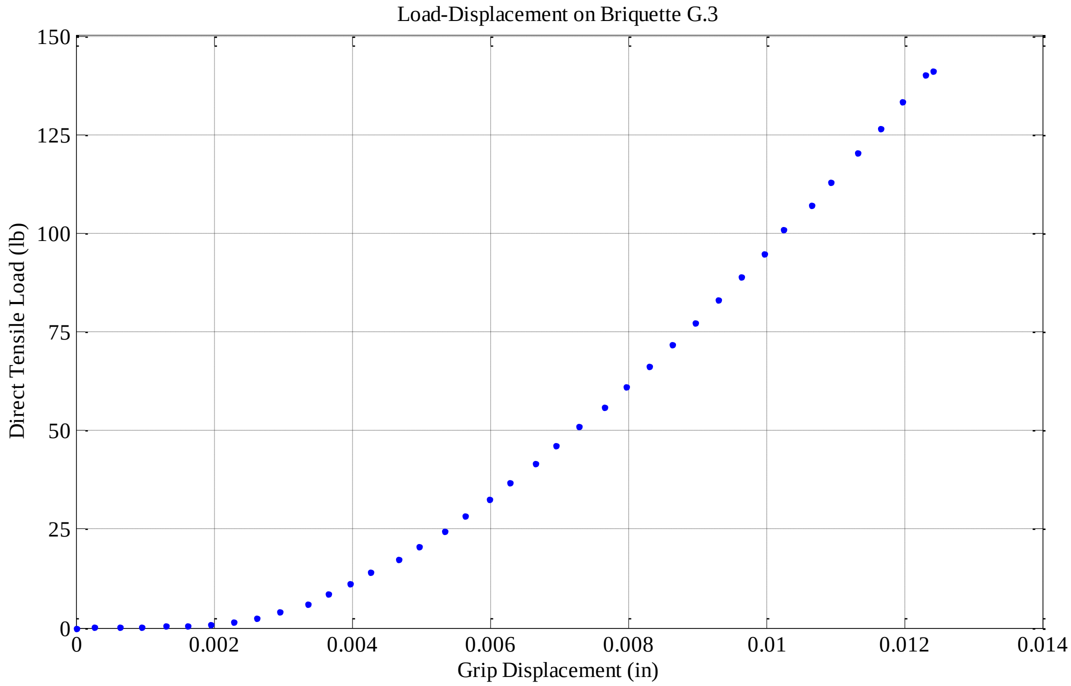

Figure Load-Displacement Curve for G.3

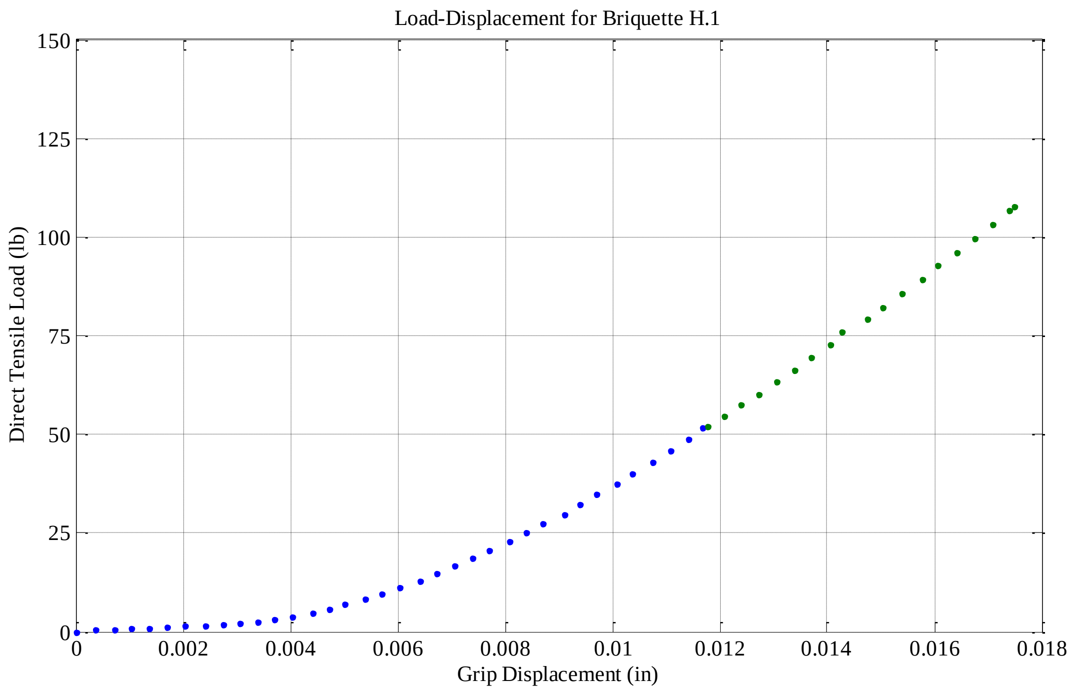

Figure Load-Displacement Curve for H.1

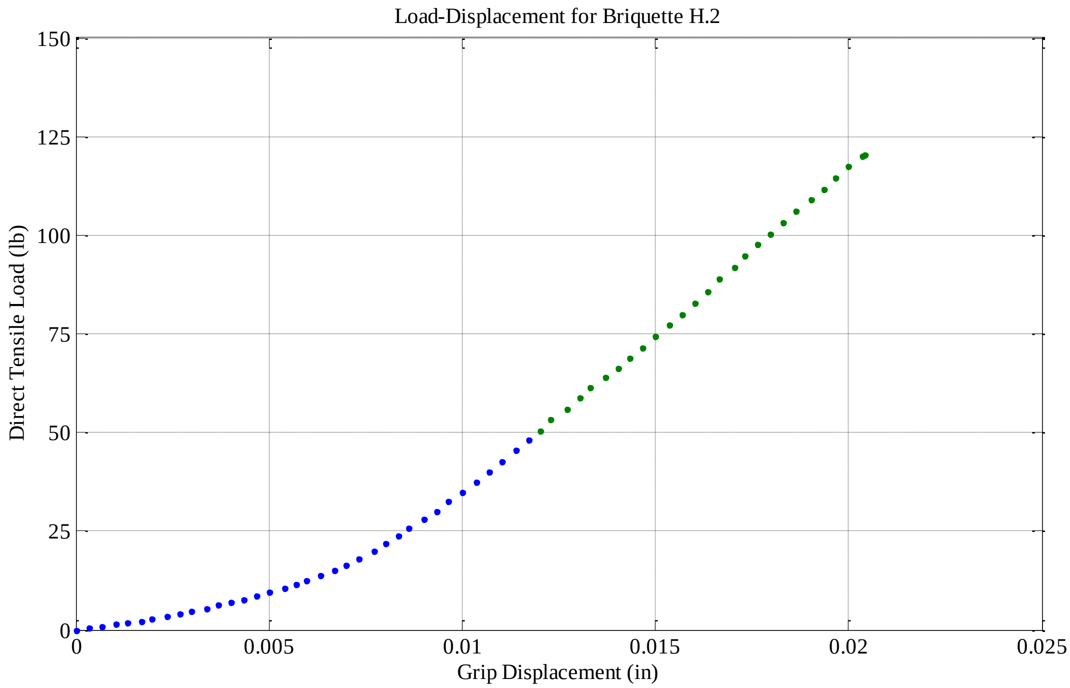

Figure Load-Displacement Curve for H.2

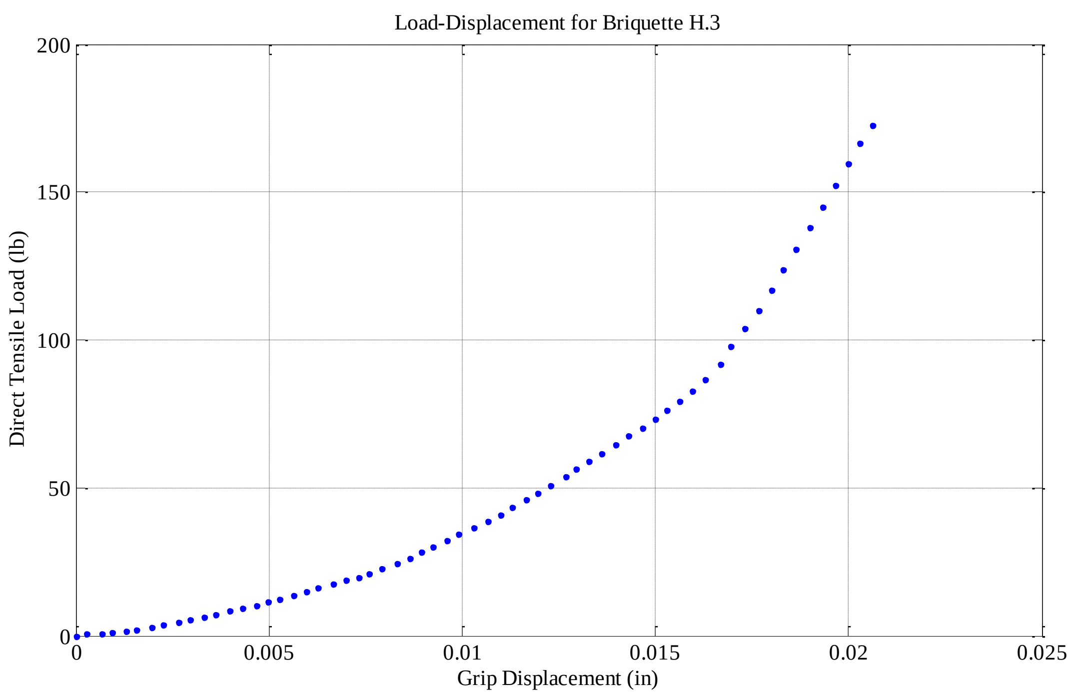

Figure Load-Displacement Curve for H.3