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INFLUENCE OF RETARDERS ON SHRINKAGE AND COMPRESSIVE STRENGTH IN RAPID SET CONCRETE

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INFLUENCE OF RETARDERS ON SHRINKAGE AND COMPRESSIVE STRENGTH IN RAPID SET CONCRETE

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BY

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For in Him we live and move and have our being.

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Abstract

The purpose of this project is to study the influence and behavior of citric acid on calcium sulfoaluminate (CSA) concrete and compare with industry standard retarders. A review of the available literature on calcium sulfoaluminate (CSA) cements tends to center on the chemical composition and behavior. Current literature fails to effectively address either granulated citric or liquid retarders in CSA cements. Almost all current literature discusses granulated retarders and their interaction with Portland cement. Previously, CSA cements have not been widely used despite the clear advantages of this concrete type possibly due to difficulty in placement. The benefit of using an effective liquid retarder with a CSA concrete would be easier placement while causing no negative long term strength or shrinkage issues. This could greatly increase the use of CSA cements.

Laboratory experiments were performed to investigate the effects of the retarders studied. These experiments included compression, shrinkage, and fresh property tests. All compression testing was conducted according to ASTM C-39 using 4”x8” cylinders. Shrinkage testing was conducted via two methods. The first method utilized the ASTM C-157 test. The second method utilized Geokon Vibrating Wire Stain Gauges (VWSG) to monitor the shrinkage continuously without the user bias involved in the standard ASTM test for shrinkage. It has been definitively shown that citric acid acts as an effective retarder for the dosages tested. The citric acid also acts as a superplasticizer, which increases the workability of the concrete. One previously unknown influence is that at large dosages of citric acid, plastic shrinkage occurs as well as permanent strength reduction. An industry retarder called Recover® had absolutely no influence on the retardation of CSA hydration. The retarder Delvo® had moderate retardation influence.

Chapter 1: Introduction

1.1 Problem Summary

This research was primarily motivated by phenomena observed in other research projects at the Donald G. Fears Structural Engineering Laboratory. The case study that formed the basis for this research was a slab poured at Fears Lab in the summer of 2014. This 37.5ft. by 37.5 ft. by 14 in. slab utilized a belitic calcium sulfoaluminate (CSA) cement known as Rapid Set® with a one percent citric dosage by cement weight. Historically CSA based concrete has been found to be very stable. In this case, the slab exhibited slow strength gain and shrinkage cracking the same day it was poured. The symptoms manifested by the slab indicated a problem in the mix design. Therefore, an objective of this study was to attempt to characterize the behavior of Rapid Set® under retardation. In this way, the results of the slab might be duplicated and more thoroughly understood. A secondary motivation was a lack of literature and research reflecting the use of retarders on CSA based cements in concrete, even though there is a considerable amount of literature available concerning retarders and superplasticizers in Portland cement based concretes.

The goal of this study is to characterize the effect of several types of retarders on Rapid Set® cement. This characterization includes the effects on workability, early age strength, and shrinkage of concrete. The initial premise was that the type of citric acid used in the Fears' lab was inhibiting strength gain and causing early age plastic shrinkage. The citric acid type used was citric acid that was dissolved in the concrete mix water. The citric acid is generally used in industry as a set time retarder to provide more workability and time for placement with CSA based cements. The slow strength gain was not as much of a concern as the very early occurrence of cracking. This phenomenon had not been experienced in over a decade using Rapid Set® cement. One of the primary difficulties with Rapid Set® cement is its rapid set time. To extend the set time at Fears Lab, a retarder is generally used for placement of the concrete. Thus, a better understanding of the use of and effect of retarders may improve the use for this cement.

There are many forms of commercially available CSA cements. Two that are of particular interest are Type K cement and Rapid Set® cement. The latter product is the focus of this thesis research. While Type K cement, a shrinkage compensating cement, is of comparable cost to Portland cement, Rapid Set® cement is more expensive. When using a Type K cement, a shrinkage compensating mineral additive such as Komponent® is combined with Portland cement. This creates a cement with expansive properties   A CSA cement such as Rapid Set®, however, is not combined with any Portland cement. While all CSA cements share good general durability, Type K cements are designed to create expansive concrete, while Rapid Set® cements are designed to achieve very high early strength.

Portland cement has been a product in widespread use since the 1800s. This product is the primary cement in ready-mix use. Portland cement is broken into the following categories:

- Type I: General Use
- Type II: Moderate Heat of Hydration
- Type III: High Early Strength
- Type IV: Low Heat of Hydration
- Type V: Sulfate Resistance

For this research project, the Rapid Set cement will be compared to Type III Portland cement as a performance baseline. The general framework of the Portland cement's interaction with retarders will be used to compare with and build a description for CSA behavior in the presence of set time retarders.

Rapid setting CSA cements have the ability to set within 15 minutes of water being added to the mix. If no retarders are used during mixing of the concrete and no retarders were included during the manufacturing of the cement, a process called flash set may occur. Flash set occurs when the cement reacts so quickly with the mix water that concrete hardens immediately, before placement occurs. This can damage equipment as well as delay construction. Thus, one effect of retarders is that they can prevent flash set. Another potential effect of retarders is mix-killing. This occurs when too much retarder is employed, so that the concrete either will not set or will have permanent strength reduction.

There are many set time retarders available or in use in industry today. Almost all retarders used for Portland cement concrete are liquid retarders. However, for CSA cement based concretes, both granular and liquid retarders are employed. Historically, citric acid was the standard retarder for CSA based concretes; however, liquid retarders are becoming more commonly used. This research compares the citric acid to several standard liquid retarders to determine if the behavior is similar. The liquid retarders chosen were ones most commonly utilized by industry in general practice. These retarders are Delvo® and Recover®. The research for this project entailed batching of concrete using Rapid Set® cement, retarded by varying amounts of citric acid, Delvo®, and Recover®.

1.2 Objectives

The current knowledge of CSA cements is completely rooted in experiments and/or engineering case studies. From experience and available literature, several lines of inquiry have been developed. First, citric acid is believed to be an effective retarder. Literature suggests that citric acid acts as a superplasticizer. It should be understood that a retarder does not always act as a superplasticizer. This means that the citric acid increases both the workability and placement of the concrete. Next, citric acid causes plastic shrinkage cracking to occur. Finally, it is detrimental to the long term strength and shrinkage of concrete to use excessively high dosages of citric acid as a retarder.

In order to investigate the objectives stated above, a thorough investigation of citric acid will be undertaken to characterize the properties and interactions of the retarder. This will allow for a direct comparison to the liquid retarders. Similar investigations will be executed for Recover® and Delvo®.

Chapter 2: Literature Review

2.1 Admixtures and Retarders used with Portland Cement

Concrete often requires adding a compound or admixture to extend its workability, freeze thaw resistance, or lengthened time for placement. To this end, many chemical compounds are in use by industry to satisfy these requirements. These compounds can have a profound impact on the concrete beyond the simple task it is meant to address.

Problems can develop when employing multiple admixtures. For instance, an interesting phenomenon was discovered in compound interaction between a superplasticizer and a retarder when used with Portland cement. A high citric acid dosage resulted in only 10% of the superplasticizer being adsorbed (Plank and Winter, 2008). The primary admixtures investigated were citric acid as a retarder and a recent generation polycarboxylate-based superplasticizer. High citric dosages were also found to result in a strong reduction of flowability (Plank and Winter, 2008). In self-leveling underlayments, polycarboxylate superplasticizers and citric acid are generally incompatible because the citric acid generally counters the effectiveness of the superplasticizer being used.

Their findings indicate that citric acid is incompatible with certain plasticizers, at least when binding with Portland cement particles. The competition for adsorption resulted in the citric reducing the overall effectiveness of the superplasticizer. This is not a trend that has been noted when a citric retarder is employed with a CSA cement (Plank and Winter, 2008).

The latest generation of polycarboxylates as superplasticizers remarkably reduces the water demand of Portland cement systems while improving the placeability and strength of the concrete (Belous et al., 2008). According to Belous et al., each of these polycarboxylates have a specific anionic charge density. This density creates a new charge balance within the concrete which extends the flowability (Belous et al., 2008). In order to increase work time for concrete placement, it is often necessary to introduce set time retarders. Most retarders compete with the adsorption of the superplasticizer present. This competition hinders efficiency of the plasticizer because certain retarders in acid form have a plasticizing effect. Citric acid is an exception to this case since it is believed to have no plasticizing effect. Instead, citric acid was documented to block the plasticizing effect of polycarboxylate based plasticizers when employed with Portland cement (Belous et al., 2008).

Belous et al. (2008) arrived at conclusions similar to those of Plank and Winter (2007). Citric acid acts to block the plasticizing effect of polycarboxylate-based compounds with Portland cement. Both studies concluded that this was the result of competition between the admixture and retarder to be absorbed by the Portland cement. It is impossible to extrapolate these findings to all admixtures' interaction with citric acid as these studies only examined a single family of compounds interaction. Belous, like Plank and Winter, concludes that citric acid has no plasticizing effect when used in conjunction with Portland cement. Regardless of whether citric acid acts as a superplasticizer or not, the possibility of competition for adsorption with plasticizers could be problematic.

Guoxin et al. (2012) studied the effects of both sodium gluconate and citric acid as retarders with amino sulfonic acid as a superplasticizer with Portland cement. One of the earliest conclusions of this study was that the citric acid did not improve workability with Portland cement. In general, superplasticizers perform by establishing a charge difference, or electrostatic repulsion, in the concrete paste. Batches utilizing the retarders were characterized by low fluidity in the concrete paste. In this study, the citric acid was observed to be absorbed more easily on a tricalcium silicate (C_3S) particle than the sodium gluconate. This relates back to the findings of Belous where the ease of binding on a cement particle will dictate the rate of adsorption.

As more citric acid was added, it began to compete with the amino sulfonic acid, causing competition for absorption on the tricalcium silicate. The citric was observed to be more effective in being absorbed causing a decrease in the superplasticizer's effectiveness. Additionally, the citric acid accelerated the ettringite growth in the concrete; this ettringite growth absorbed more free water than usual, resulting in increased flow loss and reduced fluidity of the fresh concrete. Both the sodium gluconate and the citric acid retarded tricalcium silicate hydration, but the citric acid was the most effective at this (Guoxin et al., 2012).

These findings may be very relevant to CSA-based cements. The conclusion that citric acid might feed ettringite production could serve to explain certain aspects of shrinkage behavior of CSA cements.

Moschner et al. in 2007 concluded that thermodynamic measurements indicated that the heat of hydration is reduced by the presence of citric acid. Their study also concluded that the citric acid is almost all removed from cement pore water by the end of the first hour of cement hydration. This was attributed to dissolution reactions causing precipitation of citric onto the cement particles. Three different concentrations of citric were employed: 0.1% by weight of cement, 0.4% by weight of cement, and 0.5% by weight of cement. The study found that in the absence of citric, main heat release due to C_3S was achieved by 12 hours while the max heat release was shifted to 17 hours when using 0.1% citric concentration. The peak shifted to 84 and 180 hours when the 0.4 and 0.5% citric concentrations were employed respectively. The presence of citric in a concentration of 0.1% had little effect on the pore solution when compared to mixes using no citric. The dissolution of C_3S and aluminate were considerably retarded by citric being present. Ettringite formation was believed to be slowed by the presence of citric acid (Moschner et al., 2007). This is displayed in Figure 1.

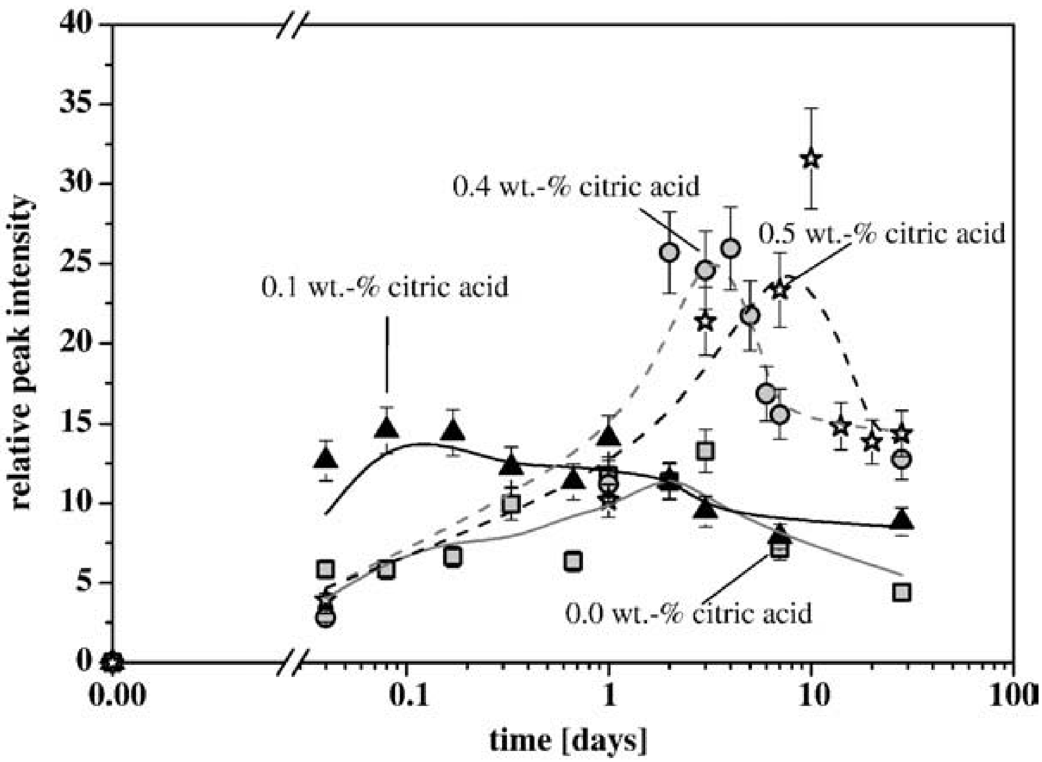

Figure 1 Changes in Ettringite Content of Samples (Moschner et al., 2007)

2.2 General CSA Behavior

One of the primary attractions of CSA cements is their higher early strength. There exist many potential explanations on why this occurs. In a study executed by Galan et al., it was proposed that early age strength is derived from the ettringite rich properties of the cement. This environment causes a tighter knit matrix within the concrete paste. The main objective of the study was to ascertain the permeability in relation to the overall effects of the ettringite rich environments (Galan et. al, 2016). A secondary objective contained within the study was the impact of the permeability on durability. This is relevant to the current study of admixtures on CSA cements because of durability. As pore structure is directly tied to permeability, it must be considered in any durability assessment. For this study, Galan et al. executed mercury intrusion porosimetry (MIP) and x-ray powder diffraction to measure the pore structure. The study concluded that despite the many available porosity tests it is almost impossible to accurately measure the pore size in the matrix given how small they are in an ettringite rich environment (Galan et. al, 2016).

The last conclusion of Galan et al. stands in contrast to a study executed by Bruyn et al. Bruyn et al. studied pore structure of both Portland and CSA cement pastes as well as durability. In the Bruyn et al. study, MIP and nitrogen sorption were both employed successfully to determine pore structure. One general note is that pore structure is created by water not used in the hydration reaction (Bruyn et al., 2017). In CSA cements, ettringite forms in the shape of needles which impact the developing pore structure. Bruyn et al maintains that the pore structure of the CSA cement paste is related to early strength properties. For this particular study, Bruyn et al. employed w/c ratios of 0.4, 0.5, and 0.6 for both the Portland and CSA mixes. Because of CSA cement's tendency to hydrate so quickly, chilled mix water was employed for the CSA mixes.

It was determined that the CSA cement bound with approximately 25% more water than the Portland cement. By MIP, CSA cement paste was characterized by having a larger pore size and critical pores size than Portland cement paste of the same w/c ratio. The CSA cement pores exhibited a coarser pore structure which Bruyn et al. attributed to the ettringite growth which takes up any water not directly being used for hydration. This reduces porosity. When subjected to durability tests, the CSA specimens performed better than Portland specimens. This is attributed to the reduced porosity of the CSA specimens (Bruyn et al., 2017)

The findings of Galan et al. are consistent with an earlier study executed by Winnefeld and Lothenbach in 2009. In their study, Winnefeld and Lothenbach were investigating hydration of CSA cements. One key aspect that they discuss is the presence of 15-25% by weight of gypsum. While this may seem irrelevant, gypsum according to the literature is beneficial for ettringite growth. Galan et al. believed that this ettringite growth affects pore structure, and this was confirmed by Winnefeld and Lothenbach. Winnefeld and Lothenbach determined that large ettringite needle formations were common in the CSA concrete microstructure. This leads to a dense, low porosity concrete matrix (Winnefeld and Lothenbach, 2009).

In the course of their study, Winnefeld and Lothenbach determined that the ettringite continued to grow, even after the gypsum was consumed (Winnefeld and Lothenbach, 2009). Hydration accelerated at between 5 and 16 hours from casting. All indications in this study pointed to ettringite being completely formed in the first 48 hours. The study utilized two different forms of CSA cement of varying composition. Figure 2 shows Scanning Electron Microscope images of the microstructure of the cements used.

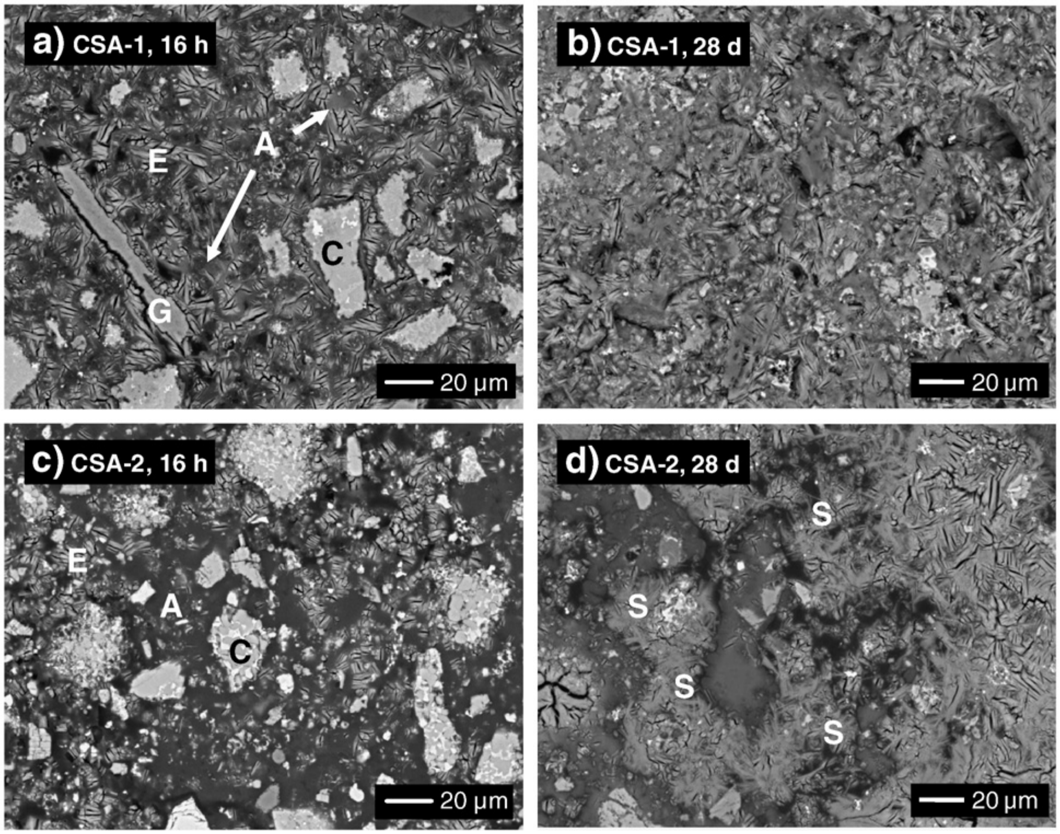

Figure 2, SEM Imaging (Winnefeld and Lothenbach, 2009)

The SEM images in Figure 2 indicates the formation of certain compounds in the concrete. In the figure, A indicates aluminum hydroxide, E indicates ettringite, G represents gypsum, C is unreacted CSA while S indicates stratlingite. In the image, the ettringite is visible in both variations of CSA based concrete (Winnefeld and Lothenbach, 2009). Also, the matrix has little to no indication of free pore space. The microstructure exhibits the dense microstructure predicted by Gallan et al.

A concern was raised by Kaufmann (2016) concerning the effects of temperature on CSA cements. He specifically cites a lack of literature on this topic. CSA cements are at an elevated risk for flash set anyway given the highly exothermic reaction that occurs (Kaufmann, 2016). Increased temperature when the cement is being used has the potential for flash set, poor consolidation, and poor placeability.

Inherent to CSA cements, one of the primary compounds is calcium sulfate, also known as gypsum. The presence of this compound, which may occur in different hydrate forms, allows ettringite as well as aluminum hydroxide to form (Winnefeld et al., 2017). In this study by Winnefeld et al., it is pointed out that calcium sulfates act to increase the hydration process of the CSA cement. The hydration kinetics are supposed to have a large impact on early age strength. They conclude that the more reactive the calcium sulfate is, the faster expansion occurs due to ettringite supersaturation (Winnefeld et al., 2017). In this study, compressive strength was measured at 1, 3, 7, and 28 days.

As would be expected, the greatest strength gain occurred in the first 7 days. However, Winnefeld et al. reported a slight strength loss between 7 and 28 days. This is the first time that the literature reports a case of strength loss in a CSA based concrete. An interesting point of discussion raised by Winnefeld et al. is the possibility that the reaction rate of calcium sulfate affects compressive strength (Winnefeld et al., 2017). Another concept stated is that high shrinkage may cause strength loss noted between 7-28 days (Winnefeld et al., 2017). However, Winnefeld et al. does not provide any insight as to why shrinkage might cause strength loss.

One type of cement, similar to CSA cements, replaces calcium with belite, C_2S. A study by Quillin (2001) replaced calcium with belite in sulfoaluminate cements and found that the concrete exhibited excellent strength development and sulfate resistance. A benefit of belite is that it can be manufactured at lower kiln temperatures. During hydration, the ettringite experiences the most growth. However, concrete using belite–sulfoaluminate cements have been shown to be prone to carbonation. The process of carbonation can lead to deterioration of reinforcement by corrosion or deterioration in the paste. Even using belite, this study recommended the use of retarding admixtures and water reducers (Quillin, 2001).

Calcium Sulfoaluminate Belitic (CSAB) cements have exhibited rapid setting, high early age strength, self-stressing, and shrinkage compensation (Chen et al., 2012). The CSAB cements in this investigation are primarily employed in pre-cast applications or for cold environments. It was determined that if most of the ettringite growth occurs before hardening, then no beneficial expansion will occur. However, if the ettringite growth occurs post hardening, expansion and cracking can be problematic (Chen et al., 2012).

Current research by Chen et al. indicates that ettringite formation occurs primarily at aluminum bearing particles, causing large expansion. Type K cements, used for shrinkage compensation, contain CSAB as a replacement for Portland cement. According to Chen et al., Type K cement experiences more expansion when in the presence of lime. All initial expansion measurements were taken after water cure but before immersion in a sulfate solution. It was determined that gypsum does help expansion, but high gypsum amounts do not cause expansion by itself. It was found that mix designs utilizing low w/c ratios also exhibited large amounts of expansion. The particle size of the cement can have a large impact on expansion. A cement with large particles will react and dissolve more slowly which enables large reserves of material available for ettringite growth (Chen et al., 2012). The study did conclude that if ettringite forms with no expansion, then the ettringite has room to grow without pressuring the matrix it exists in.

According to Telesca et al.(2014), CSA cement's behavior is governed by ettringite crystalline growth that is produced during hydration. Ettringite is characterized by the following:

1. High surface energy and specific surface area
2. Excellent binding ability
3. Early onset of mechanical strength

Under appropriate conditions, ettringite formation enables expansion to compensate for shrinkage. Telesca et al. emphasizes that current theory states that ettringite particles with high surface area and colloidal size promote expansion. Ettringite will continue to grow after the concrete has set. The use of lime to create an alkali environments has a profound effect on the ettringite production. Increased quantities of gypsum also enable greater ettringite growth (Telesca et al., 2014).

In the family of CSA cements, there exists a particular group of cements referred to as Shrinkage Compensating Cements (SCC). These cements have expansive properties which exist due to the formation of ettringite. This ettringite formation occurs even within rapid setting CSA cements. When ettringite formation occurs, a specific concern arises called Delayed Ettringite Formation (DEF). Ettringite formation occurs, generally, in the paste of the concrete (Moffat, 2005). The reason that DEF is a concern is because ACI 223 places limits on allowable expansion (Moffat, 2005).

DEF is a leading cause of early age deterioration of Portland cement based concrete. Moffat refers to DEF as a form of internal sulfate attack. The reason that this is a concern is that when retarders are employed they tend to suppress or delay normal reactions during hydration. It is possible that one of these suppressed reactions is ettringite formation. One of the dangers is that the paste aggregate interface is vulnerable to damage (Moffat, 2005). If DEF occurs here, the concrete has the potential to spall and crack severely.

Two specific conditions contribute to DEF occurring: w/c ratio and heat (Moffat, 2005). Moffat concludes that concretes with a lower w/c ratio are more susceptible because less water reduces the amount of ettringite being formed. However, the concrete still has the potential to form ettringite if exposed to moisture at any point. This means that ettringite growth could occur and cause expansion after the concrete has hardened (Moffat, 2005). Concrete in this stage has little ability to expand which causes cracking. DEF does not tend to occur in CSA cements for two reasons. First, most CSA cements are over sulfoaluminated, meaning the ettringite formation reactions are forced to completion. Second, there is a lack of C_3S, the general focus of sulfate attack in concrete. It has been observed that CSA hydration causes ettringite to form (Pera and Ambroise, 2003). The microstructure of ettringite is strongly dependent upon the presence of lime. With no calcium hydroxide present with the CSA cement, the reaction causes the material to behave expansively. This is the basis of shrinkage compensating concrete applications.

Another form of degradation in concrete is carbonation. In its simplest form, carbonation is the breaking down of the constituent compounds in the concrete, leading to cracking. In CSA based concretes, Hargis et al. postulated that the carbonation rate is inversely proportional to the w/c ratio. To measure the effects of carbonation, flexure prisms were cast and placed in a carbonation chamber at 57% relative humidity and 4% CO_2. Cracking along the surface was tracked via an indictor dye (Hargis et al., 2017). It was observed that the CSA mortar had a decreasing ability to absorb water as the w/c ratio decreased from 0.65 to 0.40. With decreasing w/c ratio, strength was observed to increase. Hargis et al. concludes that this strength increase with low w/c ratio is due to a reduced porosity in the CSA concrete. Ultimately, the study did determine that CSA based concrete has a carbonation rate that is faster than that of Portland cement. As carbonation progresses, it has a negative effect on strength as should be expected (Hargis et al., 2017). In order to counteract carbonation, the study determined that low w/c ratios of approximately 0.4 are less susceptible to the effects of carbonation.

However, once carbonation begins to occur, the breakdown of certain compounds leads to the formation of ettringite (Hargis et al., 2017). This causes a volume change which increases the damage to the concrete. The ettringite itself begins to also breakdown which increases porosity (Hargis et al., 2017). Hargis et al. concluded their study with two observations. First, CSA cements with increased calcium sulfate have increased resistance to carbonation. Second, decreased w/c ratios improve the strength performance (Hargis et al., 2017).

In 2015, a study from the University of Illinois-Urbana identified two mechanisms of concrete expansion. Both of these modes involve ettringite. These modes are referred to as the crystal growth and the swelling theory by Chaunsali and Mondal (2015). The study never clearly defines these two theories but rather refers to their existence.

This study utilized blended cement mixes of ordinary Type I Portland cement and CSA cement. One clear result of the study was the determination that ettringite supersaturation governs expansion (Chaunsali and Mondal, 2015). Chaunsali and

Mondal measured ettringite content through concentration levels of certain ionic components present. When the concentration levels reached an unstated intensity, the ettringite concentration was considered supersaturated. The primary conclusion of the study was that increased CSA cement content resulted in greater ettringite supersaturation. This in turn caused greater crystallization stress (Chaunsali and Mondal, 2015).

Very few studies have been executed on the particular product called Rapid Set®, a belitic CSA cement. A previous research project by David Frank and Dr. Ramseyer at the University of Oklahoma investigated the effect of temperature on compressive strength using Rapid Set®. In order to study these effects, it was necessary to vary both the temperature at the time of mixing and the temperature at which the specimens were cured.

The aggregates were chilled or heated to set temperatures in order to obtain certain temperatures at the time of mixing. The mixer drum was also heated or chilled to correspond with the desired mix temperature (Frank 2011). The curing temperature was set using tanks with heated or chilled water in which specimens were submerged. The coldest curing condition was created by placing specimens in water filled tubs which were placed in an industrial refrigerator (Frank, 2011). The specimens were placed in their respective curing positions in the molds they were cast in. The top of the cylinder was exposed to air. In theory, the actual concrete cylinder was not subject to water cure, only the thermal effects. Temperature was carefully monitored by thermometers. The mixer drum temperature was monitored using infrared digital thermometer.

Frank indicates that it was impossible to batch these concrete mixes without a water reducing additive of some type. In his work, he chose to employ Glenium 7500, a high range water reducer, and attempted to use citric acid in place of a high range water reducer. Glenium is a superplasticizer that is a carboxylate (Frank 2011). Through the course of his literature review, Frank determined that citric does not have an impact on long term strength. However, Frank states that little information is available on citric behavior in the presence of CSA cements. This was found to be the case for this thesis as well. It was concluded that use of citric acid in the place of a superplasticizer was simply not effective. For the remainder of the study, Glenium was used as the superplasticizer (Frank 2011).

The study did not execute any strength tests beyond 28 days because 28 days was viewed as a good indication of ultimate strength (Frank 2011). Frank concluded that mixes with a higher cement concentration were more susceptible to temperature effects. Another conclusion was that a high curing temperature increased early age strength gain. Conversely, as mix temperature decreased, the early age strength also decreased. Frank attributed this to a higher hydration rate at high ambient temperature. The higher hydration rate results in a greater strength gain (Frank 2011).

2.3 Admixtures and Retarders Used with CSA Cement

Currently, CSA products are a niche market since the increased cost of production and perception of poor workability of the products make them less appealing. Research has shown that in the presence of the proper admixtures, the CSA cements outperform Portland cement in strength and longevity (Ramseyer,2018). As CSA cements are not in great demand, there is less literature available on retarders, the most important admixture when using Rapid Set®. Rapid Set® is a specific type of CSA cement that is designed to achieve high early strength.

Osipov (1978) stated that because retarders are used to extend the workability and set time of concrete, they are sometimes referred to as surface active agents and that certain types of retarders operate in such a manner causing hydrophilization. In other words, they act so that the water is repelled from the cement, slowing the hydration process. Osipov (1978) states that retarders act as dispersing agents. When this occurs, Osipov contends that the structural formation of the concrete is affected. Although this specific phenomenon has not been noted, it has been observed that strength reduction occurs in conjunction with certain retarders (Osipov, 1978).

A primary principle contained in Osipov's study is that at some "optimum" dosage of retarder, the set time doubles. This is a statement that must be viewed with a certain amount of caution. Osipov never defines what the optimum dosage is for any of the retarders he studies. In his conclusions, Osipov states that at this "optimum" dosage the concrete set is delayed by nearly 8 hours (Osipov, 1978). This statement has a very narrow applicable window as the author never states the cement used in this study. Although several observations made in this study have also been corroborated either by other studies or by experience, Osipov never clearly defines his experiment nor does he satisfactorily support some of his key findings.

The main topic of interest in a study by Zajac et al. is retardation and its effects. However, at this point in time, almost no literature exists on retarders in CSA cements. This study in Germany experimented with various retarders in CSA cements. Their research focused on the type of reactions and immediate results of the retardation as well as how it worked.

Zajac et al. investigated three retarders: sodium gluconate, sodium potassium tartrate, and borax. All experiments were conducted using a w/c ratio of 2.0 because of how the pore structures were to be tested. All of the retarders were mixed into the mix water for all concrete batches. The retarders were all dosed at 2% by cement weight and no other study of changing dosage was investigated. The retarder's efficacy was analyzed using two criteria, the effect on dissolution reactions and the effect on precipitation (Zajac et. al, 2016).

Measurements for heat of hydration were also taken using calorimeters to determine if hydration was being impeded by the retarders. According to Zajac et. al, CSA hydration is characterized by the dissolution of ye'elmite (C_4A_3S) and the production of ettringite and $Al(OH)_3$. It was determined from this study that ettringite reaches its full potential at 24 hours.

The use of sodium potassium tartrate resulted in a depressed heat of hydration which indicated the retarder was effective. Also, it delayed ettringite growth to the point that no ettringite was located until 8 hours after casting. The reactions with the sodium potassium tartrate and cement resulted in larger amounts of sulfates and calcium (Zajac et. al, 2016). When the borax was used, the hydration was delayed for 24 hours. Once the retardation ended, a massive surge in ettringite growth occurred. The borax increased the concentration of sulfates, calcium, and silicon in the concrete. The sodium gluconate was an extremely effective retarder but did not affect ettringite growth (Zajac et. al, 2016). It simply slowed the other accompanying reactions and compound formations. In general, the sodium potassium tartrate and sodium gluconate prevented ettringite growth (Zajac et. al, 2016).

2.4 Concrete Shrinkage

To understand the importance of shrinkage, it is necessary to understand the various types of shrinkage. In 2013, Roswurm stated that drying shrinkage is the generally assumed type of shrinkage. Shadravan et al. (2015) defines drying shrinkage as a type of shrinkage that does not begin at loading or drying of a specimen but at the time water and cement come into contact. Drying shrinkage is a loss of volume because of moisture evaporation (Roswurm, 2013).

Hansen (1987) defines drying shrinkage as a time dependent deformation due to water loss at constant temperature and relative humidity. Hansen also states that despite numerous investigations, shrinkage is not a well-known property of concrete. Hansen mentions that it is clearly understood that drying shrinkage is generally an irreversible behavior that has multiple mechanisms. Hansen’s work dealt with Portland cement, Type I, and utilized w/c ratios of 0.4 and 0.6. One of the conclusions of this study was that moisture loss occurred at increased rates when the relative humidity was lower. It was also estimated that 60% of the irreversible (drying) shrinkage occurred during the first day of curing. The study concluded that any moisture gradients and duration of shrinkage stresses did not affect total shrinkage (Hansen, 1987).

In 2014, Hajibabaee and Ley released their finding from a study on wet curing impact on curling and drying shrinkage. It was their contention that shrinkage in concrete increased with reduced w/c ratios and increasing cement fineness. One of their key findings supports a claim discussed by Hansen (1987); Hajibabaee and Ley found relative humidity to be a parameter that controls shrinkage behavior. A major assumption for the purposes of their study was that all drying begins at the top surface of the specimen which in this case was a slab on grade. To force this assumption to occur, a water proof membrane was used on all slab faces except the top. The specimens under study were cured at 40% relative humidity in an effort to simulate slab on grade behavior. One of their main conclusions was that as the wet cure period increased, drying shrinkage strain also increased (Hajibabaee and Ley, 2014).

In 2015, Shadravan et al. released their findings on long term shrinkage for slabs on grade. One of the key assertions of the study was that drying shrinkage is one of the most common sources of concrete cracking. This shrinkage leads to warping, curling, and eventual cracking within the slab (Shadravan et al., 2015). Shadravan et al. states that shrinkage occurs not during curing of a specimen but begins when water is introduced to the cement in mixing of the concrete. As in previous studies on shrinkage, relative humidity is a primary factor as well as temperature (Shadravan et al., 2015). Cracking was monitored visually as well as through strain measurements. In the study, four types of concrete mixes were executed: Portland cement, CSA, and two shrinkage reducing admixtures. The CSA cement utilized was both a shrinkage compensating cement and rapid setting. One of the conclusions from the study was that the CSA based cements were less sensitive to shrinkage cracking than the typical Portland cement based mix or high performance concrete (Shadravan et al., 2015). Also, the study determined that the current ASTM C-157 designated test for drying shrinkage is inaccurate for modeling drying shrinkage in slabs on ground.

One major difference between Hajibabaee and Ley (2014) and Shadravan et al. (2015) is that Shadravan asserts that shrinkage increases with increasing w/c ratios. This difference is related to the difference of cements used in the study. Shadravan made their assertion based on a shrinkage compensating cement that is CSA based. Hajibabaee and Ley study utilized Portland cement which, in general, experiences a much greater amount of shrinkage. It is important to note that within the family of CSA cements there is a wide spectrum of shrinkage behavior dependent upon the intended use and mode of manufacture (Shadravan et al., 2015).

Chapter 3: Research Protocol

3.1 Mix Design

The following protocol was established as a mix design matrix. Three w/c ratios were chosen to represent a spread of available rapid setting CSA mixes used in industry. The three ratios were: 0.45, 0.47, and 0.50. The lower ratio means there is less water available than the cement theoretically requires for hydration. The 0.47 w/c ratio is approximately the theoretical w/c ratio for complete hydration. The 0.50 and 0.45 provide upper and lower bounds respectively, which bracket the theoretically required ratio (Ramseyer, 2018).

The retarder dosage was varied based on the type of retarder used. For all retarders, the dosage is determined by a ratio involving cement weight. The liquid retarders are measured by cement weight but have a manufacture specified dosage rate. The citric acid is dosed based on cement weight and for ease of placement. The dosage of the citric acid was based on the work of Moschner et al. (2007). One aim of this project was to standardize the dosage between liquid and granulated retarders so that results could be compared. For each w/c ratio, one batch had no retarder and is used to act as a control. Each different type of retarder was used in the full mix design matrix. The citric acid was determined to be dosed at 0.1%, 0.5%, 0.75%, and 1.0% by cement weight. The Recover® dosage was set by manufacturer to be 4 oz. /100 lb. cement, 20 oz. /100 lb. cement, and 40 oz. /100 lb. cement. The Delvo® dosage was based on the sponsor’s typical range which is: 2 oz. /100 lb. cement, 6 oz. /100 lb. cement, and 12 oz. /100 lb. cement. All liquid retarders were dosed per 100 pounds of cement. Table 1 below summarizes the test matrix discussed in this thesis.

Table 1, Concrete Batch Matrix

W/C: 0.45			W/C: 0.47			W/C: 0.50		
Citric (%)	**Delvo® (oz)**	**Recover® (oz)**	**Citric (%)**	**Delvo® (oz)**	**Recover® (oz)**	**Citric (%)**	**Delvo® (oz)**	**Recover® (oz)**
0.10	2	4	0.10	2	4	0.10	2	4
0.50	6	20	0.50	6	20	0.50	6	20
0.75	12	40	0.75	12	40	0.75	12	40
1.00			1.00			1.00		

Note: all curing occurs at 70^0F and 50% relative humidity

3.2 Testing protocol

The testing program was designed to monitor both drying shrinkage and compressive strength. All shrinkage specimens were tested using ASTM C-157 unrestrained shrinkage prisms. The use of a length comparator to determine shrinkage was employed according to current governing ASTM standards. All C-157 shrinkage readings were measured using the dial gage shown in Figure 3.

Figure 3, C-157 Dial Gage Apparatus with Comparator

In addition to the C-157 prisms, 6”x12” cylinders were fitted with Geokon Vibrating Wire Strain Gauges (VWSG). The Vibrating Wire Strain Gauges were also employed to compare with the C-157 test, which tends to experience more user bias. These strain gages had leads which were attached to the sensor by small hose clamps.

The strain gages were firmly seated in the receptor of the lead, and the hose clamp tightened by nutdriver. The data was all collected on Geokon data loggers. These loggers can handle up to 16 VWSG which may be set to gather at 5 minute increments. For this study, the time increments for early age data acquisition was set to 15 minutes. Figure 4 shows an assembled Geokon VWSG and an instrumented 6”x12” cylinder.

a) b)

Figure 4, a) Geokon VWSG b) Instrumented 6”x12” Cylinder

All compressive strength specimens were cast using 4”x8” cylinders. For every batch, there were twenty-four compressive specimens cast, one 6”x12” cylinder cast, and three C-157 prisms cast. The first compressive strength testing occurred at 3 hours after casting then at 6 hours, providing the concrete had set. Tests also occurred at 1 day, 3 day, 7 day, 14 day, and 28 day. All compression testing was executed on a Forney Compression Testing Machine which is shown in Figure 5.

Figure 5, Forney Compression Testing Machine

The shrinkage readings occurred on the same schedule as compressive strength testing. In addition to the C-157 samples vibrating wire strain gauges measured shrinkage in 15 minute intervals for approximately a year. The strength and shrinkage results were all plotted for comparison for each retarder type.

3.3 Mixing Protocol

All batches followed ASTM C-192 with the exception of the time for mixing. When mixing Rapid Set®, it is difficult to follow ASTM protocol of mixing 3 minutes, resting 3 minutes, and mixing for a final two minutes. Because of Rapid Set® is an early strength concrete, it has a propensity to quickly lose slump. It was necessary to mix quickly over a short time duration while the material had a high slump. All mixes utilized #67 Richardsonspur limestone coarse aggregate, and a Dover sand supplied by Dolese Bros which meets ASTM C-33 specifications. A high range water reducer was employed as well. For this study, it was Glenium 7500 as supplied by Dolese Bros. All moisture content measurements were conducted according to ASTM C-566. For all mixes, a battery of fresh tests were performed. These included slump (ASTM C-143), unit weight (ASTM C-138), air content (ASTM C-231), and temperature, as measured by a thermometer.

When mixing for the citric acid retarder, the citric acid was measured on a balance then mixed in a small amount of warm water to thoroughly dissolve. This mixture then became part of the mix water. The liquid retarders were added to the mix directly via a graduated cylinder once part of the mix water was added. The liquid retarders were never added to the mix water.

Because most of the batching was conducted during the summer, it was necessary to chill the mixer by adding ice, even on days when batching occurred at 6 AM. Ice was added to the drum until the drum temperature was roughly 45^0F. The ice and melt water were then discharged and batching started immediately. During the most intense parts of the summer, it was necessary to use a 50% replacement of ice by weight for the mix water. This was done to reduce slump loss during mixing and casting. For any mixes conducted during cold weather, the drum was warmed using hot water prior to the batch. All pre-batch temperatures were measured using an infrared digital thermometer.

All aggregate and cement was gathered 24 hours in advance of the batch. Moisture content samples were taken; 50 lb per bucket of the sand and rock were weighed. These buckets were sealed with lids and placed in a secondary environmental chamber. These buckets were adjusted the morning of the batch as determined by the moisture content. The cement was bucketed to the exact required amount as this was not affected by the moisture content. The cement buckets were also stored in the environmental chamber. This allowed all the aggregate to be at the same temperature, roughly 70^0F.

As mixing proceeded, sand and rock were alternately added to the drum. Next, a quarter of the mix water was added. The first bucket of cement, approximately 30 lbs, was added. This was followed by adding half the remaining mix water and Glenium, if required. The remaining cement was added, followed quickly by the remaining mix water.

During casting, the 4x8 cylinders were externally vibrated per the guidelines of ASTM C-39. This was a necessity due to the rapid setting of the concrete and the small crew available for casting. This was also the recommendation of the corporate representative from the cement manufacturer.

It was determined that set time testing should be executed for several mixes as the project was concluding. The set time testing was executed in general accordance with ASTM C-403. The time increments of testing were much finer than generally prescribed by the ASTM due to the quick setting nature of the Rapid Set®. The first reading was taken 9 minutes after the concrete was first placed on the sieve. The fresh concrete was sieved into a 10” diameter nursery pot. Enough paste was sieved such that there was approximately 3.5” in the pot. All testing occurred at 70^0F in an environmental chamber. For each test, the #1 needle was first used. In general, as the paste began to harden, the needle were changed in the following order: #1, #1/2, #1/4, #1/10, #1/20, and #1/40.

Chapter 4: Test Results

4.1 Citric Acid Retarder

This investigation was divided into three distinct sections. Each section involved a retarder which was employed at a varying dosage across three w/c ratios. The first retarder employed was the citric acid. For each w/c ratio, the citric acid was dosed at 0.1%, 0.5%, 0.75%, and 1.0% of the cement weight. A control batch was executed for each w/c ratio to provide a comparison. In addition to the retarder, Glenium 7500 was employed to ensure workability of each mix. Each w/c ratio for the citric acid was completed in approximately one month. This was primarily due to the number of dosages executed in each w/c ratio. The individual batch sheets for this mix are included in the appendix. Table 2 reports both the fresh and hardened properties for the citric acid retarder for the first w/c ratio.

Table 2, Fresh and Hardened Properties for Citric Acid for w/c of 0.45

Batch Identification			0	0.10%	0.50%	0.75%	1.0%
Slump		(in)	0.75	4.75	9.75	9.75	7.5
Unit Weight		(lb/ft^3)	147.2	145.7	145.0	145.0	146.6
Batch Temperature		(^0F)	58	54	57	78	58
Air Content		(%)	2	2.7	2.5	2.5	2.1
Compressive Strength	3 hrs	(psi)	3985	3873	0	-	-
	6 hrs	(psi)	4108	4883	202	-	-
	1 day	(psi)	5253	5898	6048	7420	6208
	3 day	(psi)	5847	6638	7057	8902	7552
	7 day	(psi)	6063	7432	7770	9065	8220
	14 day	(psi)	7260	7572	8160	8692	8960
	28 day	(psi)	7232	7802	7878	8457	8032
	1 year	(psi)	5916	6596	6578	-	7204
Shrinkage	3 hrs	(in^{-6}/in)	0.00	0.00	-	-	-
	6 hrs	(in^{-6}/in)	113.33	60.00	-	-	-
	1 day	(in^{-6}/in)	130.00	93.33	0.00	0.00	0.00
	3 day	(in^{-6}/in)	160.00	136.67	53.33	60.00	53.33
	7 day	(in^{-6}/in)	153.33	130.00	86.67	86.67	93.33
	14 day	(in^{-6}/in)	126.67	196.67	126.67	123.33	123.33
	28 day	(in^{-6}/in)	113.33	140.00	113.33	143.33	103.33
	1 year	(in^{-6}/in)	193.33	190.00	186.67	-	153.33
Mix Proportions							
Cement		(lbs)	62.67	62.67	62.67	62.67	62.67
Coarse Aggregate		(lbs)	199.66	198.47	198.47	198.75	198.47
Fine Aggregate		(lbs)	162.68	161.58	161.58	163.08	161.58
Water		(lbs)	23.30	25.66	25.66	23.80	25.66
HRWR		mL	75	75	50	50	50
w/c			0.45	0.45	0.45	0.45	0.45

The only variable that changed when employing the citric acid was the w/c ratio. When mixing, the amount of Glenium, denoted under mix proportions as HRWR, varied base on environmental conditions in order that satisfactory workability could be achieved. In general as the dosage of citric acid increased, the amount of Glenium employed could be reduced. This is displayed in each of the tables displaying fresh and hardened properties for the citric acid. Tables 2 and 3 display the fresh and hardened properties for the 0.47 and 0.50 w/c ratios respectively. The individual batch sheets for these mixes are included in the Appendix I.

Table 3, Fresh and Hardened Properties for Citric Acid for w/c of 0.47

Batch Identification			0	0.10%	0.50%	0.75%	1.0%
Slump		(in)	1.5	5.0	3.75	7.75	6.75
Unit Weight		(lb/ft^3)	146.8	146.6	147.2	137.4	147.6
Batch Temperature		(^{0}F)	58	59	56	74	57
Air Content		(%)	2.1	2.3	1.7	7.5*	1.7
Compressive Strength	3 hrs	(psi)	4278	4163	0	-	-
	6 hrs	(psi)	4930	5067	2272	-	-
	1 day	(psi)	5548	5853	6030	4170	5897
	3 day	(psi)	6263	6937	7427	5083	7922
	7 day	(psi)	6750	7468	7578	4910	7922
	14 day	(psi)	7055	8195	8107	4855	8670
	28 day	(psi)	7810	8408	8507	4787	8780
	1 year	(psi)	5378	6173	6610	-	7147
Shrinkage	3 hrs	(in^{-6}/in)	0	0	-	-	-
	6 hrs	(in^{-6}/in)	56.67	80.00	0.00	-	-
	1 day	(in^{-6}/in)	66.67	103.33	50.00	0.00	0.00
	3 day	(in^{-6}/in)	96.67	110.00	86.67	43.33	103.33
	7 day	(in^{-6}/in)	120.00	140.00	120.00	53.33	140.00
	14 day	(in^{-6}/in)	136.67	146.67	136.67	33.33	156.67
	28 day	(in^{-6}/in)	116.67	150.00	153.33	123.33	183.33
	1 year	(in^{-6}/in)	210.00	246.67	196.67	-	256.67
Mix Proportions							
Cement		(lbs)	62.67	62.67	62.67	62.67	62.67
Coarse Aggregate		(lbs)	197.89	197.89	197.87	197.41	197.87
Fine Aggregate		(lbs)	159.95	159.95	158.61	157.13	158.61
Water		(lbs)	25.72	25.72	27.15	29.14	27.15
HRWR		mL	100	50	25	30	28
w/c			0.47	0.47	0.47	0.47	0.47

*denotes data collected that is unreliable due to equipment malfunction

Table 4, Fresh and Hardened Properties for Citric Acid for w/c of 0.50

Batch Identification			0	0.10%	0.50%	0.75%	1.0%
Slump		(in)	0.75	2.875	6.50	7.00	7.50
Unit Weight		(lb/ft^3)	146.6	146.5	146.4	138.2	146.0
Batch Temperature		(^{0}F)	54	52	56	72	58
Air Content		(%)	1.9	1.6	1.5	1.8	1.1
Compressive Strength	3 hrs	(psi)	4083	3415	0	-	-
	6 hrs	(psi)	4717	4617	147	-	-
	1 day	(psi)	5455	5735	5535	5628	6038
	3 day	(psi)	5992	6597	7155	6198	7512
	7 day	(psi)	6742	6958	7267	6695	7923
	14 day	(psi)	7048	7690	7490	6975	8118
	28 day	(psi)	7275	8162	8095	6627	7540
	1 year	(psi)	5433	5833	6215	-	6167
Shrinkage	3 hrs	(in^{-6}/in)	0	0	-	-	-
	6 hrs	(in^{-6}/in)	56.67	46.67	-	-	-
	1 day	(in^{-6}/in)	83.33	86.67	0	0	0
	3 day	(in^{-6}/in)	116.67	106.67	76.67	120.00	50.00
	7 day	(in^{-6}/in)	96.67	90.00	120.00	186.67	80.00
	14 day	(in^{-6}/in)	103.33	93.33	156.67	306.67	86.67
	28 day	(in^{-6}/in)	103.33	83.33	180.00	400.00	133.33
	1 year	(in^{-6}/in)	196.67	186.67	286.67		193.33
Mix Proportions							
Cement		(lbs)	62.67	62.67	62.67	62.67	62.67
Coarse Aggregate		(lbs)	197.50	197.50	200.10	198.01	200.10
Fine Aggregate		(lbs)	153.05	153.05	155.87	153.93	155.87
Water		(lbs)	30.01	30.01	24.39	28.58	24.39
HRWR		mL	50	45	25	45	25
w/c			0.50	0.50	0.50	0.50	0.50

4.2 Delvo® Retarder

The next retarder that was tested was the Delvo®. This retarder was a liquid retarder. The Delvo was dosed based on fluid ounces per hundred pound of cement. This is in contrast to the citric acid acid which was dosed based on percent of cement weight. This percentage was based on the dry weight of the citric acid. The dosage rate for the Delvo® was based on the sponsor’s typical range: 2oz/ 100 lb cement, 6oz/ 100 lb cement, and 12 oz/ 100 lb cement. Although the citric acid required less Glenium as the dosage rate increased, the Delvo® required a higher standard amount of Glenium to maintain workability. This is reported in Tables 5, 6, and 7 which display the fresh and hardened properties for the three w/c ratios employed. The individual batch sheets for these mixes are included in Appendix II.

Table 5, Fresh and Hardened Properties for Delvo® for w/c of 0.45

Batch Identification			2 oz	6 oz	12 oz
Slump		(in)	1.25	2.5	2.00
Unit Weight		(lb/ft^3)	147.5	147.0	146.7
Batch Temperature		(^{0}F)	77	80	75
Air Content		(%)	-	-	2.3
Compressive Strength	3 hrs	(psi)	4483	4317	5485
	6 hrs	(psi)	5233	5332	5746
	1 day	(psi)	6015	5648	6452
	3 day	(psi)	6325	6818	6717
	7 day	(psi)	6787	7057	8232
	14 day	(psi)	7546	-	8348
	28 day	(psi)	7923	8118	8534
	1 year	(psi)	-	-	-
Shrinkage	3 hrs	(in^{-6}/in)	0	0	0
	6 hrs	(in^{-6}/in)	3.33	70.00	23.33
	1 day	(in^{-6}/in)	13.33	106.67	80.00
	3 day	(in^{-6}/in)	53.33	150.00	90.00
	7 day	(in^{-6}/in)	70.00	156.67	106.67
	14 day	(in^{-6}/in)	130.00	166.67	86.67
	28 day	(in^{-6}/in)	56.67	140.00	103.33
	1 year	(in^{-6}/in)	-	-	-
Mix Proportions					
Cement		(lbs)	62.67	62.67	62.67
Coarse Aggregate		(lbs)	197.48	197.48	197.70
Fine Aggregate		(lbs)	161.78	161.78	159.19
Water		(lbs)	26.44	26.44	28.88
HRWR		mL	45	80	75
w/c			0.45	0.45	0.45

Table 6, Fresh and Hardened Properties for Delvo® for w/c of 0.47

Batch Identification			2 oz	6 oz	12 oz
Slump		(in)	1.5	3.5	7.00
Unit Weight		(lb/ft^3)	146.28	146.44	143.12
Batch Temperature		(^{0}F)	78	72	73
Air Content		(%)	2.1	2.4	3.7
Compressive Strength	3 hrs	(psi)	4622	5111	4323
	6 hrs	(psi)	5053	5790	5045
	1 day	(psi)	5946	6533	6039
	3 day	(psi)	6634	6553	7487
	7 day	(psi)	7507	7629	7442
	14 day	(psi)	8277	7953	8146
	28 day	(psi)	8549	8231	8142
	1 year	(psi)	-	-	-
Shrinkage	3 hrs	(in^{-6}/in)	0	0	0
	6 hrs	(in^{-6}/in)	6.67	53.33	43.33
	1 day	(in^{-6}/in)	56.67	60.00	60.00
	3 day	(in^{-6}/in)	80.00	76.67	110.00
	7 day	(in^{-6}/in)	103.33	73.33	90.00
	14 day	(in^{-6}/in)	63.33	20.00	86.67
	28 day	(in^{-6}/in)	66.67	120.00	123.33
	1 year	(in^{-6}/in)	-	-	-
Mix Proportions					
Cement		(lbs)	62.67	62.67	62.67
Coarse Aggregate		(lbs)	197.70	196.95	196.95
Fine Aggregate		(lbs)	155.87	156.72	156.72
Water		(lbs)	30.14	30.01	30.01
HRWR		mL	75	75	80
w/c			0.47	0.47	0.47

Table 7, Fresh and Hardened Properties for Delvo® for w/c of 0.50

Batch Identification			**2 oz**	**6 oz**	**12 oz**
Slump		(in)	5.75	6.5	8.5
Unit Weight		(lb/ft^3)	145.32	145.56	144.40
Batch Temperature		(^{0}F)	75	78	78
Air Content		(%)	2.3	2.5	-
Compressive Strength	3 hrs	(psi)	3725	4615	3782
	6 hrs	(psi)	4391	5267	4622
	1 day	(psi)	5439	5644	5124
	3 day	(psi)	6062	6633	5702
	7 day	(psi)	6554	6843	6284
	14 day	(psi)	6820	7028	6634
	28 day	(psi)	7289	7256	6890
	1 year	(psi)	-	-	-
Shrinkage	3 hrs	(in^{-6}/in)	0	0	0
	6 hrs	(in^{-6}/in)	53.33	53.33	43.33
	1 day	(in^{-6}/in)	60.00	86.67	83.33
	3 day	(in^{-6}/in)	130.00	80.00	86.67
	7 day	(in^{-6}/in)	136.67	93.33	100.00
	14 day	(in^{-6}/in)	170.00	136.67	123.33
	28 day	(in^{-6}/in)	203.33	166.67	176.67
	1 year	(in^{-6}/in)	-	-	-
Mix Proportions					
Cement		(lbs)	62.67	62.67	62.67
Coarse Aggregate		(lbs)	197.53	197.53	196.95
Fine Aggregate		(lbs)	152.50	152.50	150.50
Water		(lbs)	30.54	30.54	33.15
HRWR		mL	80	80	80
w/c			0.50	0.50	0.50

4.3 Recover® Retarder

The third and final phase of this research project concluded specific retarder. This retarder was not investigated as fully. This will be discussed later in Chapter 5. Similarly to the Delvo®, Recover® was also dosed based on fluid ounces per hundred pound of cement as it is a liquid retarder. Unlike the Delvo®, the dosage rate employed for this retarder was based on the manufacturer’s typical range. The mixes executed using Recover® exhibited rapid slump loss and poor workability. Table 8 displays the fresh and hardened properties for the only w/c ratio executed for this retarder. The individual batch sheets for these mixes are included in the Appendix III.

Table 8, Fresh and Hardened Properties for Recover® for w/c of 0.45

Batch Identification			4 oz	20 oz	40 oz
Slump		(in)	2.00	3.00	1
Unit Weight		(lb/ft^3)	146.3	146.8	146.0
Batch Temperature		(^{0}F)	59	58	59
Air Content		(%)	-	2.3	2.1
Compressive Strength	3 hrs	(psi)	4495	4403	4158
	6 hrs	(psi)	4960	5295	5148
	1 day	(psi)	6064	6047	6185
	3 day	(psi)	6925	6968	6732
	7 day	(psi)	7697	7745	7080
	14 day	(psi)	8100	7650	7138
	28 day	(psi)	8162	7775	7555
	1 year	(psi)	-	-	-
Shrinkage	3 hrs	(in^{-6}/in)	0	0	0
	6 hrs	(in^{-6}/in)	30.00	26.67	63.33
	1 day	(in^{-6}/in)	60.00	46.67	90.00
	3 day	(in^{-6}/in)	73.33	63.33	106.67
	7 day	(in^{-6}/in)	83.33	90.00	110.00
	14 day	(in^{-6}/in)	73.33	116.67	126.67
	28 day	(in^{-6}/in)	93.33	150.00	223.33
	1 year	(in^{-6}/in)	-	-	-
Mix Proportions					
Cement		(lbs)	62.67	62.67	62.67
Coarse Aggregate		(lbs)	197.59	197.59	197.59
Fine Aggregate		(lbs)	161.64	161.64	161.64
Water		(lbs)	26.48	26.48	26.48
HRWR		mL	45	60	50
w/c			0.45	0.45	0.45

4.4 Unit Weight Comparison

The first retarder tested consisted of 3 w/c ratios which each had 4 dosages of citric acid ranging from 0-1.0%. This part of the research consumed so much cement that after the first summer's work that more cement had to be acquired. This cement was supplied at the start of the second summer of research. This second summer saw the completion of the project with the final two retarders. Additionally, a citric acid dosage of 0.75% was added between summers and executed with the newly acquired cement. Because the cement used for this project was acquired at different times, the unit weights and batch temperatures were tabulated separately in order to more clearly observe the concrete performance and determine discrepancies. These unit weights are reported in Table 9.

Table 9, Unit Weights and Batch Temperatures

Cement #1		Unit Weight (lb/ft^3)	Batch Temperature(^0F)
0.45 w/c	zero citric acid	147.2	58
	0.1% citric acid	145.7	54
	0.5% citric acid	145.0	57
	1.0% citric acid	146.6	58
0.47 w/c	zero citric acid	146.8	58
	0.1% citric acid	146.6	59
	0.5% citric acid	147.2	56
	1.0% citric acid	147.6	57
0.50w/c	zero citric acid	146.6	54
	0.1% citric acid	146.5	52
	0.5% citric acid	146.4	56
	1.0% citric acid	146.0	58
Cement #2			
0.45 w/c	0.75% citric acid	145.0	78
	4 oz Recover©	146.3	59
	20 oz Recover©	146.8	58
	40 oz Recover©	146.0	59
	2 oz Delvo©	147.5	77
	6 oz Delvo©	147.0	80
	12 oz Delvo©	146.7	75
0.47 w/c	0.75% citric acid	137.4	74
	2 oz Delvo©	146.3	78
	6 oz Delvo©	146.4	72
	12 oz Delvo©	143.1	73
0.50w/c	0.75% citric acid	138.2	72
	2 oz Delvo©	145.3	75
	6 oz Delvo©	145.6	78
	12 oz Delvo©	144.4	78

Chapter 5: Discussion of Results

5.1 Compressive Strength for Citric Acid at 0.45 w/c

It is generally understood that a retarder can act as a superplasticizer in that it extends workability. Each w/c ratio had a baseline mix which contained zero citric acid. In each batch that was cast where no citric acid was employed, the workability was quite poor and the slump was practically zero. Because no retarder was employed, the casting had to be executed quite quickly. Each of these mixes exhibited poor consolidation due to the rapid set of the concrete.

One of the ways in which the effectiveness or activity of the retarder could be visually gauged is through the graphs for strength. Even for low level doses of citric acid, the mix was noticeably less dry and required less high range water reducer for workability. As consolidation increased with increasing levels of citric acid, strength began to increase noticeably. Figure 6 displays the compressive strength trends through 3 days.

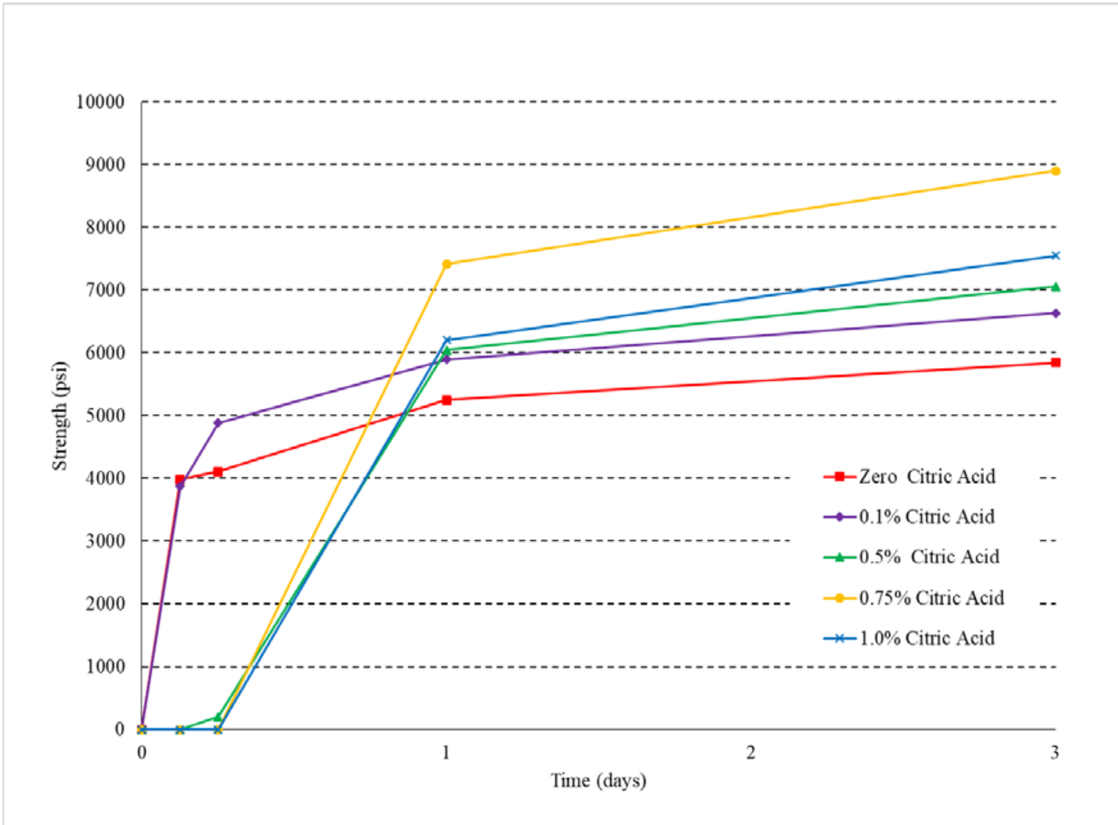

Figure 6, 3 Day Compressive Strength of Citric Acid with 0.45 w/c

As can be seen in the Figure 6, the zero citric acid and the 0.1% citric acid both attained a 3 hour strength of 4000 psi. The 0.5%, 0.75%, and 1.0% citric acid were still unable to register load under testing by 6 hours. However, strength gain by was markedly different by the 1 day mark. At 1 day, the 0.1%, 0.5% and 1.0% citric acid were all essentially at the same compressive strength of approximately 6000 psi. This is a rapid rebound in strength over an 18 hour period to go from zero compressive strength to nearly 6000 psi. Even though the compressive strength was essentially lowered by the higher dosages of citric acid within the first 6 hours, the compressive strength is not permanently hampered. As citric acid dosage increased, the amount of high range water reducer used was decreased. The strength trend of the 0.75% citric acid is unusual as it achieves a very high 24 hour strength near 7500 psi. The cement for the 0.75% citric acid was acquired after the original dosages of citric had been executed. Also, this batch was executed under a cold weather batch protocol. This specific dosage proved to be difficult to deal with across all batches and had no discernible pattern of behavior. The zero citric acid had the lowest strength at 24 hours. This was anticipated due to poor consolidation. Figure 7 displays the compressive strength trends through 28 days.

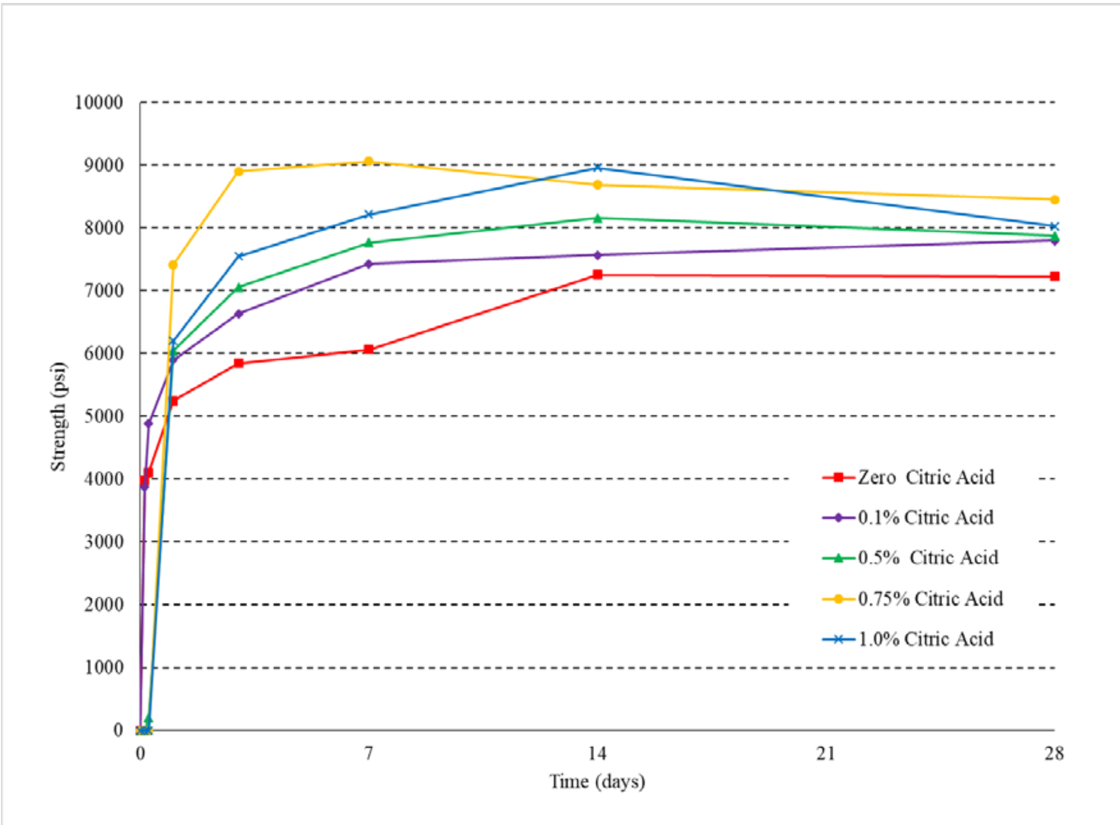

Figure 7, 28 Day Compressive Strength of Citric Acid with 0.45 w/c

Immediately apparent from the 28 day strength is the ordering of the trends. As the citric acid dosage increased, the strength increases as well. The 0.75% citric acid achieves a higher strength at 7 days than the 1.0% citric acid. Once again, the 0.75% remains difficult to understand as its strength is drastically outperforms the other dosages at 7 days but then loses strength form 7 days to 28 days. The 1.0% citric acid also displays a strength loss form 14 days to 28 days. The zero, 0.1%, and 0.5% either gain strength or plateau from 7 to 28 days. The 0.1, 0.5, and 1.0% citric acid all achieve a similar 28 day strength of 8000 psi. The Figure 8 reports the compressive strength trends through 1 year.

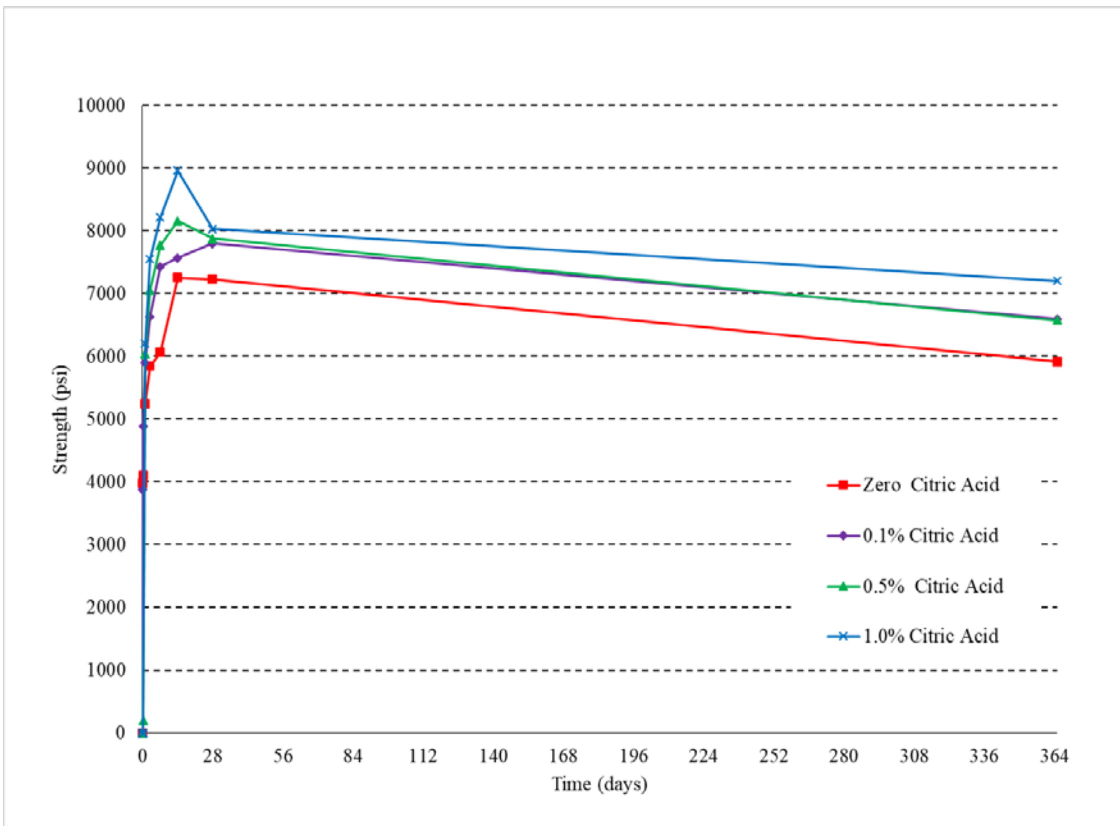

Figure 8, 1 Year Compressive Strength of Citric Acid with 0.45 w/c

The 0.75% citric acid is not shown here because it had not yet achieved 1 year strength. The zero citric acid maintains its position of lowest strength across the entire year of testing. The 1.0% citric acid achieved the highest strength at 28 days and maintained the highest strength at 1 year. At 1 year, the 0.1% and 0.5% citric acid reach approximately the same compressive strength of 6600 psi. From 28 days, all dosages lose strength. The ordering of the trends does not change during the strength loss. The average strength loss from 28 to 365 days is 1162 psi for this w/c ratio. This is approximately 15% of 28 day strength. The batch temperatures for the majority of this w/c ranged from 54^0F to 58^0F. In order to maintain this temperature consistency, the mix water was 50% ice. This was necessary due to extreme ambient temperature during mixing. The only exception was the 0.75% citric acid which was cast in the winter. As a result, the mix water had to be heated due to ambient air temperature at the time mixing occurred. The unit weights were consistent across this w/c, ranging from 144.96 lb/ft^3 to 147.24 lb/ft^3. The fresh properties indicate that the batches were very consistent with the exception of the batch temperature for the 0.75% citric acid.

5.2 Compressive Strength for Citric Acid at 0.47 w/c

The 0.47 w/c ratio included a baseline mix which contained zero citric acid. As was observed when casting the zero citric acid for the 0.45 w/c ratio, the workability was quite poor, and the slump was practically zero. Because no retarder was employed, the casting had to be executed quite quickly. The slump improved slightly from the 0.45 to the 0.47 w/c ratio. The same citric acid dosages as were employed for the 0.45 w/c ratio were executed for the 0.47 w/c ratio. Figure 9 displays the compressive strength trends through 3 days.

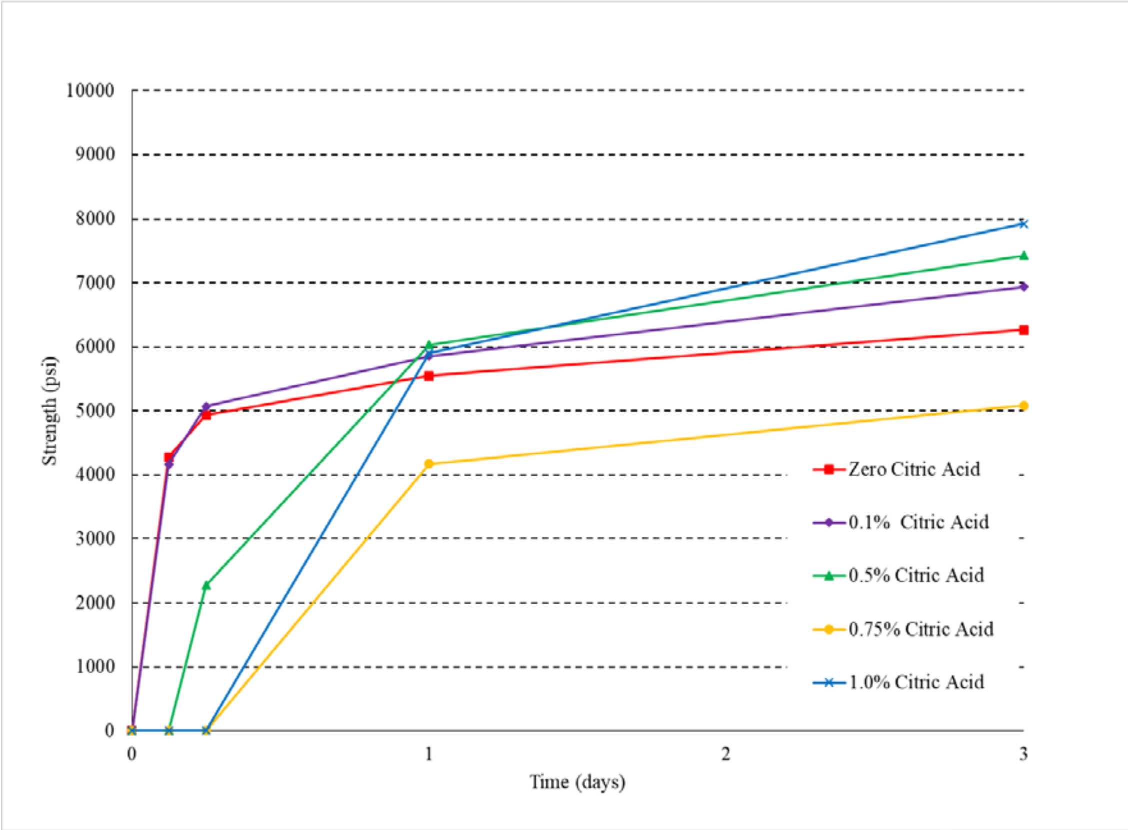

Figure 9, 3 Day Compressive Strength of Citric Acid with 0.47 w/c

The zero and 0.1% citric acid achieve similar 3 and 6 hour strengths of 4200 psi and 5000 psi respectively. The 0.5% citric acid attains a 6 hour strength near 2200 psi while both the 0.75% and 1.0% citric acid were unable to be tested before 24 hours due to insufficient set. At the 24 hour mark, all of the dosages except the 0.75% citric acid have attained similar compressive strength. Because the high citric acid dosages increased set time, the compressive strength was suppressed for the first 6 hours. The 0.5%, 0.75%, and 1.0% experienced rapid compressive strength rebound from 6 to 24 hours. At 24 hours, the 0.75% citric acid is lower than the lowest strength mix by 19%. The zero citric acid in this w/c ratio outperforms the 0.75% citric acid in terms of compressive strength gain. Figure 9 displays the 28 day compressive strength for the 0.47 w/c ratio.

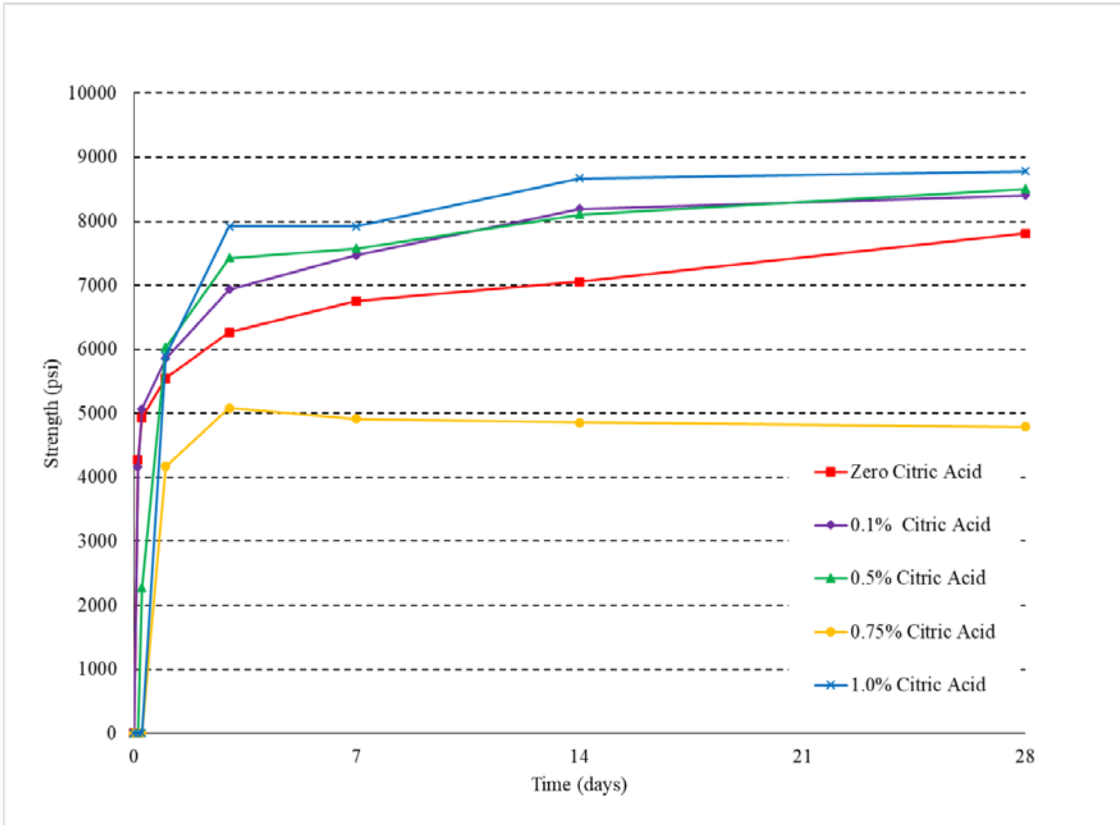

Figure 10, 28 Day Compressive Strength of Citric Acid with 0.47 w/c

Figure 10 demonstrates that the 1.0% citric acid gains strength faster than the other dosages beyond 24 hours, achieving a 28 day strength of 8700 psi. The 0.5% and 0.1% citric acid gain strength at a similar rates based on the slope of the trends being similar between 7 and 28 days. These dosages achieve a 28 day compressive strength of 8500 psi. In general, the compressive strength trend for the 0.75% citric acid indicates constant compressive strength between 3 day and 28 day. Figure 11 reports the 1 year compressive strength for the 0.47 w/c.

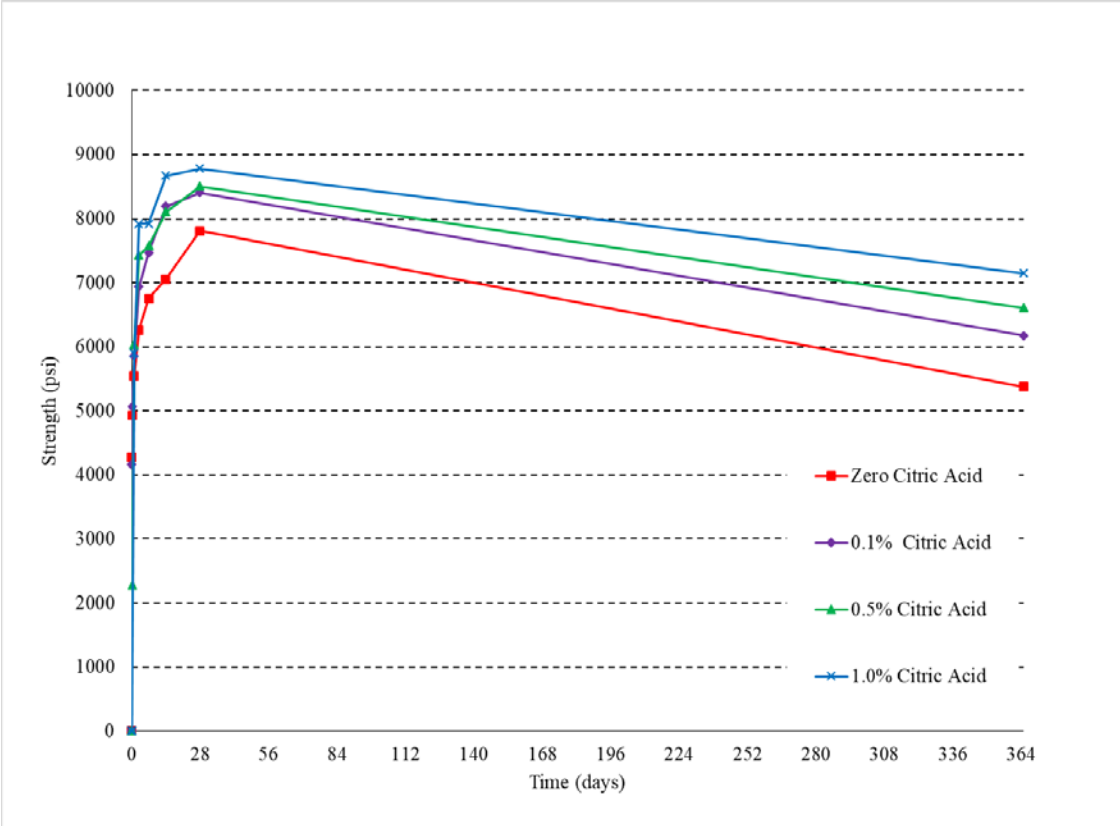

Figure 11, 1 Year Compressive Strength of Citric Acid with 0.47 w/c

The 0.75% citric acid is not shown here because it had not yet achieved 1 year strength. The zero citric acid maintains its position of lowest strength across the entire year of testing. The 1.0% citric acid achieved the highest strength at 28 days and maintained the highest strength at 1 year. At 1 year, the 0.1% and 0.5% citric acid reached compressive strengths of 6100 psi and 6600 psi respectively. From 28 days, all dosages lose strength. The ordering of the trends does not change during the strength loss. The average strength loss from 28 to 365 days is 2050 psi for this w/c ratio. This is approximately 25% of 28 day strength. The batch temperatures for the majority of this w/c ranged from 56^0F to 59^0F. As research progressed, it was necessary to employ 50% ice in the mix water so that batch consistency and workability could be maintained across this w/c ratio. The only exception was the 0.75% citric acid which was cast in the winter. As a result, the mix water had to be heated due to ambient air temperature at the time mixing occurred. The unit weights were consistent across this w/c, ranging from 146.6 lb/ft^3 to 147.6 lb/ft^3. Once again, the 0.75% citric acid was an exception. The unit weight for this dosage was 137.4 lb/ft^3. This is almost 10 lb/ft^3 lower than the bottom of the range for this w/c ratio. At this w/c ratio, slump was much better allowing for better consolidation.

5.3 Compressive Strength for Citric Acid at 0.50 w/c

The 0.50 w/c was the final w/c ratio which employed the citric acid. As was observed when casting the zero citric acid for the previous w/c ratios, the workability was poor. The slump was exactly the same as the 0.45 w/c ratio, 0.75”. This w/c ratio was cast during the most intense part of the summer, so the protocol of drum chilling and 50% ice for the mix water was maintained. Figure 12 displays the compressive strength trends through 3 days.

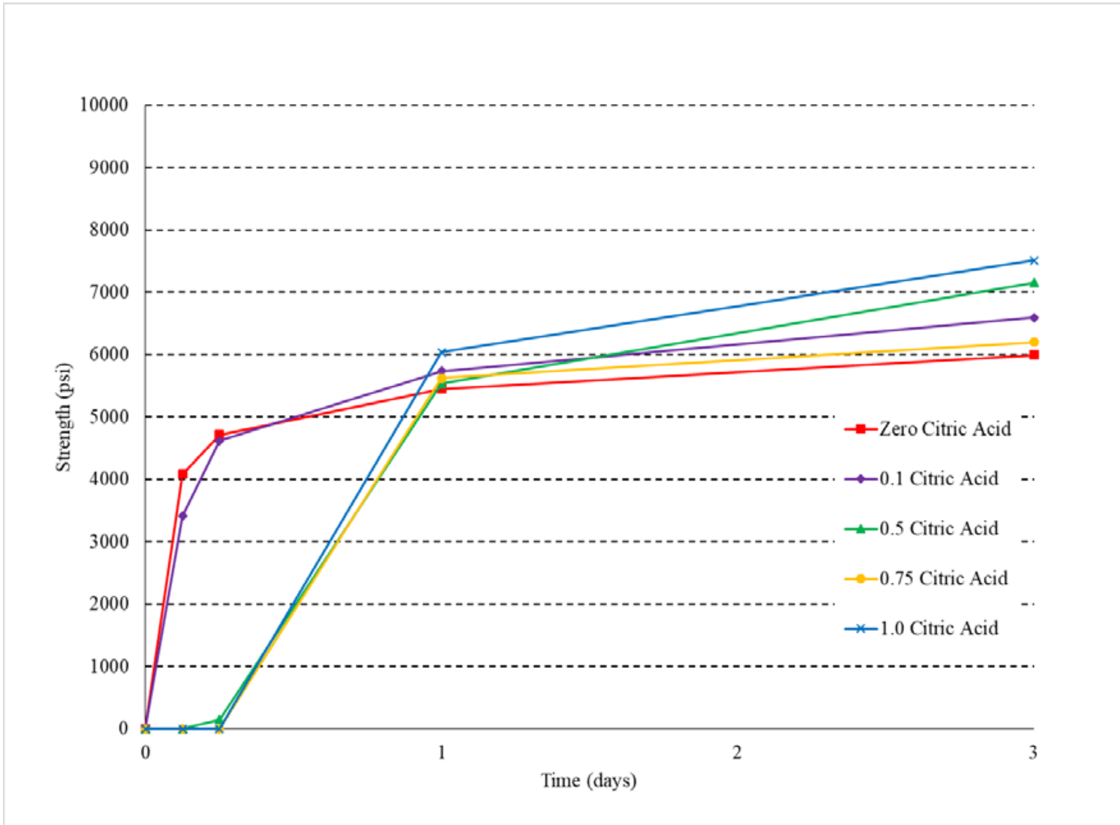

Figure 12, 3 Day Compressive Strength of Citric Acid with 0.50 w/c

In Figure 12, the 0.1% citric acid and the zero citric acid both achieved near 4700 psi by 6 hours. The higher doses of citric acid cylinders were still not set to enable compressive testing by 6 hours. At 24 hours, the results for all the dosages are remarkably close, clustered around 5500 psi. The 1.0% citric acid achieves 6000 psi by 24 hours and climbs steadily, reaching 7500 psi by 3 days. Despite early reduction in strength for the first 6 hours due to high doses of citric acid, the compressive strength is not permanently reduced. The trends are ordered in a pattern such that strength increases with increasing dosage of citric acid. The exception is the 0.75% citric acid which performs similarly to the zero citric acid. The 0.75% citric acid also required more high range water reducer to produce good workability. This was unusual because in general the high range content was able to be reduced as the dosage rate of citric acid increased. Figure 13 reports the 28 day compressive strength for the 0.50 w/c ratio.

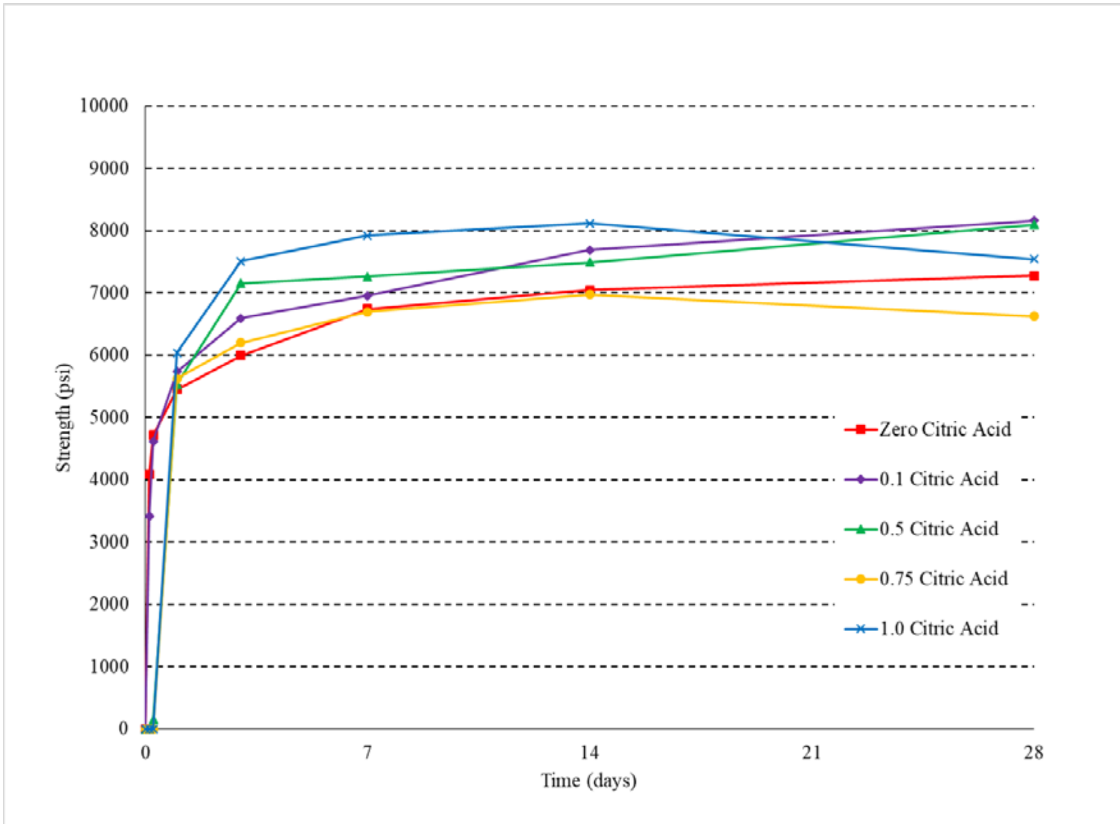

Figure 13, 28 Day Compressive Strength of Citric Acid with 0.50 w/c

From Figure 13, it is observed that the 1.0% citric acid continues to have the highest compressive strength between 24 hours and 14 days. However, from 14 to 28 days, the 1.0% citric acid loses approximately 500 psi. By contrast, the 0.1% and 0.5% citric acid continue to gain strength, reaching a 28 day compressive strength of 8000 psi. The 0.75% citric acid lost strength from 14 days to 28 days. The zero citric acid actually achieves a strength close to that of the 1.0% by 28 days. Figure 14 displays the 1 year compressive strength for the 0.50 w/c ratio.

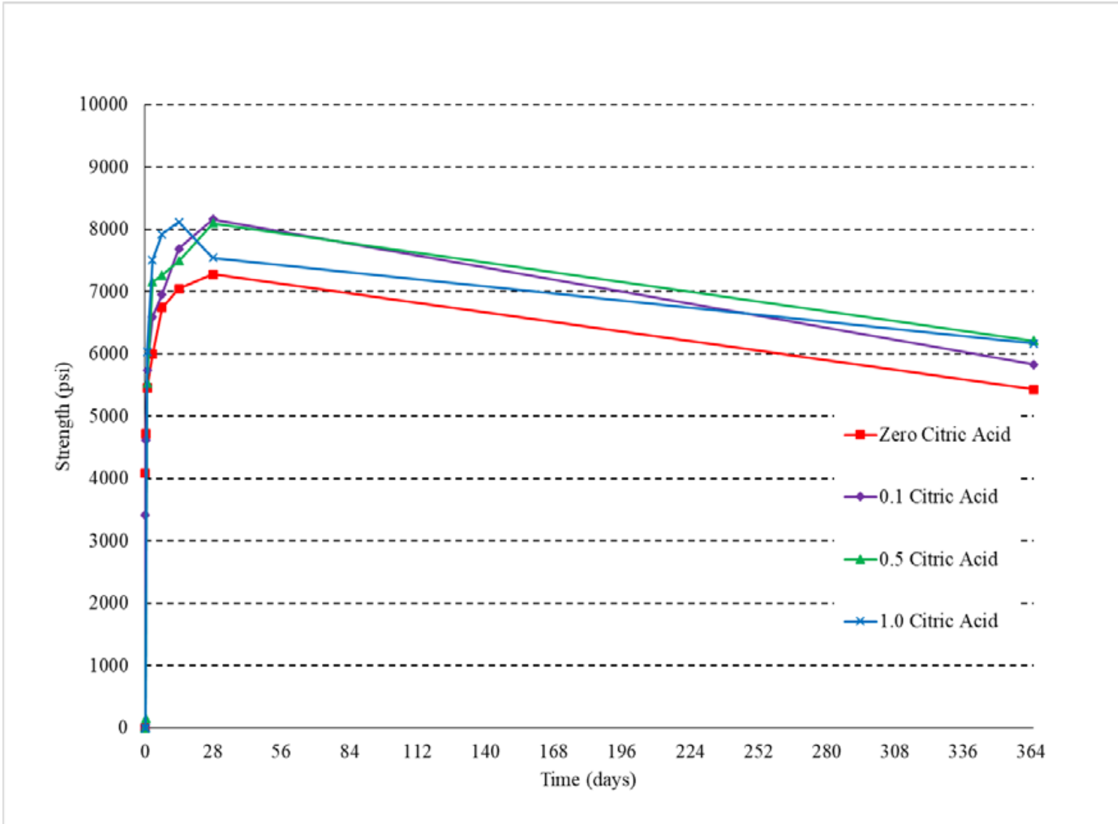

Figure 14, 1 Year Compressive Strength of Citric Acid with 0.50 w/c

The strength loss noted previously in the 0.45 and 0.47 w/c continues with the 0.50 w/c. The zero citric acid is once again the lowest compressive strength at the end of 1 year. The 1.0% citric acid achieved the highest strength at 28 days but fell to the same compressive strength as the 0.5% citric acid, 6100 psi. At 1 year, the 0.1% and zero citric acid reached the compressive strengths of 5800 psi and 5400 psi respectively. From 28 days, all dosages lose strength. The average strength loss from 28 to 365 days is 1860 psi for this w/c ratio. This is approximately 24% of 28 day strength. The batch temperatures for the majority of this w/c ranged from 52^0F to 58^0F. The environmental conditions necessitated the use 50% ice in the mix water. The only exception was the 0.75% citric acid which was cast in the winter. As a result, the mix water had to be heated due to ambient air temperature at the time mixing occurred. The unit weights were consistent across this w/c, ranging from 146.0 lb/ft^3 to 146.6 lb/ft^3. The 0.75% citric acid proved to be an exception. The unit weight for this dosage was 138.2 lb/ft^3. At this w/c ratio, slump was much more consistent which improved consolidation.

As mentioned earlier, the 0.75% citric acid proved difficult to understand. The only variable that changed was the temperature at the time of casting. This particular dosage was added to the matrix after the citric portion of the study had been completed during the prior summer. As a result, these batches were conducted during the winter break. The batching was executed indoors to help prevent temperature effects. When the 0.45 W/C was cast, the temperature inside the lab testing bay was approximately 52^{0}F. The mix was measured at 78^{0}F coming out of the mixer. This had been the warm weather target for mix temperature. The 0.47 was cast when the temperature in the high bay closer to 40^{0}F. The mix temperature was 74^{0}F. Delays forced the last w/c ratio of 0.50 to be cast in May of the spring semester. In this instance, temperature was now not an issue, and the summer protocol employed.

In his Thesis, Frank stated that mixes performed better long term when the mix temperature was low. In his case, this was 40^{0}F (Frank, 2011). It was specifically stated that early age strength was decreased when the mix temperature was low (Frank, 2011). In this case though, the mix temperature was in the seventies while air temperature was near his cold mix temperatures. Because specimens were not put immediately into the environmental chamber, it is possible that the much lower air temperature had a profound impact on the specimens while casting was completed. This seems difficult to understand because casting only took 25 minutes at most. By 35 minutes, all specimens were in the environmental chamber which was set at 70^{0}F. The effect of the intense cold the day the 0.47 W/C was cast is believed to definitely have an impact, though through what exact mechanism it is not clear. The difference in unit weight is also problematic. The unit weight for the citric acid for the 0.47 w/c ratio was 7.03% lower than the theoretical value. Similarly, the unit weight for the citric acid for the 0.50 w/c ratio was 5.91% lower than the theoretical value for unit weight. Aside from these two specific mixes, no other mix was greater than 2.5% different from the theoretical values. Table 10 displays percent difference between theoretical and measured unit weight for each citric acid mix.

Table 10, Theoretical and Measured Unit Weights for Citric Acid

	Dosage	Unit Weight (lb/ft^3)		Δ	T (^{0}F)
		Theoretical	Measured		
0.45 w/c	0	148.6	147.2	0.88	58
	0.10%	148.6	145.7	1.93	54
	0.50%	148.6	145.0	2.42	57
	0.75%	148.6	145.0	2.42	78
	1.00%	148.6	145.6	2.01	58
0.47 w/c	0	147.9	146.8	0.72	58
	0.10%	147.9	146.6	0.88	59
	0.50%	147.9	147.2	0.47	56
	0.75%	147.9	137.5	7.03	74
	1.00%	147.9	147.6	0.18	57
0.50 w/c	0	146.8	146.6	0.14	54
	0.10%	146.8	146.5	0.25	52
	0.50%	146.8	146.4	0.27	56
	0.75%	146.8	138.2	5.91	72
	1.00%	146.8	146.0	0.57	58

5.4 Compressive Strength for 0.1% Citric Acid

In Figure 15, the various w/c ratios are very tightly grouped to 3 days. There is a slight spread that occurs after 7 days. This group of w/c ratios achieves similar strengths throughout 28 days; the compressive strength gain is generally constant across the three mixes.

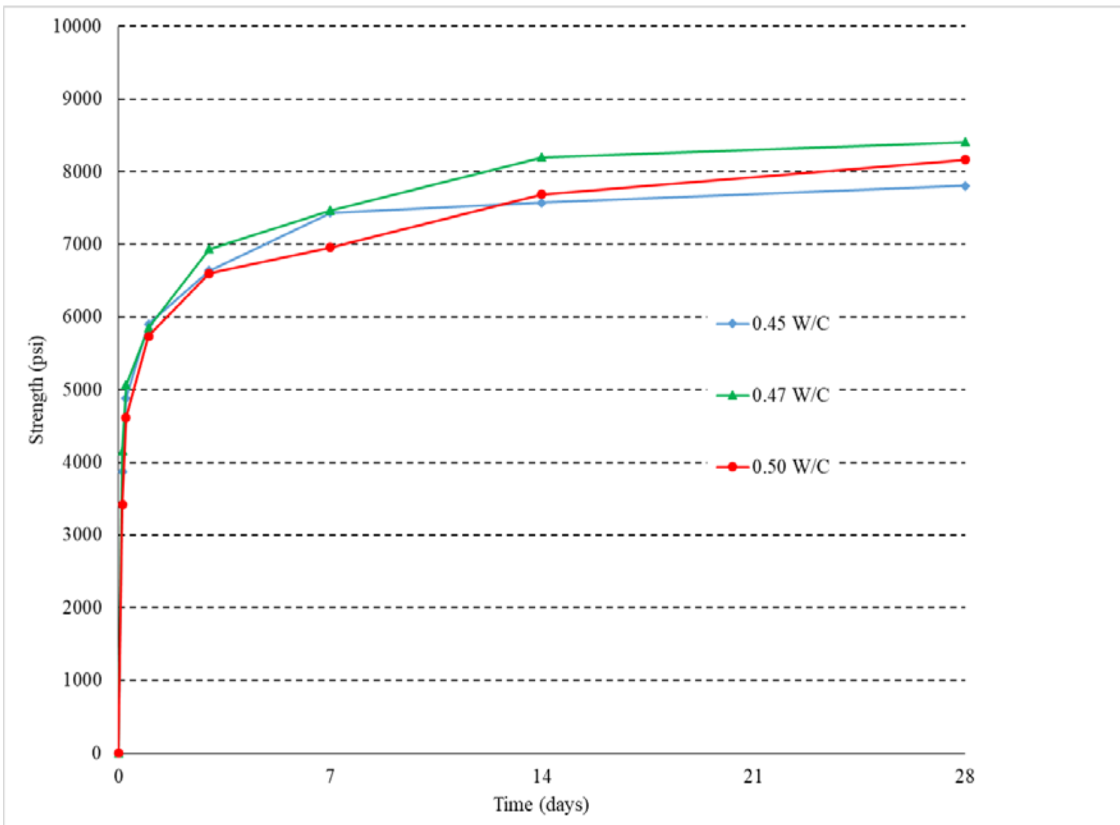

Figure 15, 28 Day Compressive Strength for 0.1% Citric Acid

5.5 Compressive Strength for 0.5% Citric Acid

From Figure 16, it is observed that the various w/c ratios are very tightly grouped until 3 days. The trends separate slightly after 7 days. This group of w/c ratios achieves similar strengths throughout 28 days; the compressive strength gain is generally constant.

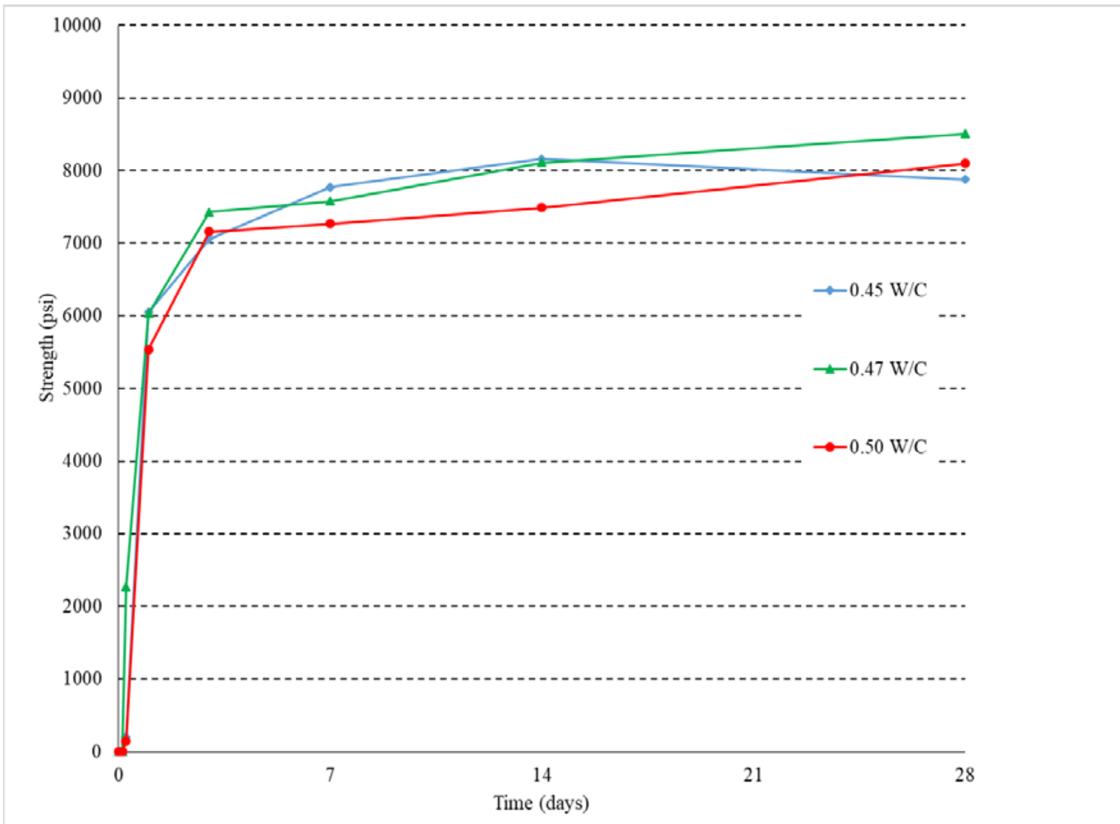

Figure 16, 28 Day Compressive Strength for 0.5% Citric Acid

5.6 Compressive Strength for 0.75% Citric Acid

From Figure 17, it is observed that the various w/c ratios achieve a range of compressive strengths of 5600 psi to 7400 psi from 6 to 24 hours. The trends separate after 3 days. This group of w/c ratios behave very irregularly across 28 days. The compressive strength gain is generally constant for each w/c ratio, but when compared to each other, there is no discernible trend.

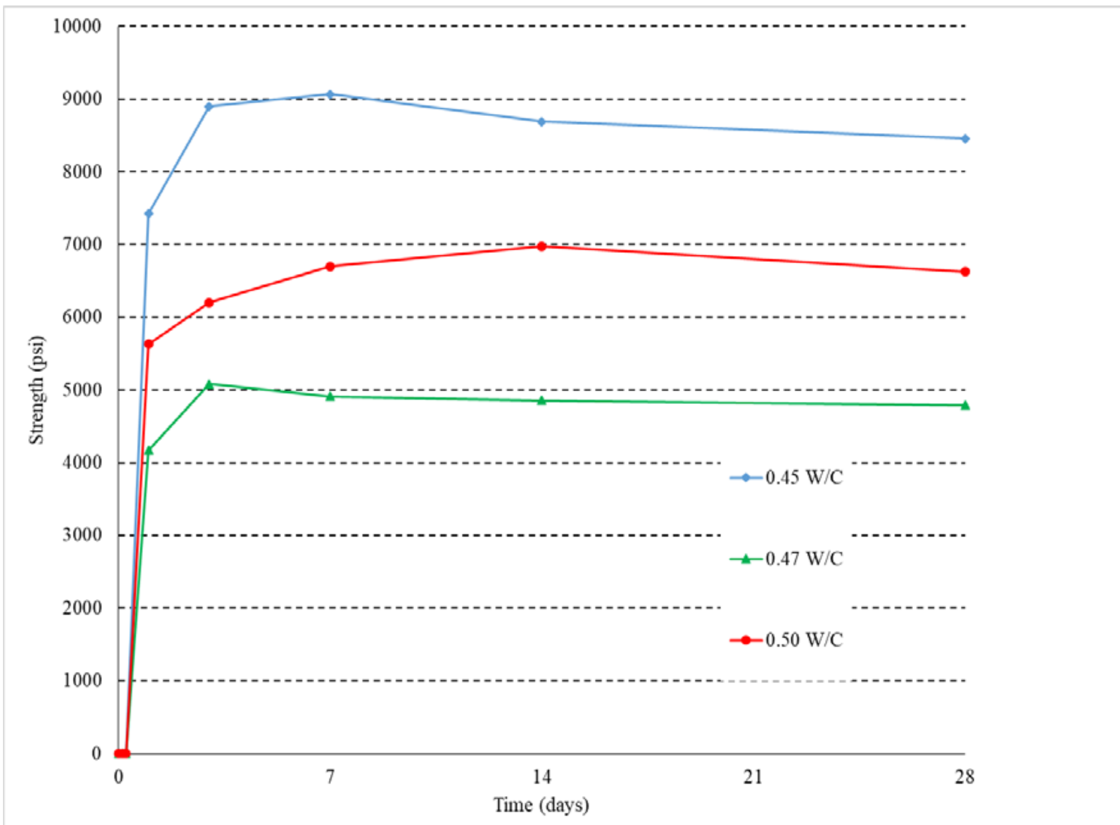

Figure 17, 28 Day Compressive Strength for 0.75% Citric Acid

5.7 Compressive Strength for 1.0% Citric Acid

In Figure 18, the various w/c ratios are very tightly grouped to 3 days. There is a slight spread that occurs after 7 days. This group of w/c ratios achieves similar strengths throughout 28 days; the compressive strength gain is generally constant. With the exception of the 0.75% citric acid, it is observed that the various w/c ratios attain similar compressive strength with a constant dosage of citric acid.

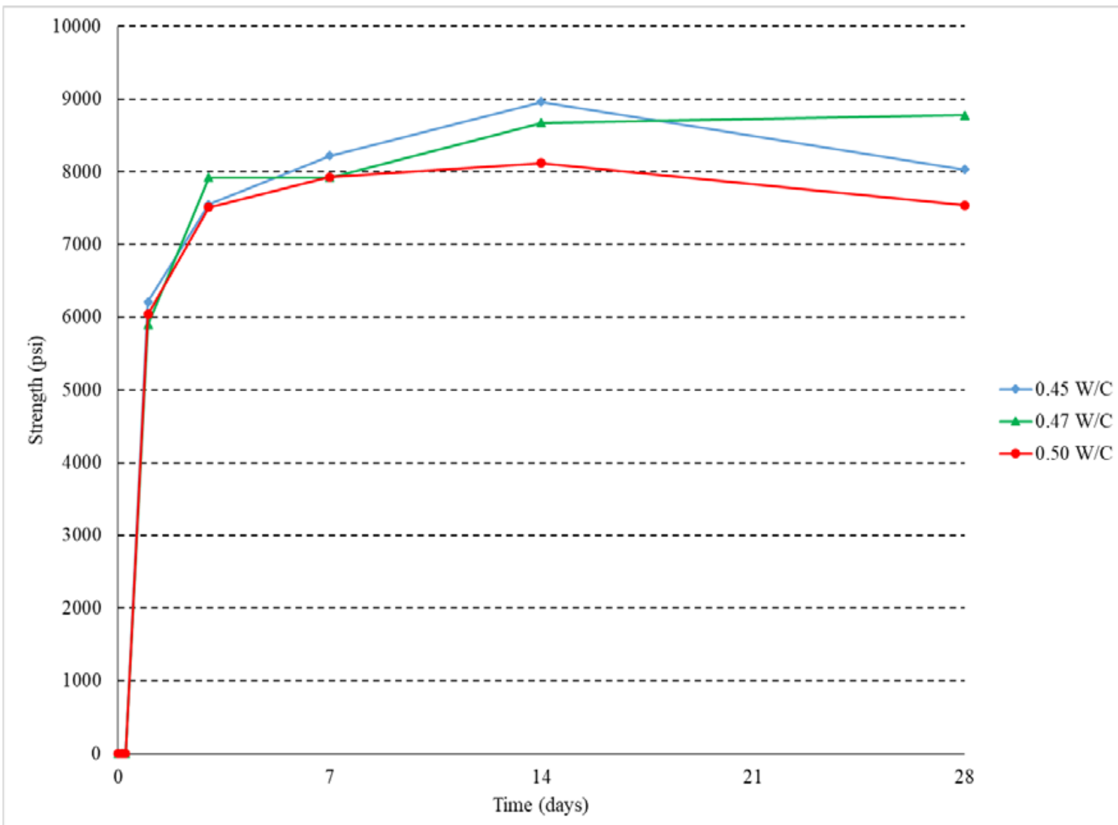

Figure 18, 28 Day Compressive Strength for 1.0% Citric Acid

5.8 Compressive Strength for Delvo® at 0.45 w/c

Delvo® is a liquid retarder. Whereas the citric acid was mixed in the mix water, the Delvo® was added by graduated cylinder directly into the batch after first water was added. The original supply of Rapid Set® cement was exhausted at the conclusion of the citric acid portion of batching with the exclusion of the 0.75% citric acid mixes. This necessitated the acquisition of more cement to continue the project. Fresh properties were carefully recorded to determine any material differences based on the new cement. Even as the dosage of the Delvo® increased, the Glenium content remained constant, though dosed at a higher level than that required for the citric acid mixes. The Delvo® mixes exhibited good consolidation with fair workability. Slump was low, ranging from1”to 2”. Figure 19 displays the compressive strength trends through 3 days.

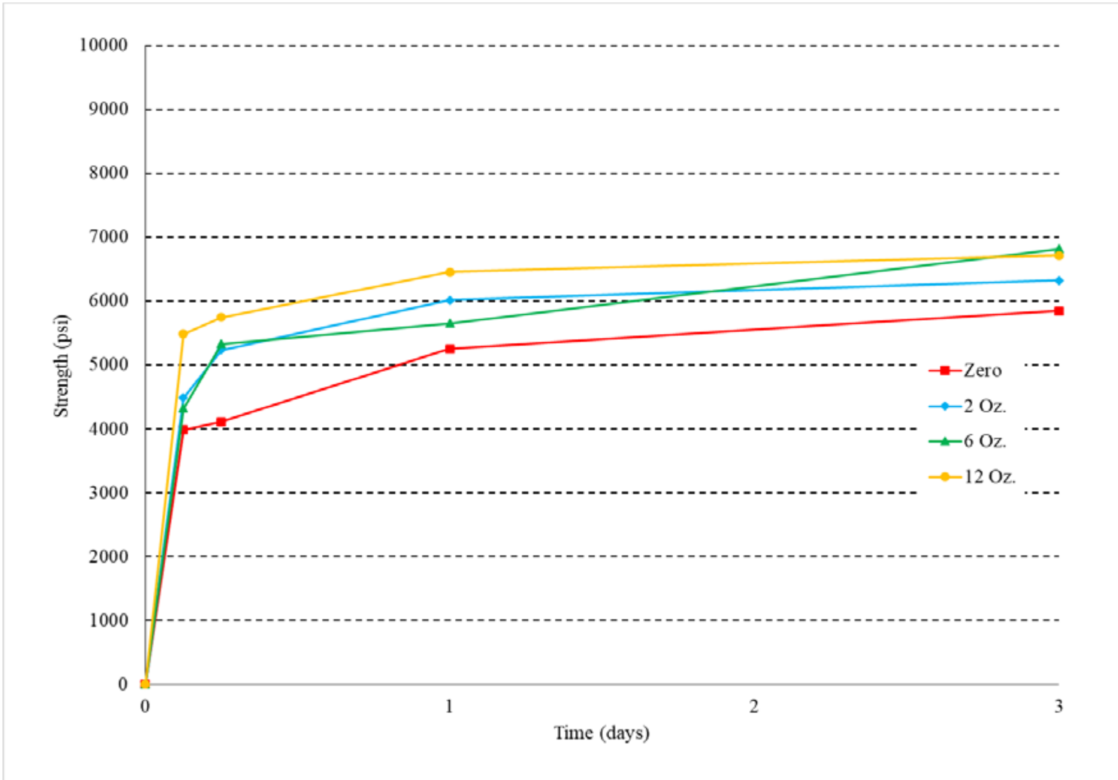

Figure 19, 3 Day Compressive Strength of Delvo® with 0.45 w/c

As opposed to the citric acid, the Delvo® was able to undergo compressive strength testing at 3 hours, regardless of the w/c ratio. Unlike the mixes which utilized citric acid, the Delvo® does not inhibit early compressive strength gain. Both the 2 oz and 6oz Delvo® dosages achieved near 4500 psi by 3 hours. The 12 oz Delvo® achieved 5500 psi by 3 hours. By three days, the 12 oz and 6 oz Delvo® had achieved a compressive strength of 6700 psi while the 2 oz and the zero Delvo® were approximately 6000 psi. The compressive strength for the 6 oz Delvo rapidly increases from 6 hours to 3 days. Figure 20 reports the 28 day strength for compressive strength of Delvo® mixes for the 0.45 w/c ratio.

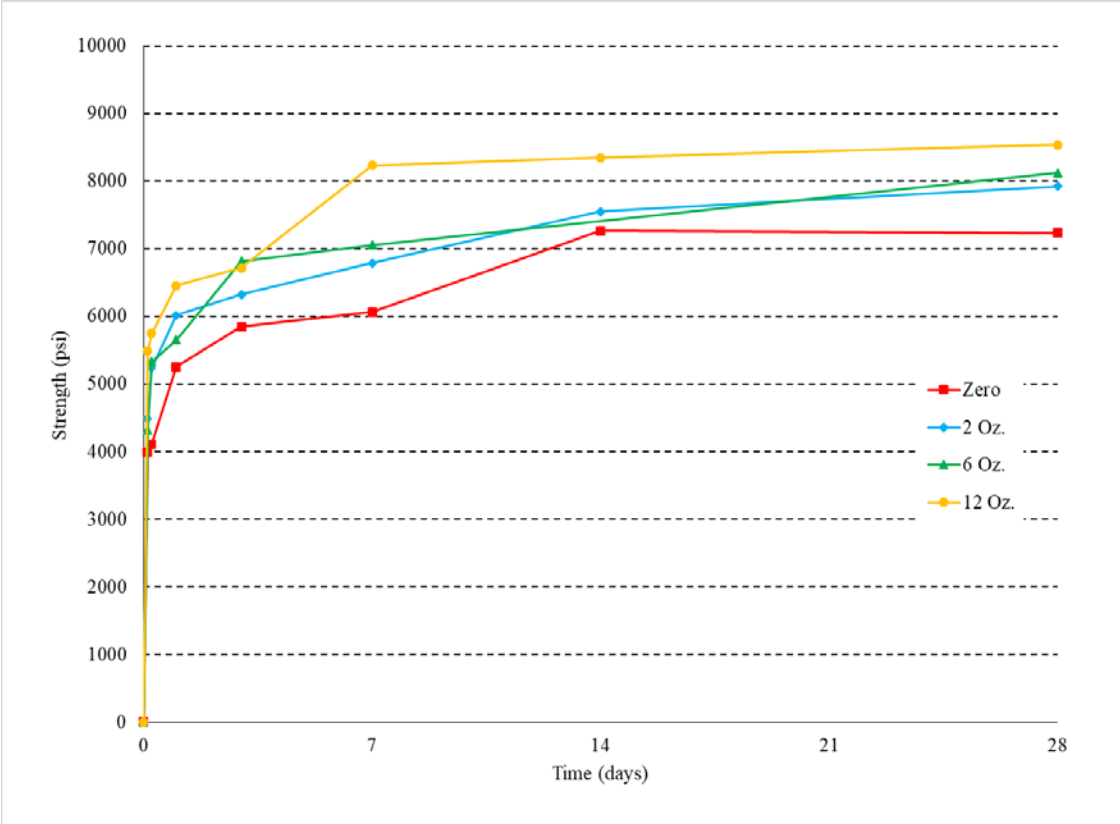

Figure 20, 28 Day Compressive Strength of Delvo® with 0.45 w/c

The 12 oz Delvo® out gains all of the other dosages to achieve a maximum compressive strength of over 8500 psi. The 2 oz and 6 oz Delvo® remain very close together in terms of strength gain from 7 to 28 days. These two doses achieve a 28 day strength of near 8000 psi. The strength gain for the zero Delvo® had plateaued from 14 to 28 days. By contrast, the 2, 6, and 12 oz Delvo® all indicated varying degrees of strength gain still occurring. The Delvo® specimens were cast beginning in May of 2017 and were not available for testing at one year. The batch temperature ranged from 75^0F to 80^0F. The unit weight was consistent varying from 146.68 (lb/ft^3) to 147.52 (lb/ft^3).

5.9 Compressive Strength for Delvo® at 0.47 w/c

The Delvo® dosage remained constant across all w/c ratios. The only variable changed was the w/c ratio. The Glenium dosage did not change when the w/c ratio was varied. The Glenium content was higher than that required by the citric acid mixes at the same w/c ratio. The Delvo® batches were cast very early in the day and did not require 50% ice. Slump was improved, ranging from 1.5”-7” at a constant dosage of Glenium. Figure 21 displays the 3 day compressive strength for Delvo® at a w/c ratio of 0.47.

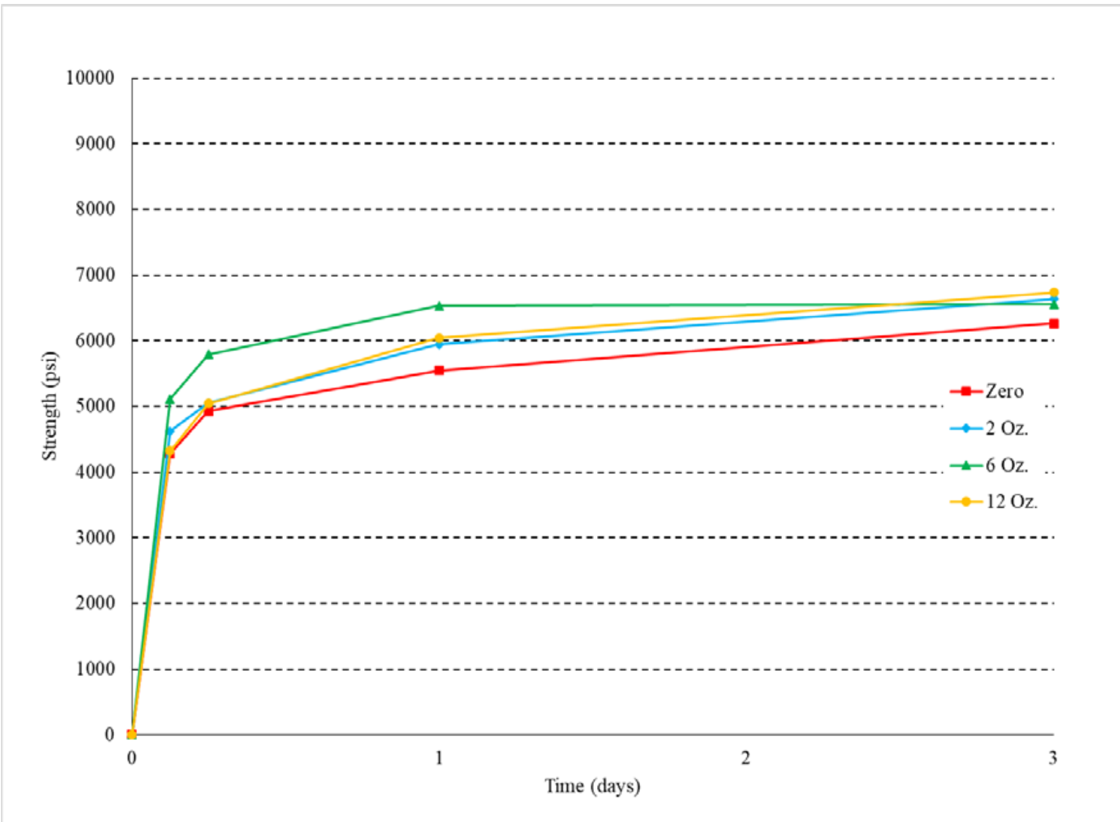

Figure 21, 3 Day Compressive Strength of Delvo® with 0.47 w/c

From Figure 21, it is observed that the 3 hour compressive strengths are very close together. However, the 6 oz Delvo® outgains the other three dosages by nearly 800 psi by the 6 hour mark. Beyond 6 hours, the compressive strength trends begin to converge. In contrast to mixes with citric acid, the Delvo® does not inhibit early compressive strength gain. By 3 days, all doses achieved a similar compressive strength of near 6500 psi. At three days, the heaviest dosage of Delvo® , 12 oz, attained the highest strength of 6700 psi. Figure 22 displays the compressive strength at 28 days for the Delvo® at a w/c of 0.47.

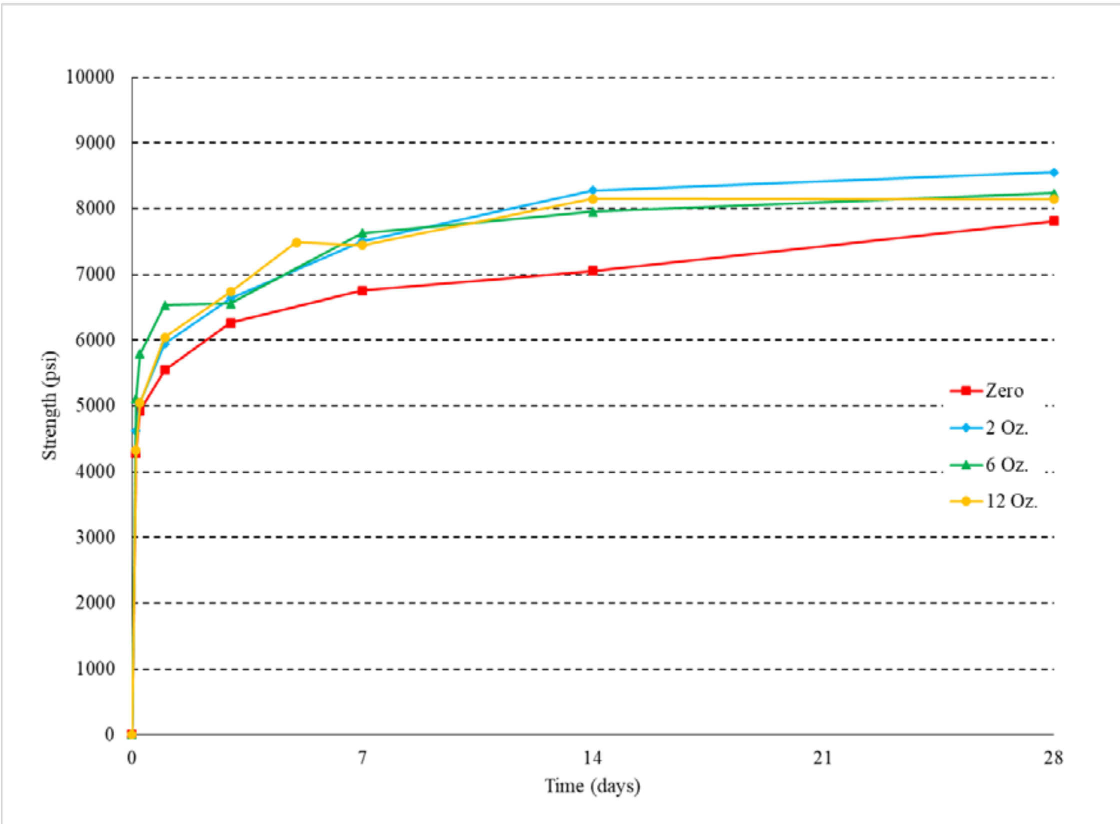

Figure 22, 28 Day Compressive Strength of Delvo® with 0.47 w/c

The compressive strength trends remain very tightly bunched. From 14 days to 28 days, the 2 oz Delvo® achieves the highest strength, 8500 psi by 28 days. The 6 and 12 oz Delvo® gained strength at comparable rates from 7 days until 28 days. The difference in strength among these four dosages is not very large, ranging from 7810 psi to 8550 psi at 28 days. The batch temperature varied from 72^0F to 78^0F. The unit weight ranged from 143.12(lb/ft^3) to 146.44(lb/ft^3).

5.10 Compressive Strength for Delvo® at 0.50 w/c

The final w/c ratio for the Delvo® exhibited the best workability with a slump ranging from 5.75”- 8.5”. As stated previously, the Glenium dosage was constant across all Delvo® batches. Figure 23 displays the 3 day compressive strength for Delvo® at 0.50 w/c ratio.

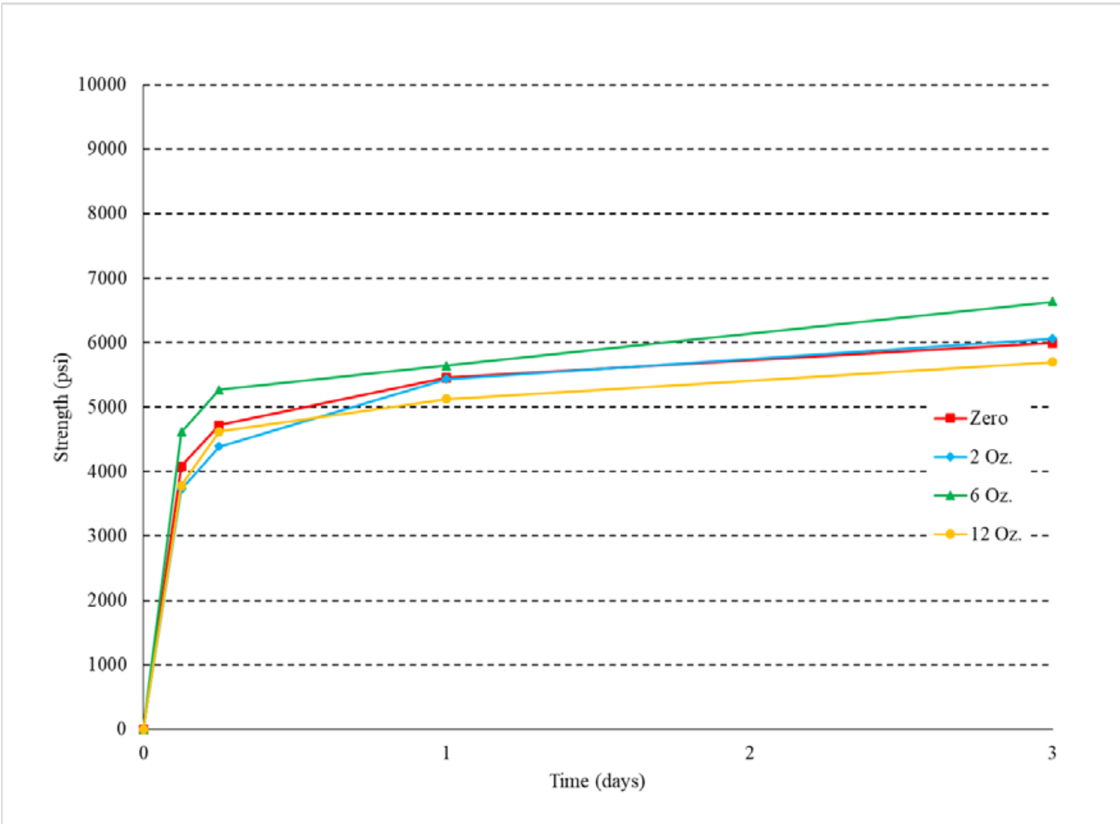

Figure 23, 3 Day Compressive Strength of Delvo® with 0.50 w/c

Through the first 3 hours, the compressive strength remains tightly clustered as shown by Figure 23. The 6oz Delvo® dosage is slightly stronger than the other dosages from 3 to 3 days. Generally, the compressive strength is within 200 to 400 psi across the early strength period. In contrast to mixes with citric acid, the Delvo® does not reduce early compressive strength gain. The max strength achieved is 6600 psi by the 6 oz Delvo® at 3 days. Figure 24 displays the 28 day compressive strength of Delvo® at a

0.50 w/c ratio.

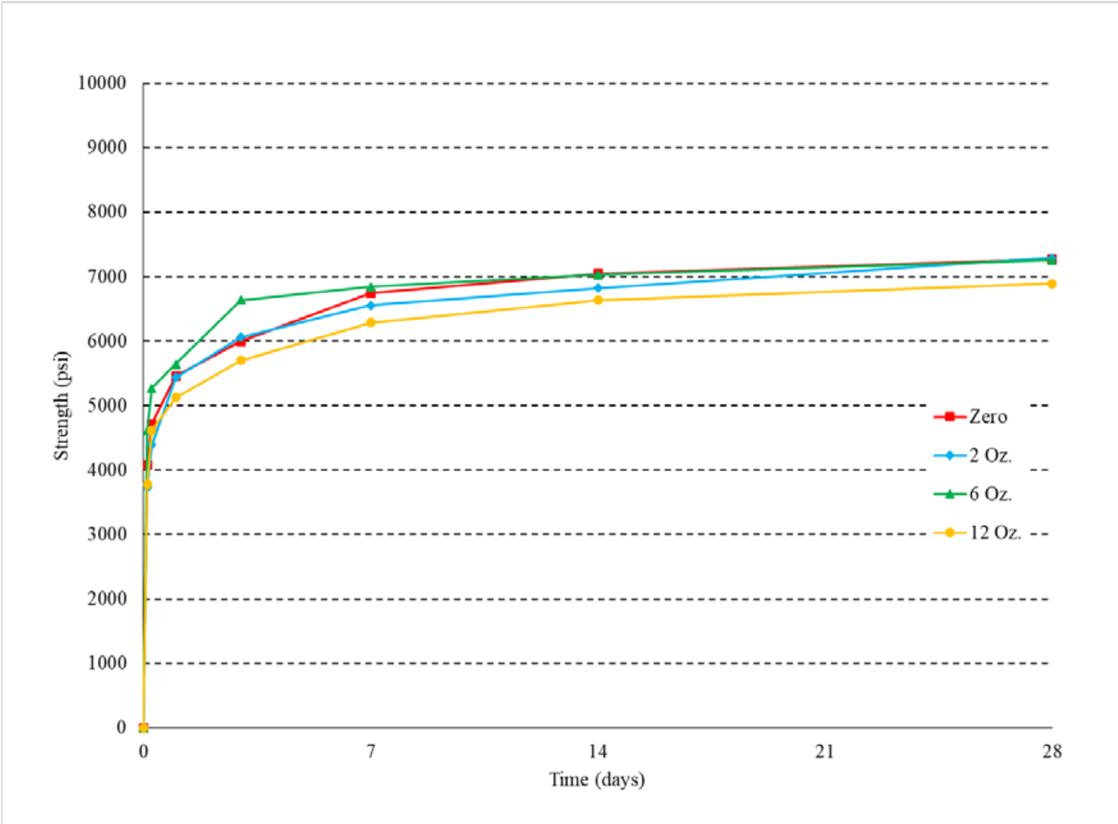

Figure 24, 28 Day Compressive Strength of Delvo® with 0.50 w/c

At increased age, the overall strength range at a given time becomes smaller for each of the dosages. Surprisingly, the zero dosage performs as well as the even the most heavily retarded mix. This is unusual as the control mixes with zero retarder had poor consolidation due to very poor workability. Three mixes, comprised of the zero, 2 oz, and 6 oz Delvo®, all achieved the same 28 day strength of 7200 psi. This was the max compressive strength reached in 28 days. The 12 oz Delvo® had the lowest 28 day strength of 6900 psi. Among the Delvo® mixes, the increasing dosage level generally correlated with the highest or close to the highest strength. The difference in strength between the max compressive strength, 6 oz, and the 12 oz is only 370 psi, which is not a large compressive strength discrepancy. The batch temperature only ranged from 75^{0}F to 78^{0}F. The unit weight was very uniform only varying from 144.40(lb/ft^3) to 145.56(lb/ft^3).

5.11 Compressive Strength for Recover® at 0.45 w/c

The liquid retarder Recover® was surprising in its performance. This specific retarder was a sponsor recommended product. Its efficacy was not readily apparent at its low dosage. This was initially assumed to occur because the dosage was too low. The next level of dosage was five times as large as the lowest recommended dosage prescribed by the manufacturer. There was absolutely no observable retardation of the mix when the Recover® was employed. Even at the highest dosage of 40 oz per hundred pounds of cement, the mix completely lost workability 15 minutes after first water was applied. This was true even when high range water reducer was employed to increase workability.

Because the batches exhibited short set times, the batch matrix was terminated. This was due to the danger of damage to the mixer from concrete setting. The faculty adviser determined that this part of the batch matrix should be suspended. Upon the conclusion of all other aspects of research, it became desirable to substantiate experientially that Recover® was ineffective. As a result, a set time test was conducted in the final months of the project. Even when the Glenium (high range water reducer) was employed at increasing amounts, the Recover® mixes exhibited poor workability. Slump for these mixes varied from 1” to 3”. Figure 25 displays the compressive strength at 3 days at a w/c ratio of 0.45.

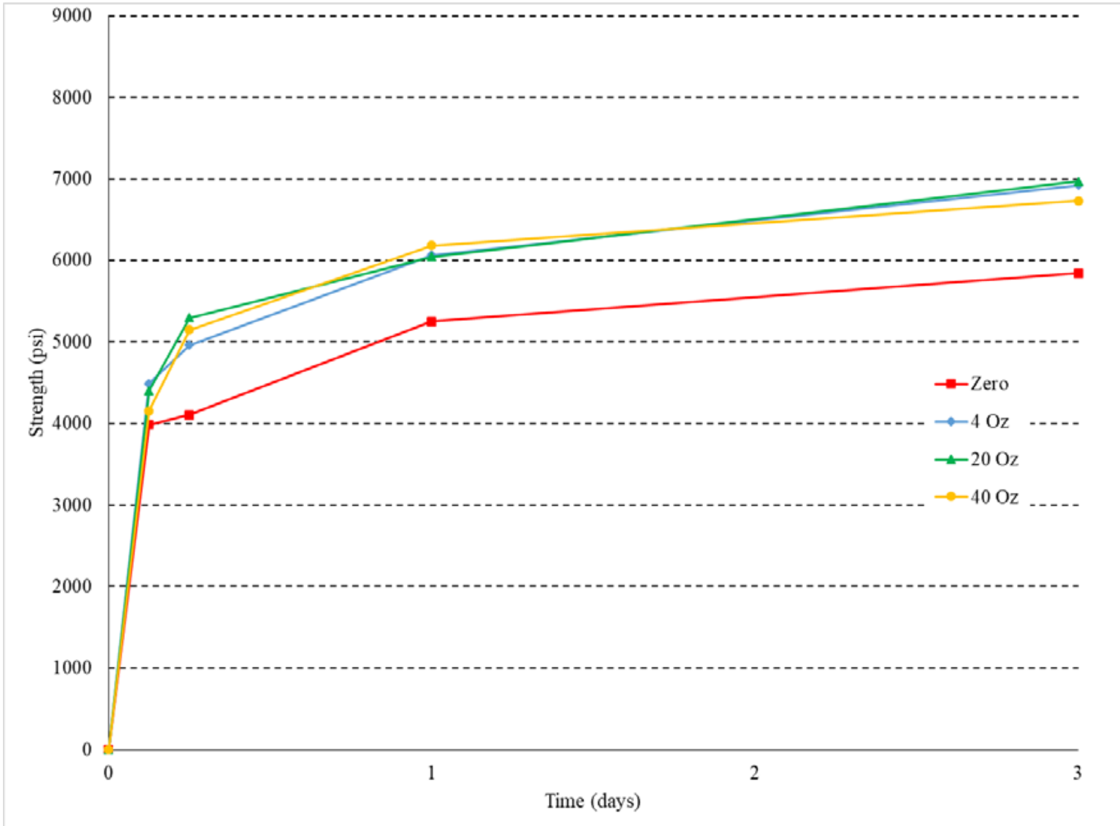

Figure 25, 3 Day Compressive Strength of Recover® with 0.45 w/c

In Figure 25, there exists almost no discernable difference in the compressive strength at 3 hours. By 6 hours, the Recover® mixes perform better than the mix with zero retarder by almost 1000 psi. The compressive strength gain is tremendous from 6 hours to 3 days, increasing by almost 2000 psi. By three days, the Recover® mixes still exceed the zero retarded mix by 1000 psi. Figure 26 displays the 28 day strength for the Recover® at a w/c ratio of 0.45.

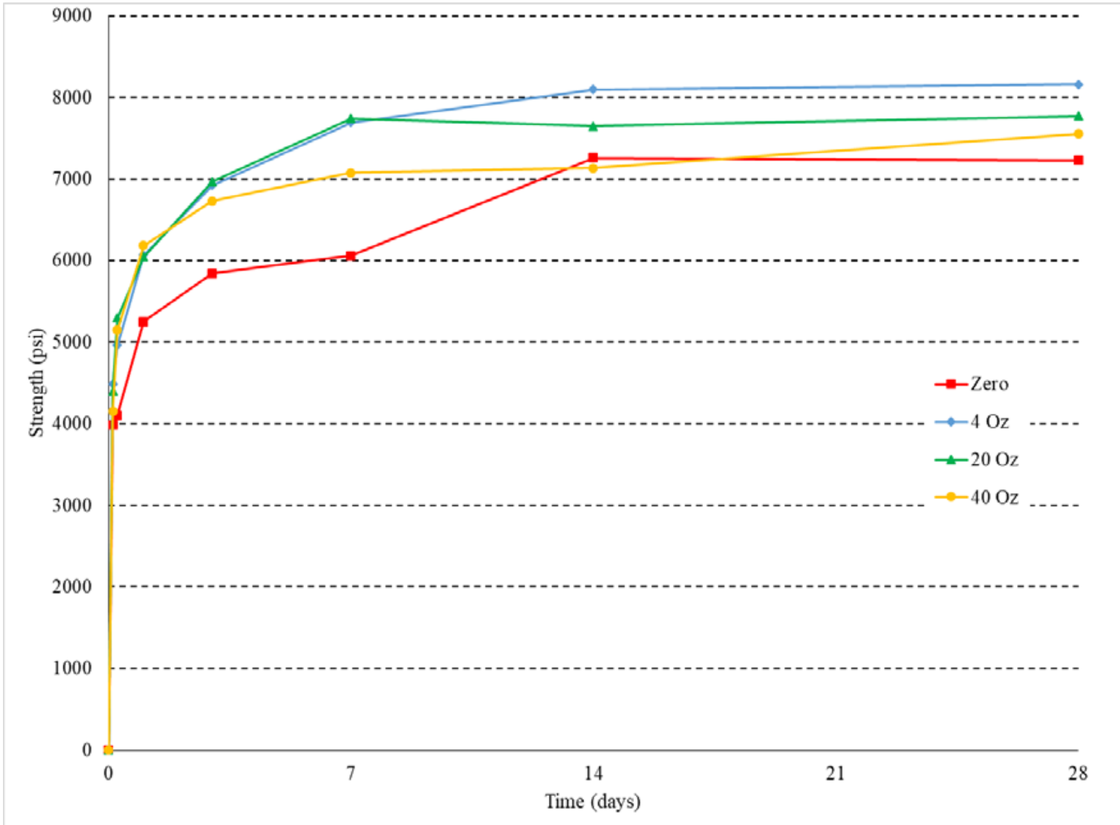

Figure 26, 28 Day Compressive Strength of Recover® with 0.45 w/c

Figure 26 shows that beyond 3 days the compressive strength gain is not nearly as rapid. The various dosages of Recover separate themselves slightly by 7 days. The compressive strength plateaus between 14 and 28 days across all mixes. Even though the 4 oz Recover® achieves the max compressive strength of 8100 psi, the various dosages vary only by several hundred psi at 28 days. The batch temperature was very uniform only ranging from 58^{0}F to 59 ^{0}F. There was also very little variation in the unit weight which ranged from 146.0 (lb/ft^3) to 146.8(lb/ft^3).

5.12 Set Time Testing

Figure 27 displays the set time graph comparing the three retarders executed at a w/c of 0.45. One of the first observations of the graph is that the citric far exceeds the other two retarders in terms of time to set. Although the Delvo® is close to the Recover®, the Recover reached final set at 51 minutes while Delvo® achieved final set at 61 minutes. While a ten minute difference seems miniscule, an extra ten minutes of work time is critical when using Rapid Set®. In light of this test, it can be observed that the Recover® has the quickest set time. In other words, it fails to achieve the primary objective of this study, retard the set time of the concrete.

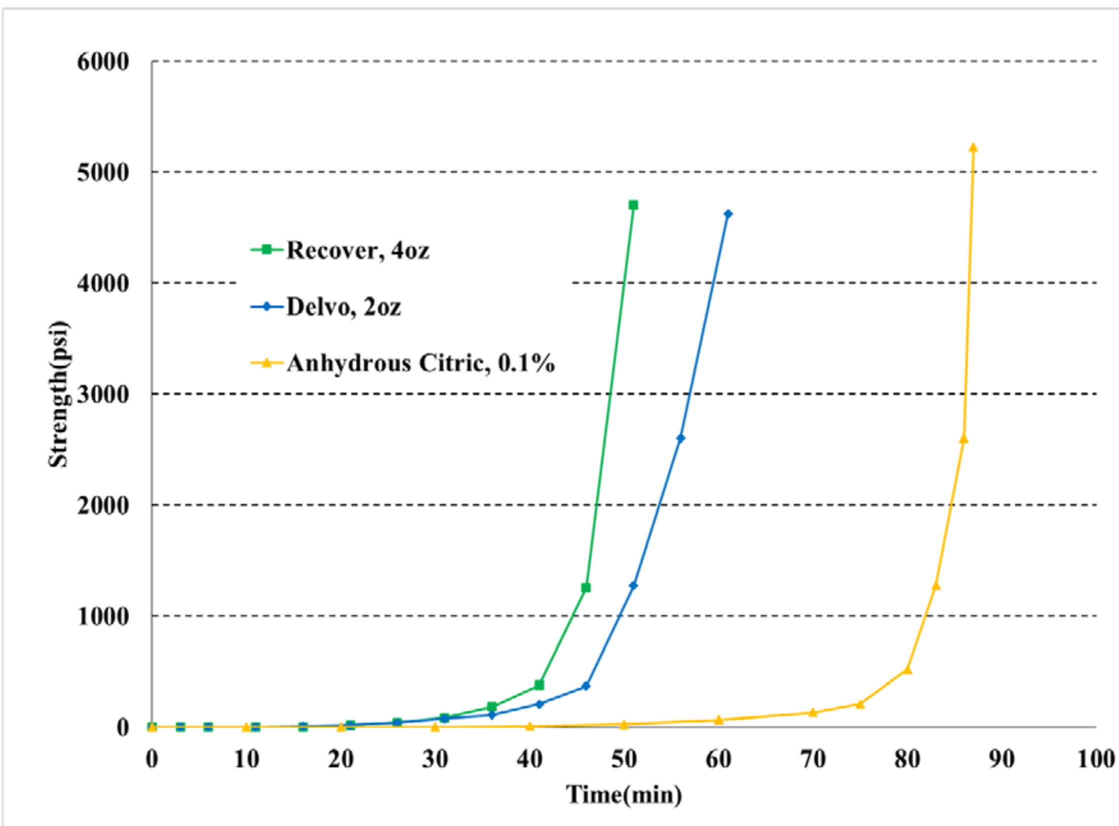

Figure 27, Set Time Testing Results

This graph confirms what was determined during the actual casting of Recover® specimens. During cast, the concrete was barely workable at the thirty minute mark. At the one hour mark, the concrete was completely hard. The 3 hour compression specimens achieved a strength of approximately 4500 psi. The interesting aspect of this test was the result of the Delvo®. For the Delvo®, the concrete achieved set ten minutes later than the Recover®; however, the Delvo® allowed a greater level of workability during the casting process. When Delvo® was employed, there was never a problem of a loss of workability. The effect of the lowest level dosage of citric acid to that of the other retarders was tremendous. The citric acid achieved set at 87 minutes. This was a full half hour after the Delvo®. Workability was noted to have decreased substantially as the penetration resistance approached 500 psi. The strength of the citric at 3 hours was approximately 4000 psi. There was no significant difference in the 3 hour strength among the three retarders. The only difference was the apparent efficacy of the retarders. The Recover® fails to achieve the desired performance, as proven by set time test, and the decision to cease testing justified. However, set time testing is sensitive to temperature. Thus, any variation in ambient temperature and mix temperature will change set time.

5.13 C-157 Shrinkage for Citric Acid at 0.45 w/c

The literature clearly indicates that the presence of retarders of any type slows the hydration process and halts any ettringite formation until the retarder is consumed by the formation reactions. The only literature that actually placed a length of time on the efficacy of a retarder was Osipov (1978). In his work, it was stated with an appropriate dosage the set time could be delayed up to 8 hours. Depending on the dosage amount of citric acid, the C-157 specimens could not be demolded until the

4”x8” specimens held at least a couple hundred psi. The C-157 specimens were not demolded if their exposed surface was still soft. This was to prevent damage on the studs required for shrinkage measurements. One aspect of shrinkage that was anticipated was shrinkage cracking. This was a result found everywhere in the slab cast at Fears in 2014. The initial shrinkage readings were conducted at 3 hours for the zero and 0.1% citric acid. The initial readings for 0.5%-1.0% were taken at 1 day. However, there were no shrinkage cracks found on any of the C-157 prisms, even at the highest citric dosage of 1.0%. Figure 28 displays the C-157 shrinkage measurement for the 0.45 w/c ratio.

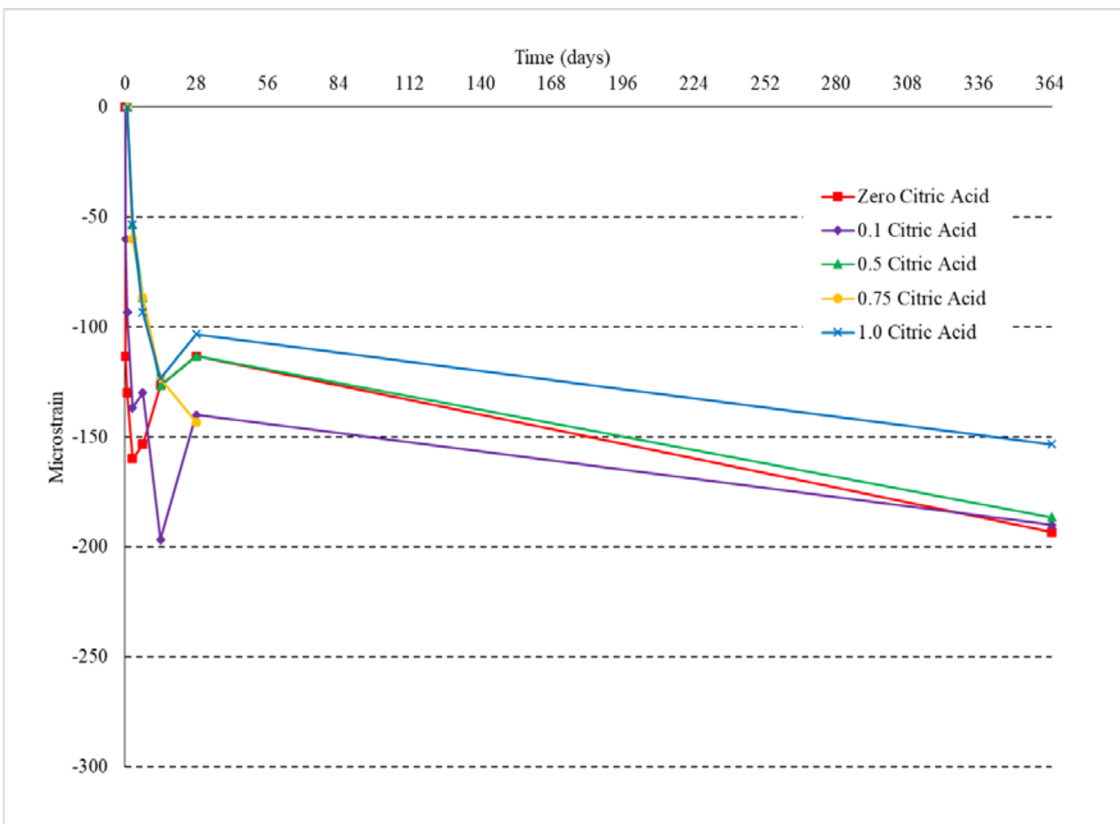

Figure 28, C-157 Shrinkage with 0.45 w/c

In Figure 28, the zero citric acid and 0.75% citric acid achieve similar shrinkage from initial measurement to 1 year. The 0.1% citric acid attained the maximum shrinkage of approximately 200 microstrain at 14 days. This mix had expanded slightly by 28 days before shrink back to nearly 200 microstrain. At 1 year, there was almost no difference in the magnitude of the shrinkage across all dosages of the citric acid mixes.

5.14 C-157 Shrinkage for Citric Acid at 0.47 w/c

From Figure 29, it is observed that through the first 28 days the data is very tightly grouped. The shrinkage for the various mixes is ordered such that shrinkage increases with increasing dosage of citric acid. The 0.75% citric acid only had test data out to 28 days as 1 year testing had not occurred by the conclusion of the project. The 1.0% citric acid achieves the highest amount of shrinkage at 256 microstrain by 1 year. The 0.1% citric acid nearly achieves the same level of shrinkage at the same time. The zero citric acid and 0.5% citric acid both attain around 200 microstrain of shrinkage.

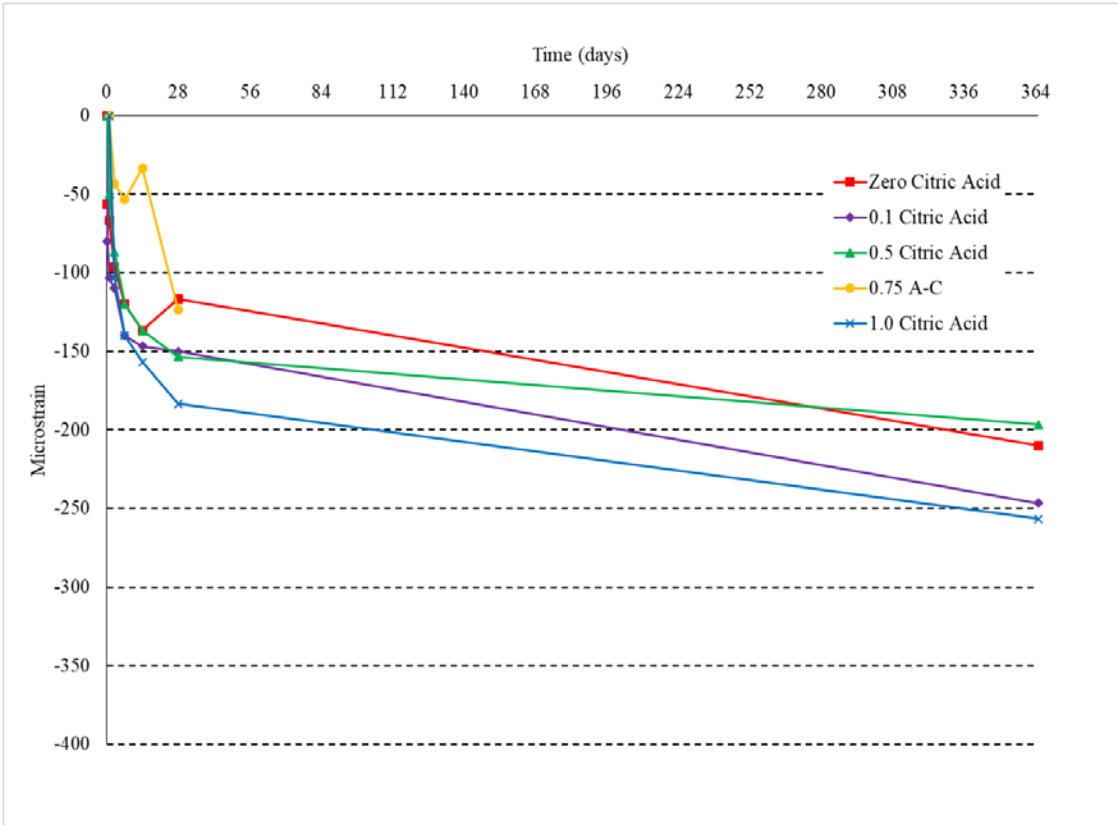

Figure 29, C-157 Shrinkage with 0.47 w/c

5.15 C-157 Shrinkage for Citric Acid at 0.50 w/c

In Figure 30, the 0.75% citric acid achieved the maximum shrinkage for this w/c of 400 microstrain. This is unusual as none of the previous 0.75% citric acid mixes attained such a level of shrinkage strain. The line is almost linear from the initial measurement. The shrinkage does not follow the previous patterns in Figures 26 and 25 of increasing shrinkage with increasing citric acid dosage. There is no discernible trend for this w/c ratio. The 0.5% citric acid achieves 300 microstrain by one year while the zero, 0.1%, and 1.0% citric acid all reached 200 microstrain of shrinkage.

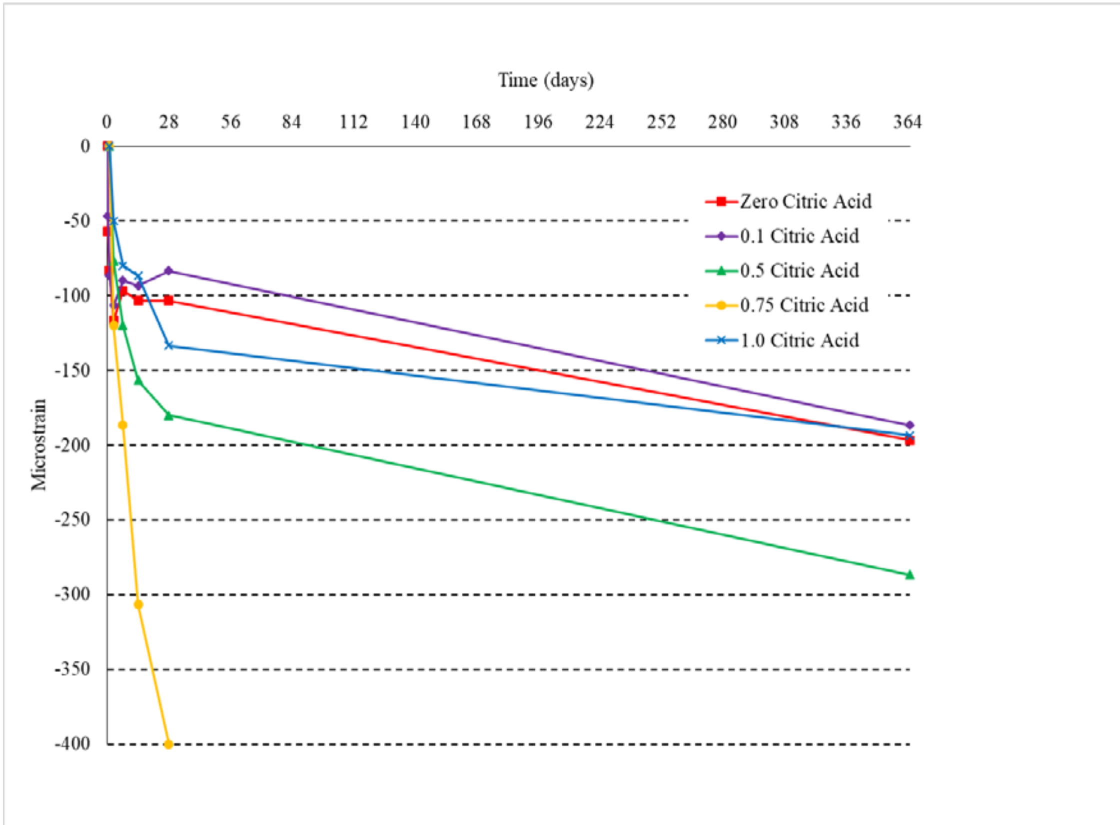

Figure 30, **C-157 Shrinkage with 0.50 w/c**

5.16 Geokon VWSG Shrinkage for Citric Acid at 0.45 w/c

Even though the C-157 test is considered the standard ASTM referee test, the user bias inherent in the test has left some of its results in question. Also, this test can only begin once the concrete is able to hold load and not become damaged during testing. This limits the ability to capture what may be going on in early hydration periods. Another problem is the time increment of measurement. The test is not difficult but time consuming. To eliminate errors in precision, only one user may execute the C-157. To improve accuracy, the Geokon Vibrating Wire Strain Gauges were employed. These allow a very fine time increment for an extremely long time with much less user bias in the data collection. The Geokon also measures to 1 microstrain while the C-157 test measures to an accuracy of 10 microstrain. For all Geokon data, the VWSG data was zeroed to initial set for each individual batch.

In Figure 31, it is observed that the zero citric acid and that of the 0.75% citric acid are both missing. These trends were attempted to be captured on two separate occasions but a failure in the data acquisition system prevented successful measurement. Also, it is observed that the 0.1% citric acid shrinks the least of the three mixes measured for shrinkage. The straight lines in the trend lines represent places where data was missing from the data logger. The maximum amount of shrinkage measured was 216 microstrain from the 1.0%citric acid mix.

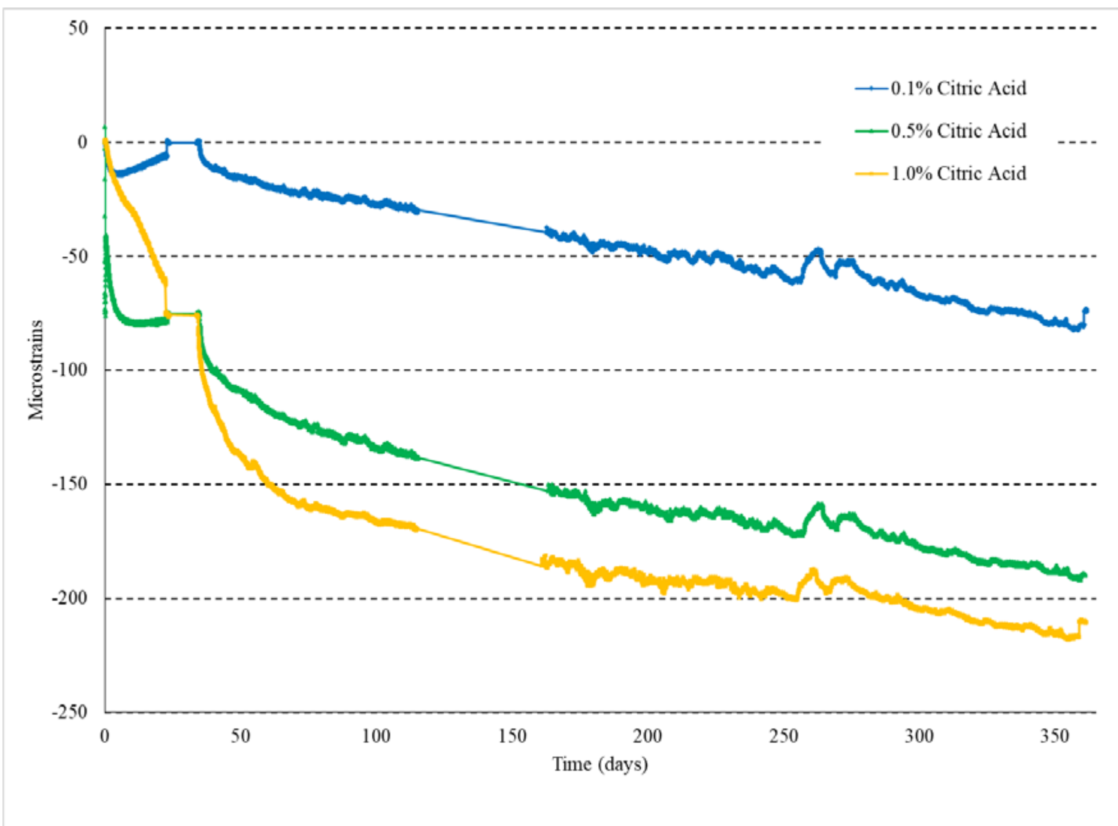

Figure 31, 6”x12” Cylinder VWSG Shrinkage with 0.45 w/c

5.17 Geokon VWSG Shrinkage for Citric Acid at 0.47 w/c

All of the 6”x12” cylinders which were instrumented for VWSG were placed inside the environmental chamber on foam to prevent thermal effects through the concrete floor of the chamber. Before casting a cylinder for shrinkage measurement, the wire to the cylinder from the logger was marked with the batch identification for that specific mix. All casting occurred inside the chamber due to the short leads for the strain gauges. Figure 32 displays the shrinkage measurement of 6”x12”s for the 0.47 w/c ratio.

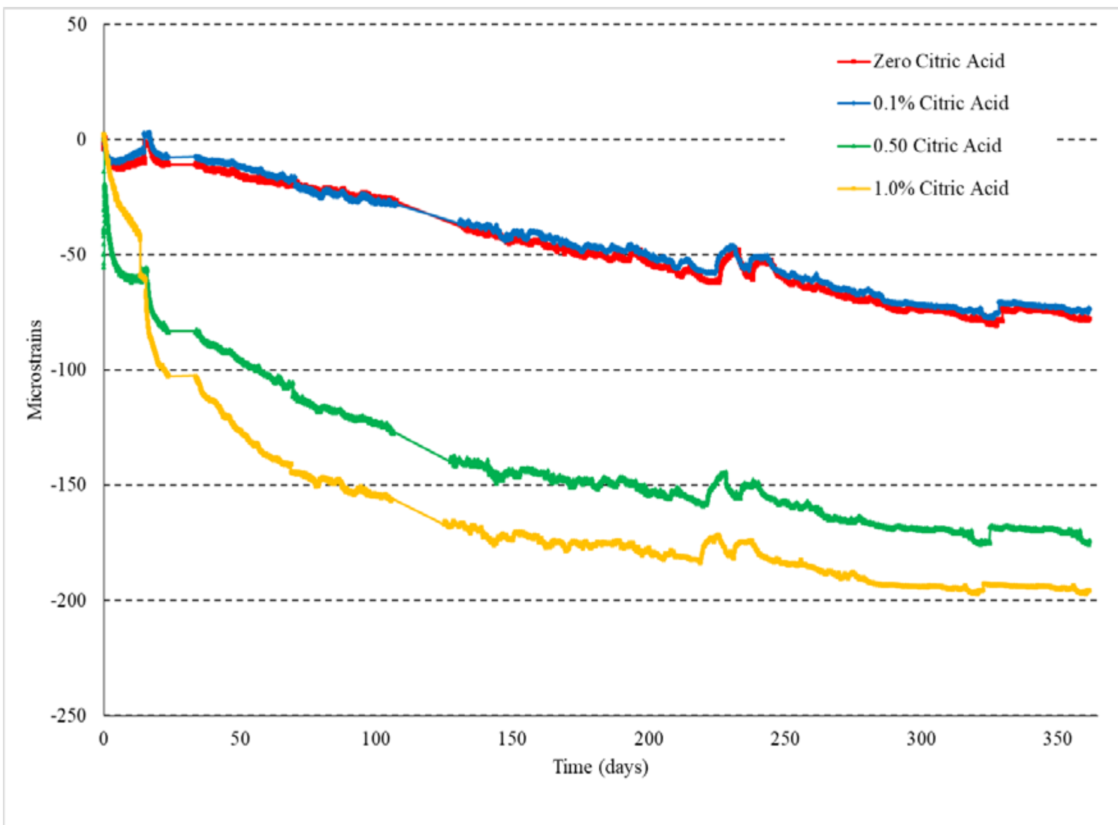

Figure 32, 6”x12” Cylinder VWSG Shrinkage with 0.47 w/c

The same ordering of trends was observed in Figure 31 occurs in Figure 32 where the magnitude of shrinkage increases with increasing dosage of retarder. The 1.0% citric acid mix exhibits the most shrinkage followed closely by the 0.5% citric acid mix. The maximum shrinkage measured was approximately 200 microstrain. This ordering of shrinkage trends was almost identical across both the 0.45 and 0.47 w/c ratios. The 0.75% citric acid mix was cast several times for this w/c ratio. However, technical errors in the data logger prevented any effective data collection from occurring. This was not an uncommon experience throughout this project. Often a failure in the logger would prevent any effective data gathering from occurring. When the logger actually recorded, the data produced was remarkably clean, producing smooth trends.

5.18 Geokon VWSG Shrinkage for Citric Acid at 0.50 w/c

From Figure 33, it is observed that the various mixes in this w/c ratio are all very tightly grouped. This is exactly the behavior displayed in Figures 31 and 32 where shrinkage increases with increasing content of citric acid. Various errors in the data logger and sensor failures made capturing any shrinkage trend for the 0.75% citric acid mix impossible. The data logger ceased recording data at 250 days. The maximum shrinkage occurred in the 1.0% citric acid at 100 microstrain.

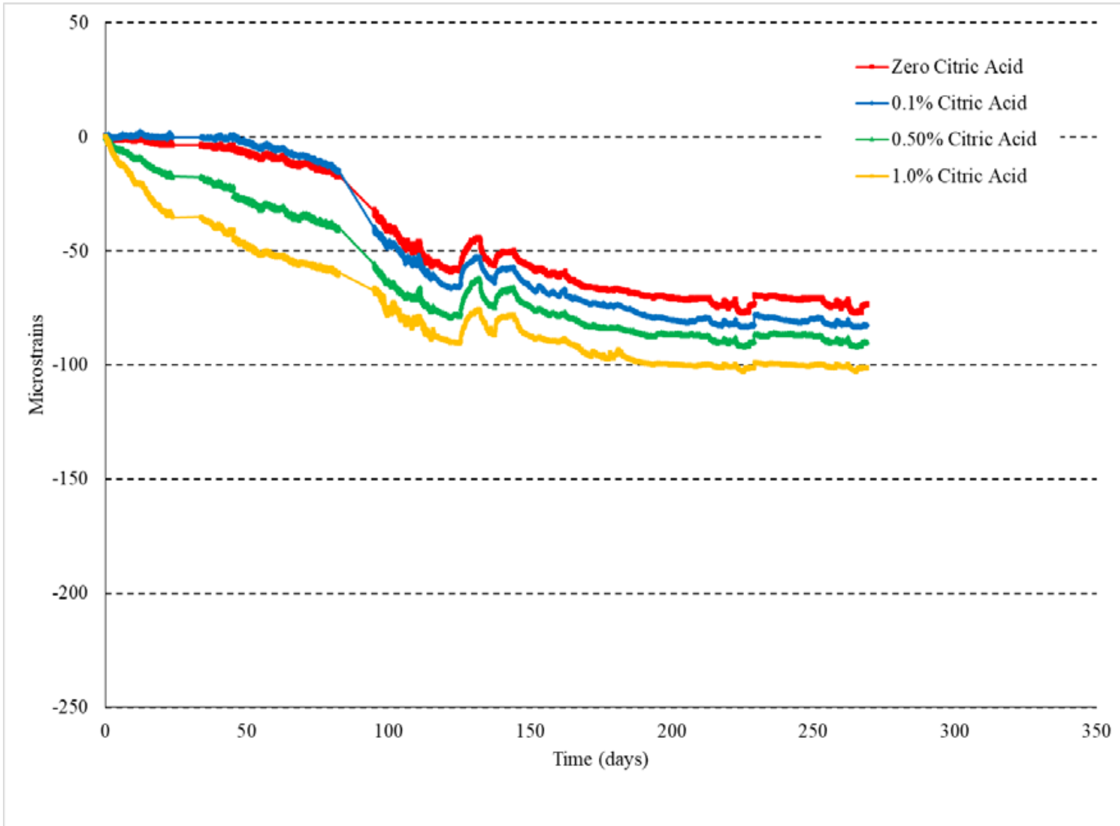

Figure 33, 6”x12” Cylinder VWSG Shrinkage with 0.50 w/c

5.19 C-157 Shrinkage for Delvo® at 0.45 w/c

The strength trends for the Delvo® were remarkably clean and straightforward to distinguish. Unfortunately, the shrinkage measurements for the Delvo® was not nearly as easy to discern and understand. Approximately three days after being cast, the air conditioning unit for the environmental chamber went down. The specimens for shrinkage were affected for a period of 24-36 hours until repairs were completed. Additionally, an experiment which utilized water cure in the environmental chamber for 7 days during these tests. This water cure caused the humidity to spike to near 80%. In this time, the C-157 specimens registered less shrinkage or in some circumstances actually appeared to expand. The behavior recorded by the C-157 test does indicate shrinkage is halted by the presence of high humidity, whether expansion is occurring is difficult to determine. As a result of these circumstance the individual graphs of the w/c ratios are very cluttered, and it is hard to distinguish patterns. Figure 34 displays the shrinkage results for 28 days at a w/c ratio of 0.45.

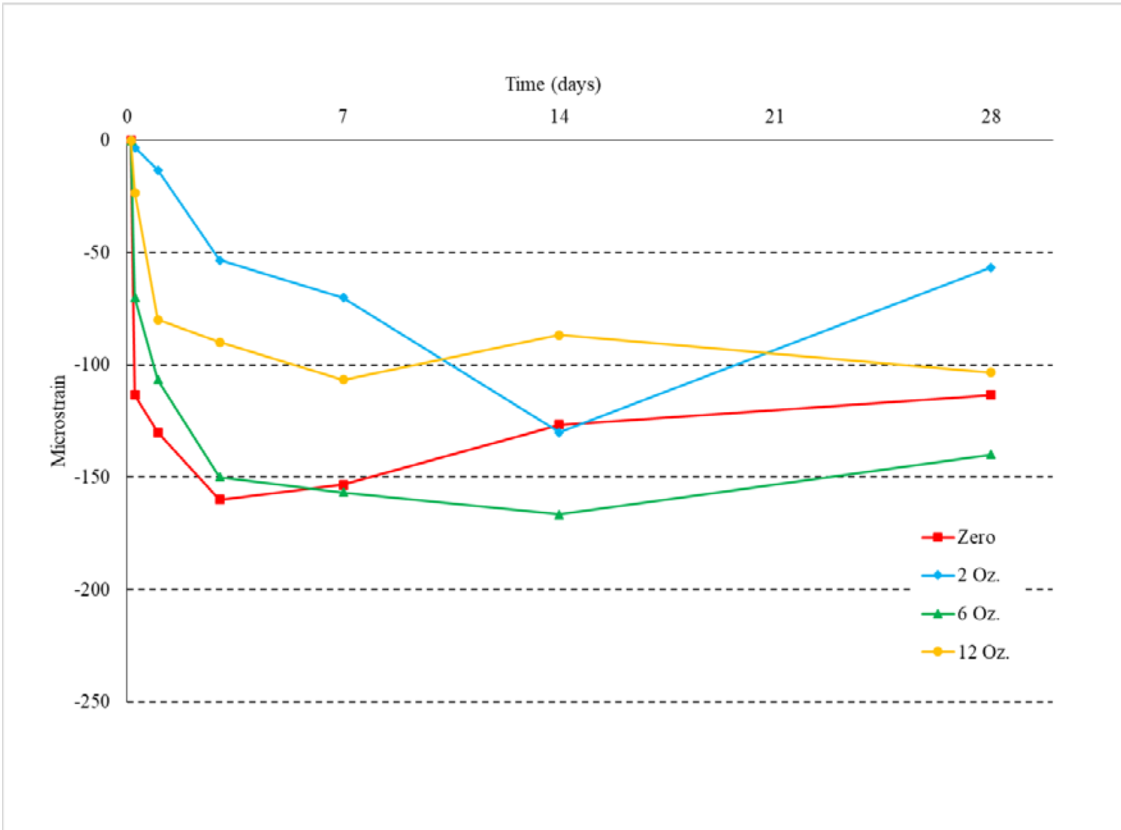

Figure 34, 28 Day C-157 Shrinkage with 0.45 w/c

From Figure 34, the only Delvo® dosages affected were the 2 oz and 6 oz from the 0.45 w/c ratio. These dosages were only influenced by water cure between day 14 and day 21. By 28 days, the 2 oz Delvo mix had expanded by nearly 60 microstrain while the 6 oz Delvo® mix had expanded by nearly 20 microstrain. The zero retarded mix was cast before the water cure occurred. Shrinkage measurements for the mix utilizing 12 oz Delvo® exhibited approximately 20 microstrain worth of expansion.

This is difficult to understand as this mix was not cast and subsequently under testing when water cure occurred. The max shrinkage achieved in this w/c ratio was 167 microstrain by the 6 oz Delvo® mix.

5.20 C-157 Shrinkage for Delvo® at 0.47 w/c

Figure 34 displays the shrinkage measurements at 28 days for a 0.45 w/c ratio. This set of mixes was conducted during extreme heat with moderate ambient humidity characteristic of mid-summer. The standard protocol for hot weather batching as detailed in section 3.3 was employed. The prisms were always moved directly into the environmental chamber following cast to prevent thermal effects from skewing the measurements. Figure 35 displays the shrinkage results for 28 days at a w/c ratio of 0.47.

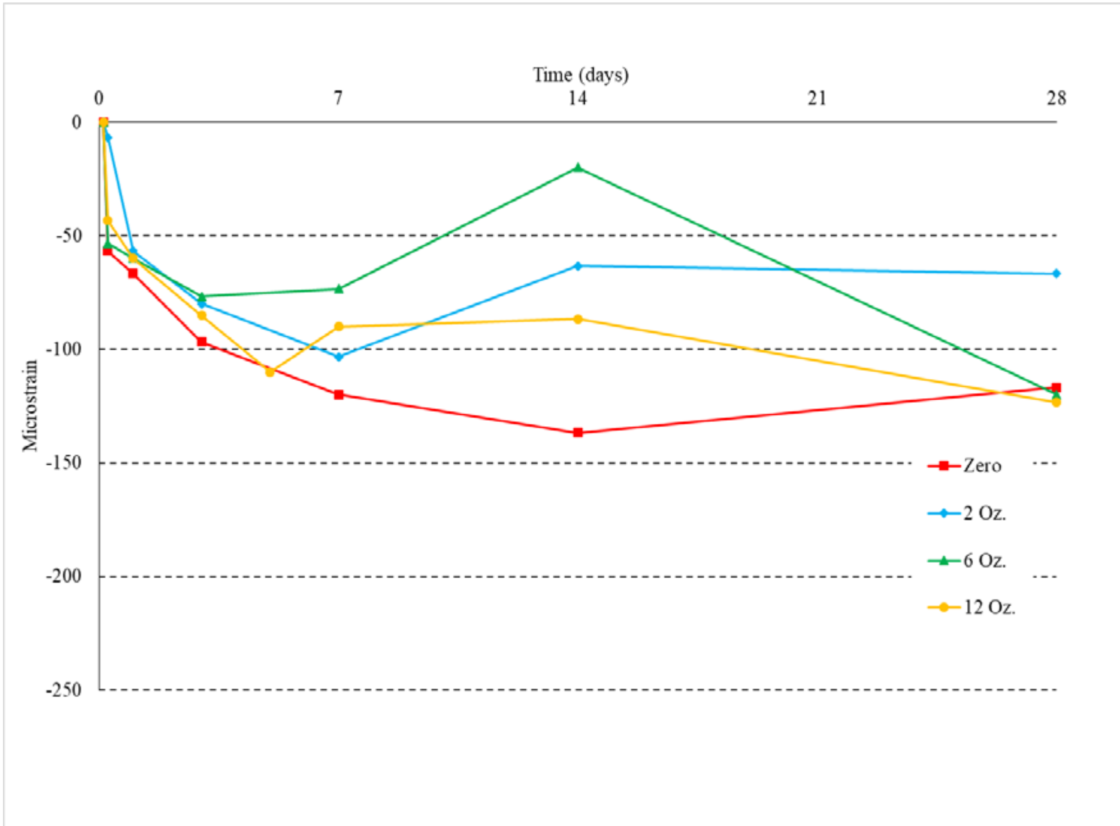

Figure 35, 28 Day C-157 Shrinkage with 0.47 w/c

From Figure 35, the shrinkage behavior is similar to that of the 0.45 w/c ratio in Figure 34. This is because the 0.47 w/c ratio for Delvo® was begun seven days prior to a second water cure occurring in the environmental chamber. Under normal environmental conditions, rapid setting CSA cements exhibit very low shrinkage, but they do not typically expand. Under high moisture conditions, all of the mixes utilizing Delvo® experienced expansion ranging from 4 microstrain to nearly 50 microstrain. The mix with zero Delvo® continued to shrink, experiencing the maximum shrinkage measured of 137 microstrain. At 28 days, the zero, 6 oz, and 12 oz mixes all measured near 120 microstrain of shrinkage.

5.21 C-157 Shrinkage for Delvo® at 0.50 w/c

The final w/c ratio for the Delvo® was executed toward the end of summer. These batches were executed under remarkably hot temperatures with low ambient humidity. At the time of casting and curing, all water curing experiments that previously coincided with previous mixes had been completed. Figure 36 displays the shrinkage measurements for the 0.50 w/c ratio at 28 days.

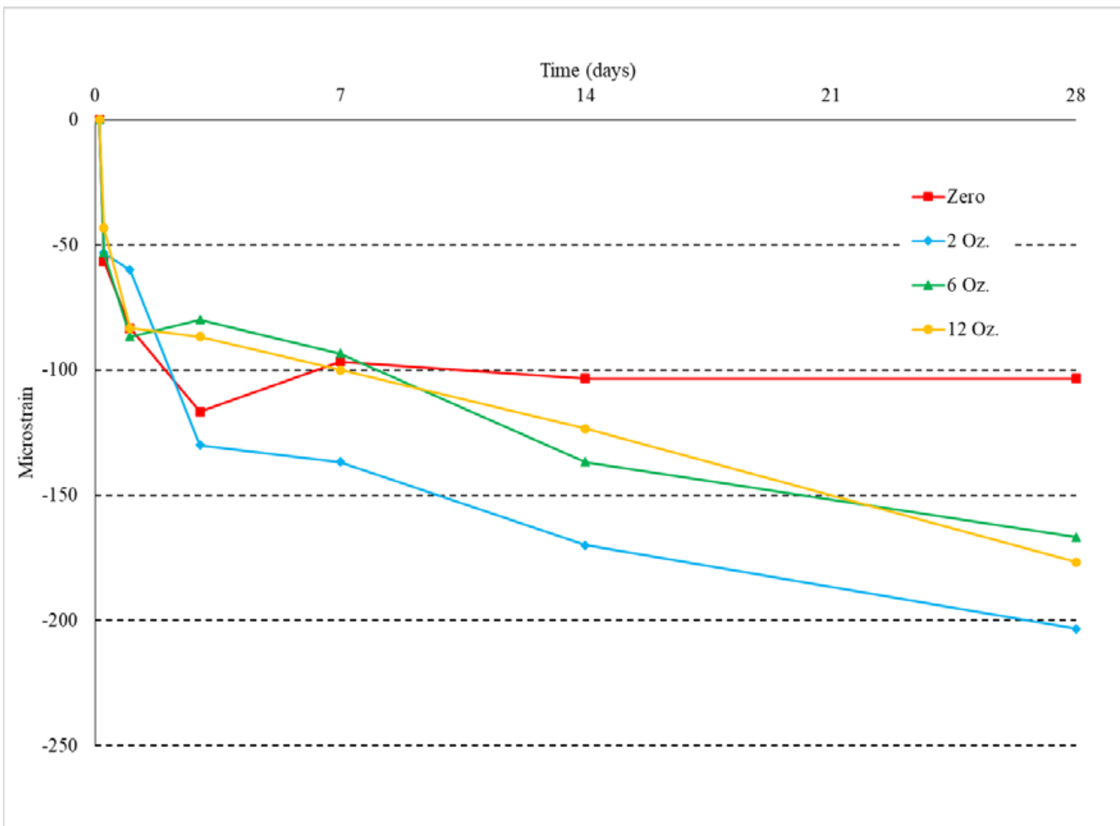

Figure 36, 28 Day C-157 Shrinkage with 0.50 w/c

In Figure 36, the various mixes exhibit a noticeable amounts of shrinkage by the 3 day mark. From 7 to 14 days, the shrinkage measurements become more spread out with the lower dosage Delvo® mixes registering more shrinkage than the 12 oz Delvo® mix. The maximum shrinkage of 203 microstrain occurred in the 2 oz Delvo mix. The 6 oz and 12 oz Delvo mixes measured approximately 170 microstrain at 28 days. The zero Delvo mix was did not change in terms of shrinkage from 14 to 28 days. No shrinkage measurements were made for the Delvo® mixes at 1 year because the specimens did not achieve that age by the time the project was concluded. No VWSG data was able to be collected for the Delvo® mixes due to technical failures.

Chapter 6: Findings, Conclusions, and Future Work

6.1 Findings

- As the dosage of citric acid increased across all w/c ratios, the amount of Glenium employed was decreased to maintain the same fresh properties.
- When Delvo® was employed, the amount of Glenium was increased to achieve the desired workability.
- The majority of both C-157 and Geokon readings for citric acid indicated shrinkage reaching a maximum of 200 microstrain by 28 days and 300 microstrain at 1 year.
- A similar result was found for the Delvo®.
- Increasing citric acid caused a reduction in early age strength gain.
- Increasing Delvo® caused no reduction in early age strength gain.
- At 28 days, both the Delvo® and citric acid achieved a compressive strength of 8000-9000 psi.
- At 28 days, the 4”x8” compressive specimens failed due to shear in the coarse aggregate.
- All mixes with citric acid experienced compressive strength loss at 1 year.
- Control batches with no retarder experienced compressive strength loss at 1 year.

6.2 Conclusions

- Citric acid is an effective retarder.
- Citric acid has a superplasticizing effect.
- Citric acid inhibits early age strength gain.
- Delvo© has no superplasticizing effect, requires more Glenium.
- Delvo® has a moderate retardation influence.
- Recover© fails to act as an effective retarder.
- Geokon VWSG indicate that increasing anhydrous citric acid dosages result in increasing shrinkage.
- Increasing dosage of Delvo® does not influence magnitude of shrinkage at 28 days.
- The effectiveness of a retarder is at an end when initial set occurs.
- The mode of introduction of a retarder into the mix may influence its efficacy

6.3 Future Work

- Execute a new set of batches for the 0.75% citric acid across all three w/c ratios
- Execute a new batch for the 0.45 w/c for Delvo©
- Investigate the influence of a high range water reducer on strength and shrinkage
- Investigate the idea of competitive absorption with retarders and superplasticizers
- Experiment with differing modes of introduction of retarder
- Study the combined effects of temperature and a retarder
- Utilize a set time test to further establish the effectiveness of a retarder

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Appendices

Appendix I: Batch Sheets for Citric acid

Rapid Set, control batch

6/28/2016

w/cm =	0.45		Sand % water =	3.080	start	7:50 AM
PC =	0	type III	Rock % water =	1.375	batch	8:00 AM
RS =	564				stop	8:20 AM
Komp =	0					
FA =	0					

Moisture Content

Sand :	Wt (lb)		
Pan	0.39	Mc =	3.080
Pan + wet Sand	5.41		
Pan + dry Sand	5.26		
Aggregates :			
Pan	0.54	Mc =	1.375
Pan + wet Agg	5.7		
Pan + dry Agg	5.63		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1796.9	199.66	lb
Fine Aggregate, Dover Sand		1464.1	162.68	lb
Water		209.7	23.30	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.00	lb
Glenium (MRWR)	oz	0.0	75.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0 % Citric added to prolong set time; 75mL Glenium added for workability

Concrete Temperature	58
Air Temperature	79
Humidity	84%
Air Content	2.00%
Slump	.75"
Unit Weight Pot Empty	7.76
Unit Weight Pot Full	44.57

Expected Unit Wt		148.55
Measured	36.81	147.24
Difference	%	0.88

Unit Weight: 160.04 lb/ft.^3

Early batch

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg.	strain
3 hr	3905	3905	4145	**10.2449**	**10.2383**	**10.2486**	0.125	3985	0.00000	0.00000	0.00000	0.00000	0
6 hr	3210	4670	4445	10.2424	10.2379	10.2481	0.25	4108.333	-0.00250	-0.00040	-0.00050	-0.00113	-113.333
24 hr	5310	5270	5180	10.2423	10.2375	10.2481	1	5253.333	-0.00260	-0.00080	-0.00050	-0.00130	-130
3 day	5690	6085	5765	10.2420	10.2371	10.2479	3	5846.667	-0.00290	-0.00120	-0.00070	-0.00160	-160
7 day	6375	6970	4845	10.242	10.2372	10.2480	7	6063.333	-0.00290	-0.00110	-0.00060	-0.00153	-153.333
14 day	7335	6755	7690	10.2422	10.2375	10.2483	14	7260	-0.00270	-0.00080	-0.00030	-0.00127	-126.667
28 day	7225	7720	6750	10.2426	10.2375	10.248	28	7231.667	-0.00230	-0.00080	-0.00030	-0.00113	-113.333
1 yr	6214	5272	6262	10.2417	10.2368	10.248	365	5916	-0.00320	-0.00150	-0.00110	-0.00193	-193.333

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.45 0.1% citric batch

6/29/2016

w/cm =	0.45		Sand % water =	2.381	start	8:55 AM
PC =	0	type III	Rock % water =	0.771	batch	9:00 AM
RS =	564				stop	9:20 AM
Komp =	0					
FA =	0					

Moisture Content

Sand :	Wt (lb)		
Pan	0.39	Mc =	2.381
Pan + wet Sand	2.97		
Pan + dry Sand	2.91		
Aggregates :			
Pan	0.54	Mc =	0.771
Pan + wet Agg	4.46		
Pan + dry Agg	4.43		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1786.2	198.47	lb
Fine Aggregate, Dover Sand		1454.2	161.58	lb
Water		230.9	25.66	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.06	lb
Glenium (MRWR)	oz	0.0	75.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0 % Citric added to prolong set time;75mL Glenium added for workability

Concrete Temperature	54	Expected Unit Wt		148.55
Air Temperature	70	Measured	36.42	145.68
Humidity	83%	Difference	%	1.93
Air Content	2.70%			
Slump	4.75"			
Unit Weight Pot Empty	7.76	Unit Weight:	158.35	lb/ft.^3
Unit Weight Pot Full	44.18			

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg	strain
3 hr	3980	3875	3765	**10.2163**	**10.2222**	**10.2684**	0.125	3873.333	0.00000	0.00000	0.0000	0.00000	0
6 hr	4940	4840	4870	10.2159	10.2216	10.2676	0.25	4883.333	-0.0004	-0.00060	-0.0008	-0.00060	-60
24 hr	6260	5940	5495	10.2155	10.2213	10.2673	1	5898.333	-0.0008	-0.00090	-0.0011	-0.00093	-93.3333
3 day	6835	6500	6580	10.2152	10.2209	10.2667	3	6638.333	-0.0011	-0.00130	-0.0017	-0.00137	-136.667
7 day	7435	7410	7450	10.2152	10.2209	10.2669	7	7431.667	-0.0011	-0.00130	-0.0015	-0.00130	-130
14 day	8015	7370	7330	10.2146	10.2203	10.2661	14	7571.667	-0.0017	-0.00190	-0.0023	-0.00197	-196.667
28 day	7985	7770	7650	10.2150	10.2209	10.2668	28	7801.667	-0.0013	-0.00130	-0.0016	-0.00140	-140
1 yr	6630	6728	6429	10.2147	10.22	10.267	365	6595.667	-0.0016	-0.00220	-0.0019	-0.00190	-190

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.45 0.5% citric batch

6/29/2016

w/cm =	0.45		Sand % water =	2.381	start	8:55 AM
PC =	0	type III	Rock % water =	0.769	batch	9:00 AM
RS =	564				stop	9:20 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.39	Mc =	2.381
Pan + wet Sand	2.97		
Pan + dry Sand	2.91		
Aggregates :			
Pan	0.53	Mc =	0.769
Pan + wet Agg	4.46		
Pan + dry Agg	4.43		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

	Theoretical	Weight	Volume
Portland Cement		0.0	0.00
Rapid Set Cement		564	3.14
Komponent		0	0.00
Fly Ash		0	0.00
Water		253.8	4.07
Rock		1772.6	10.60
Air Entrapped 2%		0.0	0.54
DCI-chemical part		0.0	0.00
Sand		1420.4	8.65
	Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1786.2	198.47	lb
Fine Aggregate, Dover Sand		1454.2	161.58	lb
Water		231.0	25.66	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.31	lb
Glenium (MRWR)	oz	0.0	75.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0 % Citric added to prolong set time; 50mL Glenium added for workability

Concrete Temperature	57
Air Temperature	73
Humidity	83%
Air Content	2.50%
Slump	9.75"
Unit Weight Pot Empty	7.76
Unit Weight Pot Full	44

Expected Unit Wt		148.55
Measured	36.24	144.96
Difference	%	2.41

Unit Weight: 157.57 lb/ft.^3

Note: too soft to demould

Note: firm on top too wet too hold load, demould @ 24hrs

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg.	strain
3 hr	0	0	0	0	0	0.0000	0.125	0					
6 hr	180	285	140	0	0	0.0000	0.25	201.6667					
24 hr	6205	5920	6020	10.2417	10.2378	10.2449	1	6048.333	0.00000	0.00000	0.0000	0.00000	0
3 day	7065	6890	7215	10.2412	10.2372	10.2444	3	7056.667	-0.0005	-0.0006	-0.0005	-0.00053	-53.3333
7 day	7660	7810	7840	10.2409	10.2369	10.2440	7	7770	-0.0008	-0.0009	-0.0009	-0.00087	-86.6667
14 day	8595	7805	8080	10.2404	10.2365	10.2437	14	8160	-0.0013	-0.0013	-0.0012	-0.00127	-126.667
28 day	7600	8010	8025	10.2405	10.2366	10.244	28	7878.333	-0.0012	-0.0012	-0.0010	-0.00113	-113.333
1 yr	6229	6795	6711	10.2399	10.2359	10.243		6578.333	-0.0018	-0.0019	-0.0019	-0.00187	-186.667

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, 0.45 0.75% citric batch

1/20/2017

w/cm =	0.45		Sand % water =	3.333	start	9:40 AM
PC =	0	type III	Rock % water =	0.915	batch	9:00 AM
RS =	564				stop	9:20 AM
Komp =	0					
FA =	0					

Moisture Content

Sand :	Wt (lb)		
Pan	0.39	Mc =	3.333
Pan + wet Sand	4.42		
Pan + dry Sand	4.29		
Aggregates :			
Pan	0.49	Mc =	0.915
Pan + wet Agg	4.9		
Pan + dry Agg	4.86		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

	Theoretical Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1788.8	198.75	lb
Fine Aggregate, Dover Sand		1467.7	163.08	lb
Water		214.2	23.80	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.47	lb
Glenium (MRWR)	oz	0.0	50.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0 % Citric added to prolong set time; 50mL Glenium added for workability

Concrete Temperature	78		Expected Unit Wt		148.55
Air Temperature	57		Measured	36.24	144.96
Humidity	83%		Difference	%	2.41
Air Content	2.50%				
Slump	9.75"				
Unit Weight Pot Empty	7.76		Unit Weight:	157.57	lb/ft.^3
Unit Weight Pot Full	44				

Note: too soft to demould

Note: firm on top too wet too hold load, demould @ 24hrs

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg.	strain
3 hr	0	0	0	0	0	0	0.125	0					
6 hr	0	0	0	0	0	0	0.25	0					
24 hr	7315	7585	7360	10.2195	10.2512	10.328	1	7420	0.00000	0.00000	0.0000	0.00000	0
3 day	8380	9090	9235	10.2188	10.2506	10.328	3	8901.667	-0.0007	-0.0006	-0.0005	-0.00060	-60
7 day	9090	9155	8950	10.2187	10.2504	10.327	7	9065	-0.0008	-0.0008	-0.0010	-0.00087	-86.6667
14 day	8840	8430	8805	10.2182	10.2501	10.327	14	8691.667	-0.0013	-0.0011	-0.0013	-0.00123	-123.333
28 day	9005	7935	8430	10.218	10.2499	10.327	28	8456.667	-0.0015	-0.0013	-0.0015	-0.00143	-143.333
1 yr	0	0	0	0	0	0							

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.45 1.0% citric batch

6/29/2016

w/cm =	0.45		Sand % water =	2.381	start	8:55 AM
PC =	0	type III	Rock % water =	0.769	batch	9:00 AM
RS =	564				stop	9:20 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.39	Mc =	2.381
Pan + wet Sand	2.97		
Pan + dry Sand	2.91		
Aggregates :			
Pan	0.53	Mc =	0.769
Pan + wet Agg	4.46		
Pan + dry Agg	4.43		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1786.2	198.47	lb
Fine Aggregate, Dover Sand		1454.2	161.58	lb
Water		231.0	25.66	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.63	lb
Glenium (MRWR)	oz	0.0	50.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0 % Citric added to prolong set time; 50mL Glenium added for workability

Concrete Temperature	58	Expected Unit Wt		148.55	
Air Temperature	79	Measured	36.64	146.56	
Humidity	65%	Difference	%	1.34	
Air Content	2.10%				
Slump	7.5"				
Unit Weight Pot Empty	7.76	Unit Weight:	159.3	lb/ft.^3	
Unit Weight Pot Full	44.4				

Note: too soft to demould
Note: too soft to demould

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg.	strain
3 hr	0	0	0	0	0	0.0000	0.125	0					
6 hr	0	0	0	0	0	0.0000	0.25	0					
24 hr	6280	6265	6080	10.2279	10.2366	10.2460	1	6208.333	0.00000	0.00000	0.00000	0.00000	0
3 day	7655	7340	7660	10.2268	10.2362	10.2459	3	7551.667	-0.00110	-0.00040	-0.00010	-0.00053	-53.3333
7 day	8435	7865	8360	10.2263	10.2359	10.2455	7	8220	-0.00160	-0.00070	-0.00050	-0.00093	-93.3333
14 day	8660	9500	8720	10.226	10.2355	10.2453	14	8960	-0.00190	-0.00110	-0.00070	-0.00123	-123.333
28 day	8380	7515	8200	10.2261	10.2358	10.246	28	8031.667	-0.00180	-0.00080	-0.00050	-0.00103	-103.333
1 yr	7396	6690	7525	10.2263	10.2443	10.245		7203.667	-0.00160	0.00770	-0.00150	-0.00153	-153.333

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, control batch

7/7/2016

w/cm =	0.47		Sand % water =	3.509	start	6:42 AM
PC =	0	type III	Rock % water =	0.475	batch	6:45 AM
RS =	564				stop	7:09 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.39	Mc =	3.509
Pan + wet Sand	3.34		
Pan + dry Sand	3.24		
Aggregates :			
Pan	0.53	Mc =	0.475
Pan + wet Agg	4.76		
Pan + dry Agg	4.74		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	265.1	4.25
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1390.7	8.47
Sum	3992.35	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1781.0	197.89	lb
Fine Aggregate, Dover Sand		1439.5	159.95	lb
Water		231.5	25.72	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.00	lb
Glenium (MRWR)	oz	0.0	100.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0 % Citric added to prolong set time; 100 mL Glenium added for workability

Concrete Temperature	58	Expected Unit Wt		147.86	
Air Temperature	79	Measured	36.7	146.80	
Humidity	79%	Difference	%	0.72	
Air Content	2.10%				
Slump	1.5"				
Unit Weight Pot Empty	7.76	Unit Weight:	159.57	lb/ft.^3	
Unit Weight Pot Full	44.46				

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg.	strain
3 hr	4365	4290	4180	**10.2305**	**10.1842**	**10.2341**	0.125	4278.333	0.0000	0.0000	0.0000	0	0
6 hr	4730	4890	5170	10.2299	10.1836	10.2336	0.25	4930	-0.0006	-0.0006	-0.0005	-0.00057	-56.6667
24 hr	5835	5275	5535	10.2296	10.1836	10.2336	1	5548.333	-0.0009	-0.0006	-0.0005	-0.00067	-66.6667
3 day	6220	6025	6545	10.2295	10.1834	10.2330	3	6263.333	-0.0010	-0.0008	-0.0011	-0.00097	-96.6667
7 day	6420	6935	6895	10.2292	10.1832	10.2328	7	6750	-0.0013	-0.0010	-0.0013	-0.0012	-120
14 day	6395	7420	7350	10.2291	10.183	10.2326	14	7055	-0.0014	-0.0012	-0.0015	-0.00137	-136.667
28 day	7280	7775	8375	10.2294	10.1831	10.233	28	7810	-0.0011	-0.0011	-0.0013	-0.00117	-116.667
1 yr	6291	4834	5010	10.2284	10.1821	10.232		5378.333	-0.0021	-0.0021	-0.0021	-0.0021	-210

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, 0.47 0.1% citric batch

7/7/2016

w/cm =	0.47		Sand % water =	3.509	start	7:32 AM
PC =	0	type III	Rock % water =	0.475	batch	7:40 AM
RS =	564				stop	7:50 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.39	Mc =	3.509
Pan + wet Sand	3.34		
Pan + dry Sand	3.24		
Aggregates :			
Pan	0.53	Mc =	0.475
Pan + wet Agg	4.76		
Pan + dry Agg	4.74		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	265.1	4.25
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1390.7	8.47
Sum	3992.35	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1781.0	197.89	lb
Fine Aggregate, Dover Sand		1439.5	159.95	lb
Water		231.5	25.72	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.06	lb
Glenium (MRWR)	oz	0.0	50.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0.1 % Citric added to prolong set time; 50mL Glenium added for workability

Concrete Temperature	59	Expected Unit Wt		147.86
Air Temperature	79	Measured	36.64	146.56
Humidity	72%	Difference	%	0.88
Air Content	2.30%			
Slump	5.0"			
Unit Weight Pot Empty	7.76	Unit Weight:	159.3	lb/ft.^3
Unit Weight Pot Full	44.4			

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg.	Strain
3 hr	4150	4210	4130	**10.2517**	**10.250**	**10.2401**	0.13	4163.333	0.00000	0.00000	0.00000	0	0
6 hr	5095	5260	4845	**10.251**	**10.2490**	**10.2394**	0.25	5066.667	-0.00070	-0.00100	-0.00070	-0.0008	-80
24 hr	5675	5670	6215	**10.2508**	**10.2488**	**10.2391**	1	5853.333	-0.00090	-0.00120	-0.00100	-0.00103	-103.333
3 day	6810	7110	6890	**10.2507**	**10.2488**	**10.2390**	3	6936.667	-0.00100	-0.00120	-0.00110	-0.0011	-110
7 day	7555	7210	7640	**10.2505**	**10.2485**	**10.2386**	7	7468.333	-0.00120	-0.00150	-0.00150	-0.0014	-140
14 day	8410	8150	8025	**10.2503**	**10.2485**	**10.2386**	14	8195	-0.00140	-0.00150	-0.00150	-0.00147	-146.667
28 day	9025	8080	8120	10.2504	10.2484	10.239		8408.333	-0.00130	-0.00160	-0.00160	-0.0015	-150
1 yr	6460	5332	6727	10.2492	10.2477	10.238		6173	-0.00250	-0.00230	-0.00260	-0.00247	-246.667

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to vastly improve cylinder consolidation

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set,0.47 0.5% citric batch

7/8/2016

w/cm =	0.47		Sand % water =	2.643	start	7:40 AM	
PC =	0	type III	Rock % water =	0.467	batch	7:45 AM	
RS =	564				stop	8:00 AM	
Komp =	0						
FA =	0						

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.53	Mc =	2.643
Pan + wet Sand	5.19		
Pan + dry Sand	5.07		
Aggregates :			
Pan	0.39	Mc =	0.467
Pan + wet Agg	2.54		
Pan + dry Agg	2.53		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	265.1	4.25
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1390.7	8.47
Sum	3992.35	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1780.8	197.87	lb
Fine Aggregate, Dover Sand		1427.5	158.61	lb
Water		244.3	27.15	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.31	lb
Glenium (MRWR)	oz	0.0	25.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0.5 % Citric added to prolong set time; 25mL Glenium added for workability

Concrete Temperature	56	Expected Unit Wt		147.86	
Air Temperature	77	Measured	36.79	147.16	
Humidity	89%	Difference	%	0.48	
Air Content	1.70%				
Slump	3.75				
Unit Weight Pot Empty	7.76	Unit Weight:	159.96	lb/ft.^3	
Unit Weight Pot Full	44.55				

Note: 3 hr too soft

Note: prism 3 too long and has loose studs

Time	Compressive Strength (psi)			Shrink (in/in)			time	f'c	1	2	3	avg	strain
	#1	#2	#3	#1	#2	#3							
3 hr	0	0	0	0	0	0.0000							
6 hr	2100	2310	2405	10.2295	10.2492	10.4547			0	0.0000	0.0000	0	0
24 hr	6165	6075	5850	10.229	10.2487	10.4542			-0.0005	-0.0005	-0.0005	-0.0005	-50
3 day	7410	7215	7655	10.2287	10.2483	10.4538			-0.0008	-0.0009	-0.0009	-0.00087	-86.6667
7 day	7355	7910	7470	10.2283	10.2478	10.4537			-0.0012	-0.0014	-0.0010	-0.0012	-120
14 day	8040	7965	8315	10.2282	10.2477	10.4534			-0.0013	-0.0015	-0.0013	-0.00137	-136.667
28 day	8770	8460	8290	10.2281	10.2475	10.4532			-0.0014	-0.0017	-0.0015	-0.00153	-153.333
1 yr	6735	6445	6650	10.2276	10.2469	10.453			-0.0019	-0.0023	-0.0017	-0.00197	-196.667

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.45 0.75% citric batch

2/3/2017

w/cm =	0.47		Sand % water =	1.685	start	9:45 AM
PC =	0	type III	Rock % water =	0.235	batch	9:55 AM
RS =	564				stop	10:00 AM
Komp =	0					
FA =	0					

Moisture Content

Sand :	Wt (lb)		
Pan	0.39	Mc =	1.685
Pan + wet Sand	4.01		
Pan + dry Sand	3.95		
Aggregates :			
Pan	0.58	Mc =	0.235
Pan + wet Agg	4.85		
Pan + dry Agg	4.84		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0
H2O SG=	1.0				
C SG=	3.15				
RS SG=	2.88				
Komp SG	2.88				
FA SG=	2.58				

Fineness Modulus = 2.5

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	265.1	4.25
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1390.7	8.47
Sum	3992.35	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1776.7	197.41	lb
Fine Aggregate, Dover Sand		1414.2	157.13	lb
Water		262.3	29.14	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.47	lb
Glenium (MRWR)	oz	0.0	30.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0.75 % Citric added to prolong set time; 30mL Glenium added for workability

Concrete Temperature	74
Air Temperature	34
Humidity	44%
Air Content	7.50%
Slump	7.75"
Unit Weight Pot Empty	7.76
Unit Weight Pot Full	42.12

Expected Unit Wt		147.86
Measured	34.36	137.44
Difference	%	7.05

Unit Weight: 149.39 lb/ft.^3

Note: 3 hr too soft

Note: prism 3 too long and has loose studs

Time	Compressive Strength (psi)			Shrink (in/in)			time	f'c	1	2	3	avg	strain
	#1	#2	#3	#1	#2	#3							
3 hr	0	0	0	0	0	0							
6 hr	0	0	0	0	0	0			0	0.0000	0.0000	0	0
24 hr	4095	4355	4060	10.2211	10.2350	10.1981			0	0.0000	0.0000	0	0
3 day	5105	5015	5130	10.2210	10.2342	10.1977			-1E-04	-0.0008	-0.0004	-0.00043	-43.3333
7 day	5015	5190	4525	10.2210	10.2340	10.1976			-1E-04	-0.0010	-0.0005	-0.00053	-53.3333
14 day	4820	5005	4740	10.2209	10.2348	10.1975			-0.0002	-0.0002	-0.0006	-0.00033	-33.3333
28 day	4775	4715	4870	10.2205	10.2332	10.1968			-0.0006	-0.0018	-0.0013	-0.00123	-123.333
1 yr	0	0	0	0	0	0							

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, 0.47 1.0% citric batch

7/8/2016

w/cm =	0.47		Sand % water =	2.643	start	8:35 AM
PC =	0	type III	Rock % water =	0.467	batch	8:43 AM
RS =	564				stop	9:08 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.53	Mc =	2.643
Pan + wet Sand	5.19		
Pan + dry Sand	5.07		
Aggregates :			
Pan	0.39	Mc =	0.467
Pan + wet Agg	2.54		
Pan + dry Agg	2.53		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	265.1	4.25
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1390.7	8.47
Sum	3992.35	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1780.8	197.87	lb
Fine Aggregate, Dover Sand		1427.5	158.61	lb
Water		244.3	27.15	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.63	lb
Glenium (MRWR)	oz	0.0	28.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 1.0 % Citric added to prolong set time; 28mL Glenium added for workability

Concrete Temperature	57	Expected Unit Wt		147.86
Air Temperature	77	Measured	36.9	147.60
Humidity	89%	Difference	%	0.18
Air Content	1.70%			
Slump	6.75"			
Unit Weight Pot Empty	7.76	Unit Weight:	160.43	lb/ft.^3
Unit Weight Pot Full	44.66			

Note: 3 hr too soft

Note: no 157 readings, execute at 24 hrs

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg	strain
3 hr	0	0	0	0	0	0	0.125	0					
6 hr	0	0	0	0	0	0	0.25	0					
24 hr	5735	5970	5985	10.2540	10.2220	10.2363	1	5896.667	0	0	0	0	0
3 day	7720	7755	8290	10.2534	10.2212	10.2346	3	7921.667	-0.0006	-0.0008	-0.0017	-0.00103	-103.333
7 day	7830	8130	7805	10.2531	10.2211	10.234	7	7921.667	-0.0009	-0.0009	-0.0024	-0.0014	-140
14 day	9080	8575	8355	10.2531	10.2208	10.234	14	8670	-0.0009	-0.0012	-0.0026	-0.00157	-156.667
28 day	8690	8770	8880	10.253	10.2205	10.233	28	8780	-0.001	-0.0015	-0.003	-0.00183	-183.333
1 yr	7750	6970	6720	10.2521	10.2196	10.233	365	7146.667	-0.0019	-0.0024	-0.0034	-0.00257	-256.667

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, control batch

7/26/2016

w/cm =	0.5		Sand % water =	2.319	start	6:58 AM
PC =	0	type III	Rock % water =	0.277	batch	7:10 AM
RS =	564				stop	7:34 AM
Komp =	0					
FA =	0					

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Moisture Content

Sand :	Wt (lb)		
Pan	0.58	Mc =	2.319
Pan + wet Sand	4.11		
Pan + dry Sand	4.03		
Aggregates :			
Pan	0.49	Mc =	0.277
Pan + wet Agg	4.11		
Pan + dry Agg	4.1		

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	282.0	4.52
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1346.2	8.20
Sum	3964.77	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1777.5	197.50	lb
Fine Aggregate, Dover Sand		1377.4	153.05	lb
Water		270.1	30.01	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.00	lb
Glenium (MRWR)	oz	0.0	50.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0 % Citric added to prolong set time;50mL Glenium added for workability

Concrete Temperature	54	Expected Unit Wt		146.84
Air Temperature	72	Measured	36.66	146.64
Humidity	100	Difference	%	0.14
Air Content	1.9			
Slump	.75"			
Unit Weight Pot Empty	7.76	Unit Weight:	159.39	lb/ft.^3
Unit Weight Pot Full	44.42			

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg.	strain
3 hr	3985	4180	4085	10.241	10.223	10.2275	0.125	4083.333	0.0000	0.0000	0.0000	0	0
6 hr	5080	4235	4835	10.2403	10.2225	10.2270	0.25	4716.667	-0.0007	-0.0005	-0.0005	-0.00057	-56.6667
24 hr	5440	5695	5230	10.2398	10.2224	10.2268	1	5455	-0.0012	-0.0006	-0.0007	-0.00083	-83.3333
3 day	5815	6190	5970	10.2394	10.2220	10.2266	3	5991.667	-0.0016	-0.0010	-0.0009	-0.00117	-116.667
7 day	6400	7100	6725	10.2397	10.2221	10.227	7	6741.667	-0.0013	-0.0009	-0.0007	-0.00097	-96.6667
14 day	7300	7190	6655	10.2396	10.2221	10.227	14	7048.333	-0.0014	-0.0009	-0.0008	-0.00103	-103.333
28 day	7345	7215	7265	10.2395	10.2221	10.227	28	7275	-0.0015	-0.0009	-0.0007	-0.00103	-103.333
1 yr	5622	5335	5341	10.2388	10.221	10.226	365	5432.667	-0.0022	-0.0020	-0.0017	-0.00197	-196.667

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, 0.50 0.1% citric batch

7/26/2016

w/cm =	0.5		Sand % water =	2.319	start	7:57 AM
PC =	0	type III	Rock % water =	0.277	batch	8:05 AM
RS =	564				stop	8:28 AM
Komp =	0					
FA =	0					

Moisture Content

Sand :	Wt (lb)		
Pan	0.58	Mc =	2.319
Pan + wet Sand	4.11		
Pan + dry Sand	4.03		
Aggregates :			
Pan	0.49	Mc =	0.277
Pan + wet Agg	4.11		
Pan + dry Agg	4.1		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	282.0	4.52
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1346.2	8.20
Sum	3964.77	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1777.5	197.50	lb
Fine Aggregate, Dover Sand		1377.4	153.05	lb
Water		270.1	30.01	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.06	lb
Glenium (MRWR)	oz	0.0	45.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0.1 % Citric added to prolong set time; 45mL Glenium added for workability

Concrete Temperature	52	Expected Unit Wt		146.84	
Air Temperature	73	Measured	36.62	146.48	
Humidity	100%	Difference	%	0.25	
Air Content	1.60%				
Slump	2.875"				
Unit Weight Pot Empty	7.76	Unit Weight:	159.22	lb/ft.^3	
Unit Weight Pot Full	44.38				

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg.	Strain
3 hr	3400	3125	3720	**10.2471**	**10.2156**	**10.2639**	0.13	3415	0.00000	0.00000	0.00000	0	0
6 hr	4720	4270	4860	**10.2467**	**10.2151**	**10.2634**	0.25	4616.667	-0.00040	-0.00050	-0.00050	-0.00047	-46.6667
24 hr	5805	5640	5760	**10.2463**	**10.2147**	**10.2630**	1	5735	-0.00080	-0.00090	-0.00090	-0.00087	-86.6667
3 day	6590	6540	6660	**10.246**	**10.2146**	**10.2628**	3	6596.667	-0.00110	-0.00100	-0.00110	-0.00107	-106.667
7 day	7150	6790	6935	**10.2462**	**10.2147**	**10.2630**	7	6958.333	-0.00090	-0.00090	-0.00090	-0.0009	-90
14 day	7785	7725	7560	**10.2459**	**10.215**	**10.2628**	14	7690	-0.00120	-0.00050	-0.00110	-0.00093	-93.3333
28 day	8245	8095	8145	10.2460	10.2152	10.263	28	8161.667	-0.00110	-0.00040	-0.00100	-0.00083	-83.3333
1 yr	6332	5452	5716	10.2451	10.2141	10.262	365	5833.333	-0.00200	-0.00150	-0.00210	-0.00187	-186.667

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to vastly improve cylinder consolidation

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.50 0.5% citric batch

7/27/2016

w/cm =	0.5		Sand % water =	4.202	start	7:07 AM
PC =	0	type III	Rock % water =	1.600	batch	7:15 AM
RS =	564				stop	7:42 AM
Komp =	0					
FA =	0					

Moisture Content

Sand :	Wt (lb)		
Pan	0.49	Mc =	4.202
Pan + wet Sand	2.97		
Pan + dry Sand	2.87		
Aggregates :			
Pan	0.58	Mc =	1.600
Pan + wet Agg	3.12		
Pan + dry Agg	3.08		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	282.0	4.52
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1346.2	8.20
Sum	3964.77	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1800.9	200.10	lb
Fine Aggregate, Dover Sand		1402.8	155.87	lb
Water		219.6	24.39	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.31	lb
Glenium (MRWR)	oz	0.0	25.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0.5 % Citric added to prolong set time; 25mL Glenium added for workability

Concrete Temperature	56
Air Temperature	73
Humidity	100
Air Content	1.5
Slump	6.5"
Unit Weight Pot Empty	7.76
Unit Weight Pot Full	44.37

Expected Unit Wt		146.84
Measured	36.61	146.44
Difference	%	0.27
Unit Weight:	159.17	lb/ft.^3

Note: 3 hr too soft

Time	Compressive Strength (psi)			Shrink (in/in)			time	f'c	1	2	3	avg	strain
	#1	#2	#3	#1	#2	#3							
3 hr	0	0	0	0	0	0.0000	0.125	0					
6 hr	170	95	175	0	0	0.0000	0.25	146.6667				0	0
24 hr	5260	5500	5845	10.2270	10.2647	10.2357	1	5535	0.0000	0.0000	0.0000	0	0
3 day	7225	7390	6850	10.2264	10.264	10.2347	3	7155	-0.0006	-0.0007	-0.0010	-0.00077	-76.6667
7 day	7455	7365	6980	10.226	10.2632	10.2346	7	7266.667	-0.0010	-0.0015	-0.0011	-0.0012	-120
14 day	7140	7715	7615	10.2257	10.2628	10.2342	14	7490	-0.0013	-0.0019	-0.0015	-0.00157	-156.667
28 day	8240	7965	8080	10.2255	10.2625	10.2340	28	8095	-0.0015	-0.0022	-0.0017	-0.0018	-180
1 yr	6292	6412	5942	10.2239	10.2615	10.233	365	6215.333	-0.0031	-0.0032	-0.0023	-0.00287	-286.667

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.50 0.75% citric batch

5/25/2017

w/cm =	0.5		Sand % water =	2.906	start	7:45 AM
PC =	0	type III	Rock % water =	0.536	batch	8:00 AM
RS =	564				stop	8:21 AM
Komp =	0					
FA =	0					

Moisture Content

Sand :	Wt (lb)		
Pan	0.5	Mc =	2.906
Pan + wet Sand	4.75		
Pan + dry Sand	4.63		
Aggregates :			
Pan	0.53	Mc =	0.536
Pan + wet Agg	4.28		
Pan + dry Agg	4.26		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	282.0	4.52
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1346.2	8.20
Sum	3964.77	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1782.1	198.01	lb
Fine Aggregate, Dover Sand		1385.3	153.93	lb
Water		257.2	28.58	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.47	lb
Glenium (MRWR)	oz	0.0	45.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 0.75 % Citric added to prolong set time; 45mL Glenium added for workability

Concrete Temperature	72	Expected Unit Wt		146.84
Air Temperature	0	Measured	34.54	138.16
Humidity	0	Difference	%	5.91
Air Content	1.8			
Slump	7"			
Unit Weight Pot Empty	7.76	Unit Weight:	150.17	lb/ft.^3
Unit Weight Pot Full	42.3			

Note: 3 hr too soft

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg	strain
3 hr	0	0	0	0	0	0	0.125	0					
6 hr	0	0	0	0	0	0	0.25	0				0	0
24 hr	5560	5765	5560	10.2714	10.2489	10.2919	1	5628.333	0.0000	0.0000	0.0000	0	0
3 day	6090	5410	7095	10.271	10.2481	10.2895	3	6198.333	-0.0004	-0.0008	-0.0024	-0.0012	-120
7 day	6815	5900	7370	10.2707	10.2468	10.2891	7	6695	-0.0007	-0.0021	-0.0028	-0.00187	-186.667
14 day	6910	7120	6895	10.2704	10.2452	10.2874	14	6975	-0.0010	-0.0037	-0.0045	-0.00307	-306.667
28 day	6795	6385	6700	10.2695	10.2441	10.2866	28	6626.667	-0.0019	-0.0048	-0.0053	-0.004	-400
1 yr	0	0	0	0	0	0							

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, 0.50 1.0% citric batch

7/27/2016

w/cm =	0.5		Sand % water =	4.202	start	7:59 AM
PC =	0	type III	Rock % water =	1.600	batch	8:00 AM
RS =	564				stop	8:27 AM
Komp =	0					
FA =	0					

Moisture Content

Sand :	Wt (lb)		
Pan	0.49	Mc =	4.202
Pan + wet Sand	2.97		
Pan + dry Sand	2.87		
Aggregates :			
Pan	0.58	Mc =	1.600
Pan + wet Agg	3.12		
Pan + dry Agg	3.08		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	282.0	4.52
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1346.2	8.20
Sum	3964.77	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1800.9	200.10	lb
Fine Aggregate, Dover Sand		1402.8	155.87	lb
Water		219.6	24.39	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.63	lb
Glenium (MRWR)	oz	0.0	25.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 1.0 % Citric added to prolong set time; 25mL Glenium added for workability

Concrete Temperature	58
Air Temperature	75
Humidity	89
Air Content	1.1
Slump	7.5"
Unit Weight Pot Empty	7.76
Unit Weight Pot Full	44.26

Expected Unit Wt		146.84
Measured	36.5	146.00
Difference	%	0.57

Unit Weight: 158.7 lb/ft.^3

Note: 3 hr too soft

Note: no 157 readings, execute at 24 hrs

Time	Compressive Strength (psi)			Shrink (in/in)			time	f'c	1	2	3	avg	strain
	#1	#2	#3	#1	#2	#3							
3 hr	0	0	0	0	0	0	0.125	0					
6 hr	0	0	0	0	0	0	0.25	0					
24 hr	5885	5985	6245	10.2233	10.2156	10.2155	1	6038.333	0	0	0.0000	0	0
3 day	7600	7470	7465	10.2230	10.2151	10.2148	3	7511.667	-0.0003	-0.0005	-0.0007	-0.0005	-50
7 day	8020	8035	7715	10.2225	10.2149	10.2146	7	7923.333	-0.0008	-0.0007	-0.0009	-0.0008	-80
14 day	8170	8100	8085	10.2225	10.2151	10.2142	14	8118.333	-0.0008	-0.0005	-0.0013	-0.00087	-86.6667
28 day	7430	7770	7420	10.2222	10.2146	10.2136		7540	-0.0011	-0.001	-0.0019	-0.00133	-133.333
1 yr	5943	6289	6270	10.2216	10.214	10.213		6167.333	-0.0017	-0.0016	-0.0025	-0.00193	-193.333

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Appendix II: Batch Sheets for DELVO®

Rapid Set, 0.45 Delvo 2 oz

6/16/2017

w/cm =	0.45		Sand % water =	2.510	start	8:55 AM
PC =	0	type III	Rock % water =	0.267	batch	9:00 AM
RS =	564				stop	9:20 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.49	Mc =	2.510
Pan + wet Sand	2.94		
Pan + dry Sand	2.88		
Aggregates :			
Pan	0.52	Mc =	0.267
Pan + wet Agg	4.27		
Pan + dry Agg	4.26		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1777.3	197.48	lb
Fine Aggregate, Dover Sand		1456.0	161.78	lb
Water		238.0	26.44	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	oz	0.02	1.25	oz
Glenium (MRWR)	oz	0.0	45.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 45mL Glenium added for workability

Concrete Temperature	77	Expected Unit Wt		148.55	
Air Temperature	0	Measured	36.88	147.52	
Humidity	0	Difference	%	0.69	
Air Content	NA				
Slump	1.25"				
Unit Weight Pot Empty	7.76	Unit Weight:	160.35	lb/ft.^3	
Unit Weight Pot Full	44.64				

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg	strain
3 hr	4545	4480	4425	10.2357	10.3108	10.2611	0.125	4483.333	0.00000	0.00000	0.0000	0.00000	0
6 hr	4600	5720	5380	10.2356	10.3109	10.2610	0.25	5233.333	-1E-04	0.00010	-0.0001	-0.00003	-3.33333
24 hr	6235	6095	5715	10.2355	10.3108	10.2609	1	6015	-0.0002	0.00000	-0.0002	-0.00013	-13.3333
3 day	5965	6485	6525	10.2354	10.3103	10.2603	3	6325	-0.0003	-0.00050	-0.0008	-0.00053	-53.3333
7 day	6744	6992	6624	10.2347	10.3104	10.2604	7	6786.667	-0.001	-0.00040	-0.0007	-0.00070	-70
14 day	6745	7936	7958	10.2343	10.3096	10.2598	14	7546.333	-0.0014	-0.00120	-0.0013	-0.00130	-130
28 day	8125	7796	7848	10.2349	10.3104	10.2606	28	7923	-0.0008	-0.00040	-0.0005	-0.00057	-56.6667
1 yr													

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.45 Delvo 6oz

6/16/2017

w/cm =	0.45		Sand % water =	2.510	start	9:30 AM	
PC =	0	type III	Rock % water =	0.267	batch	9:58 AM	
RS =	564				stop	10:15 AM	
Komp =	0						
FA =	0						

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.49	Mc =	2.510
Pan + wet Sand	2.94		
Pan + dry Sand	2.88		
Aggregates :			
Pan	0.52	Mc =	0.267
Pan + wet Agg	4.27		
Pan + dry Agg	4.26		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1777.3	197.48	lb
Fine Aggregate, Dover Sand		1456.0	161.78	lb
Water		238.0	26.44	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	oz	0.1	3.76	oz
Glenium (MRWR)	oz	0.0	80.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 80mL Glenium added for workability

Concrete Temperature	80	Expected Unit Wt		148.55	
Air Temperature	0	Measured	36.74	146.96	
Humidity	0	Difference	%	1.07	
Air Content	NA				
Slump	2.5"				
Unit Weight Pot Empty	7.76	Unit Weight:	159.74	lb/ft.^3	
Unit Weight Pot Full	44.5				

Time	Compressive Strength (psi)			Shrink (in/in)			time	f'c	1	2	3	avg.	strain
	#1	#2	#3	#1	#2	#3							
3 hr	3775	4705	4470	**10.3213**	**10.2949**	**10.2700**	0.125	4316.667	0.00000	0.00000	0.0000	0.00000	0
6 hr	5510	5055	5430	**10.3206**	**10.294**	**10.2695**	0.25	5331.667	-0.00070	-0.00090	-0.0005	-0.00070	-70
24 hr	5725	5810	5410	**10.3205**	**10.2933**	**10.2692**	1	5648.333	-0.00080	-0.00160	-0.0008	-0.00107	-106.667
3 day	6770	6840	6845	**10.3199**	**10.2932**	**10.2686**	3	6818.333	-0.00140	-0.00170	-0.0014	-0.00150	-150
7 day	6817	7307	7047	**10.3198**	**10.2931**	**10.2686**	7	7057	-0.00150	-0.00180	-0.0014	-0.00157	-156.667
14 day	na	na	na	**10.3196**	**10.293**	**10.2686**	14	na	-0.00170	-0.00190	-0.0014	-0.00167	-166.667
28 day	8193	8065	8095	**10.3197**	**10.2932**	**10.2691**	28	8117.667	-0.00160	-0.00170	-0.0009	-0.00140	-140
1 yr													

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, 0.45 Delvo 12 oz

6/22/2017

w/cm =	0.45		Sand % water =	0.868	start	6:59 AM
PC =	0	type III	Rock % water =	0.379	batch	7:02 AM
RS =	564				stop	7:21 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.51	Mc =	0.868
Pan + wet Sand	5.16		
Pan + dry Sand	5.12		
Aggregates :			
Pan	0.53	Mc =	0.379
Pan + wet Agg	3.18		
Pan + dry Agg	3.17		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1779.3	197.70	lb
Fine Aggregate, Dover Sand		1432.7	159.19	lb
Water		260.0	28.88	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	oz	0.1	222.40	ml
Glenium (MRWR)	oz	0.0	75.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 75mL Glenium added for workability

Concrete Temperature	75	Expected Unit Wt		148.55
Air Temperature	0	Measured	36.67	146.68
Humidity	0	Difference	%	1.26
Air Content	2.30%			
Slump	2"			
Unit Weight Pot Empty	7.76	Unit Weight:	159.43	lb/ft.^3
Unit Weight Pot Full	44.43			

Time	Compressive Strength (psi) #1	#2	#3	Shrink (in/in) #1	#2	#3	time	f'c	1	2	3	avg.	strain
3 hr	5700	5629	5125	10.3099	**10.3204**	**10.3015**	0.125	5484.667	0.00000	0.00000	0.00000	0.00000	0
6 hr	6129	5607	5503	10.3097	**10.3199**	**10.3015**	0.25	5746.333	-0.00020	-0.00050	0.00000	-0.00023	-23.3333
24 hr	6362	6355	6638	10.3091	**10.3192**	**10.3011**	1	6451.667	-0.00080	-0.00120	-0.00040	-0.00080	-80
3 day	6134	6862	7155	10.309	**10.3191**	**10.3010**	3	6717	-0.00090	-0.00130	-0.00050	-0.00090	-90
7 day	8730	8006	7960	10.3088	**10.3192**	**10.3006**	7	8232	-0.00110	-0.00120	-0.00090	-0.00107	-106.667
14 day	8585	8107	8351	10.3089	**10.3193**	**10.3010**	14	8347.667	-0.00100	-0.00110	-0.00050	-0.00087	-86.6667
28 day	8411	8457	8735	10.3088	**10.319**	**10.3009**	28	8534.333	-0.00110	-0.00140	-0.00060	-0.00103	-103.333
1 yr													

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, 0.47 Delvo 2 oz

6/22/2017

w/cm =	0.47		Sand % water =	0.868	start	7:32 AM
PC =	0	type III	Rock % water =	0.379	batch	7:40 AM
RS =	564				stop	7:50 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.51	Mc =	0.868
Pan + wet Sand	5.16		
Pan + dry Sand	5.12		
Aggregates :			
Pan	0.53	Mc =	0.379
Pan + wet Agg	3.18		
Pan + dry Agg	3.17		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

	Theoretical Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	265.1	4.25
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1390.7	8.47
Sum	3992.35	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1779.3	197.70	lb
Fine Aggregate, Dover Sand		1402.8	155.87	lb
Water		271.3	30.14	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	oz	0.02	37.07	ml
Glenium (MRWR)	oz	0.0	75.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note:

Concrete Temperature	78	Expected Unit Wt		147.86	
Air Temperature	0	Measured	36.57	146.28	
Humidity	0	Difference	%	1.07	
Air Content	2.10%				
Slump	1.5"				
Unit Weight Pot Empty	7.76	Unit Weight:	159	lb/ft.^3	
Unit Weight Pot Full	44.33				

Time	Compressive Strength (psi)			Shrink (in/in)			time	f'c	1	2	3	avg.	Strain
	#1	#2	#3	#1	#2	#3							
3 hr	4990	4452	4424	10.2982	10.3166	10.308	0.13	4622	0.00000	0.00000	0.00000	0	0
6 hr	5205	4904	5049	10.2981	10.3165	10.308	0.25	5052.667	-0.00010	-0.00010	0.00000	-6.7E-05	-6.66667
24 hr	5516	6298	6024	10.2977	10.316	10.308	1	5946	-0.00050	-0.00060	-0.00060	-0.00057	-56.6667
3 day	6332	6468	7102	10.2974	10.3157	10.307	3	6634	-0.00080	-0.00090	-0.00070	-0.0008	-80
7 day	7611	7874	7037	10.2972	10.3154	10.307	7	7507.333	-0.00100	-0.00120	-0.00090	-0.00103	-103.333
14 day	7388	8971	8473	10.2977	10.3157	10.308	14	8277.333	-0.00050	-0.00090	-0.00050	-0.00063	-63.3333
28 day	8458	8118	9072	10.2976	10.3156	10.308		8549.333	-0.00060	-0.00100	-0.00040	-0.00067	-66.6667
1 yr													

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to vastly improve cylinder consolidation

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.47 Delvo 6 oz

6/30/2017

w/cm =	0.47		Sand % water =	1.423	start	7:30 AM
PC =	0	type III	Rock % water =	0.000	batch	7:35 AM
RS =	564				stop	7:45 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.49	Mc =	1.423
Pan + wet Sand	3.34		
Pan + dry Sand	3.3		
Aggregates :			
Pan	0.52	Mc =	0.000
Pan + wet Agg	3.83		
Pan + dry Agg	3.83		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	265.1	4.25
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1390.7	8.47
Sum	3992.35	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1772.6	196.95	lb
Fine Aggregate, Dover Sand		1410.5	156.72	lb
Water		270.1	30.01	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	ml	0.060	111.10	ml
Glenium (MRWR)	oz	0.0	75.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note:

Concrete Temperature	72
Air Temperature	0
Humidity	0
Air Content	2.4
Slump	3.5"
Unit Weight Pot Empty	7.76
Unit Weight Pot Full	44.37

Expected Unit Wt		147.86
Measured	36.61	146.44
Difference	%	0.96

Unit Weight: 159.17 lb/ft.^3

Note: water cure induced expansion due to steve batch

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	**time**	**f'c**	**1**	**2**	**3**	**avg**	**strain**
3 hr	5063	5015	5254	10.3164	10.3195	10.2898	0	0	0.0000	0.0000	0.0000	0	0
6 hr	5684	5789	5898	10.3158	10.3188	10.2895	0.125	5110.667	-0.0006	-0.0007	-0.0003	-0.00053	-53.3333
24 hr	6340	6665	6595	10.3154	10.3189	10.2896	0.25	5790.333	-0.0010	-0.0006	-0.0002	-0.0006	-60
3 day	7000	5690	6970	10.3152	10.3187	10.2895	1	6533.333	-0.0012	-0.0008	-0.0003	-0.00077	-76.6667
7 day	7552	7517	7819	10.3153	10.3187	10.2895	3	6553.333	-0.0011	-0.0008	-0.0003	-0.00073	-73.3333
14 day	8223	7549	8087	10.3155	10.319	10.2906	7	7629.333	-0.0009	-0.0005	0.0008	-0.0002	-20
28 day	8450	8366	7877	10.3149	10.3182	10.2890	14	7953	-0.0015	-0.0013	-0.0008	-0.0012	-120
1 yr							28	8231					

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, 0.47 Delvo 12 oz

7/5/2017

w/cm =	0.47		Sand % water =	1.423	start	6:42 AM	
PC =	0	type III	Rock % water =	0.000	batch	6:44 AM	
RS =	564				stop	7:10 AM	
Komp =	0						
FA =	0						

Moisture Content

Sand :	Wt (lb)		
Pan	0.49	Mc =	1.423
Pan + wet Sand	3.34		
Pan + dry Sand	3.3		
Aggregates :			
Pan	0.52	Mc =	0.000
Pan + wet Agg	3.83		
Pan + dry Agg	3.83		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	265.1	4.25
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1390.7	8.47
Sum	3992.35	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1772.6	196.95	lb
Fine Aggregate, Dover Sand		1410.5	156.72	lb
Water		270.1	30.01	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	ml	0.12	222.40	ml
Glenium (MRWR)	oz	0.0	80.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note:

Concrete Temperature	73	Expected Unit Wt		147.86	
Air Temperature		Measured	35.78	143.12	
Humidity		Difference	%	3.21	
Air Content	3.70%				
Slump	7"				
Unit Weight Pot Empty	7.76	Unit Weight:	155.57	lb/ft.^3	
Unit Weight Pot Full	43.54				

Note: 7/10, steve batch water cure starts, samples will expand under humididty

Time	Compressive Strength (psi)			Shrink (in/in)			time	f'c	1	2	3	avg	strain
	#1	#2	#3	#1	#2	#3							
3 hr	4290	4530	4150	10.2428	10.3284	10.3056	0.125	4323.333	0	0	0	0	0
6 hr	5104	5037	4995	10.2424	10.3279	10.3052	0.25	5045.333	-0.0004	-0.0005	-0.0004	-0.00043	-43.3333
24 hr	6074	6076	5968	10.2422	10.3278	10.3050	1	6039.333	-0.0006	-0.0006	-0.0006	-0.0006	-60
5 day	7329	7750	7382	10.2419	10.3271	10.3045	5	7487	-0.0009	-0.0013	-0.0011	-0.0011	-110
7 day	7296	7502	7527	10.242	10.3273	10.3048	7	7441.667	-0.0008	-0.0011	-0.0008	-0.0009	-90
14 day	8407	8305	7725	10.2423	10.3272	10.3047	14	8145.667	-0.0005	-0.0012	-0.0009	-0.00087	-86.6667
28 day	8152	8423	7850	10.242	10.3268	10.3043		8141.667	-0.0008	-0.0016	-0.0013	-0.00123	-123.333
1 yr													

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set 0.50 Delvo 2 oz

7/12/2017

w/cm =	0.5		Sand % water =	1.954	start	7:32 AM
PC =	0	type III	Rock % water =	0.292	batch	7:40 AM
RS =	564				stop	7:50 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.39	Mc =	1.954
Pan + wet Sand	3.52		
Pan + dry Sand	3.46		
Aggregates :			
Pan	0.51	Mc =	0.292
Pan + wet Agg	3.94		
Pan + dry Agg	3.93		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

	Theoretical	Weight	Volume
Portland Cement		0.0	0.00
Rapid Set Cement		564	3.14
Komponent		0	0.00
Fly Ash		0	0.00
Water		282.0	4.52
Rock		1772.6	10.60
Air Entrapped 2%		0.0	0.54
DCI-chemical part		0.0	0.00
Sand		1346.2	8.20
	Sum	3964.77	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1777.7	197.53	lb
Fine Aggregate, Dover Sand		1372.5	152.50	lb
Water		274.9	30.54	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	ml	0.02	37.07	ml
Glenium (MRWR)	oz	0.0	80.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 80mL Glenium added for workability

Concrete Temperature	75	Expected Unit Wt		146.84
Air Temperature	0	Measured	36.33	145.32
Humidity	0	Difference	%	1.04
Air Content	2.3			
Slump	5.75			
Unit Weight Pot Empty	7.76	Unit Weight:	157.96	lb/ft.^3
Unit Weight Pot Full	44.09			

Time	Compressive Strength (psi)			Shrink (in/in)		
	#1	#2	#3	#1	#2	#3
3 hr	3765	3819	3591	10.2845	10.3147	10.318
6 hr	4277	4649	4247	10.2839	10.3142	10.317
24 hr	5612	5406	5300	10.2838	10.3141	10.317
3 day	5629	5989	6569	10.2834	10.3139	10.316
7 day	7124	5631	6906	10.2833	10.3138	10.316
14 day	6863	6862	6735	10.2831	10.3135	10.315
28 day	7784	7086	6998	10.2827	10.3132	10.315
1 yr						

time	f'c	1	2	3	avg.	Strain
0.13	3725	0.00000	0.00000	0.00000	0	0
0.25	4391	-0.00060	-0.00050	-0.00050	-0.00053	-53.3333
1	5439.333	-0.00070	-0.00060	-0.00050	-0.0006	-60
3	6062.333	-0.00110	-0.00080	-0.00200	-0.0013	-130
7	6553.667	-0.00120	-0.00090	-0.00200	-0.00137	-136.667
14	6820	-0.00140	-0.00120	-0.00250	-0.0017	-170
	7289.333	-0.00180	-0.00150	-0.00280	-0.00203	-203.333

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to vastly improve cylinder consolidation
Glenium Increased for better workability
Increased water content yields better paste

Rapid Set, 0.50 Delvo 6 oz

7/13/2017

w/cm =	0.5		Sand % water =	1.954	start	7:07 AM
PC =	0	type III	Rock % water =	0.292	batch	7:30 AM
RS =	564				stop	7:45 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.39	Mc =	1.954
Pan + wet Sand	3.52		
Pan + dry Sand	3.46		
Aggregates :			
Pan	0.51	Mc =	0.292
Pan + wet Agg	3.94		
Pan + dry Agg	3.93		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	282.0	4.52
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1346.2	8.20
Sum	3964.77	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1777.7	197.53	lb
Fine Aggregate, Dover Sand		1372.5	152.50	lb
Water		274.9	30.54	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	ml	0.1	111.20	lb
Glenium (MRWR)	oz	0.0	80.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note:

Concrete Temperature	78	Expected Unit Wt		146.84
Air Temperature	0	Measured	36.39	145.56
Humidity		Difference	%	0.87
Air Content	2.5			
Slump	6.5"			
Unit Weight Pot Empty	7.76	Unit Weight:	158.22	lb/ft.^3
Unit Weight Pot Full	44.15			

Note: 3 hr too soft

Note: prism 3 too long and has loose studs

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg	strain
3 hr	4439	4774	4633	10.2936	10.3299	10.325	0.125	4615.333	0	0	0	0	0
6 hr	5223	5214	5364	10.293	10.3295	10.324	0.25	5267	-0.0006	-0.0004	-0.0006	-0.00053	-53.3333
24 hr	5376	6213	5344	10.2928	10.3292	10.323	1	5644.333	-0.0008	-0.0007	-0.0011	-0.00087	-86.6667
3 day	6048	6827	7023	10.2927	10.3292	10.324	3	6632.667	-0.0009	-0.0007	-0.0008	-0.0008	-80
7 day	6681	7087	6761	10.2926	10.329	10.324	7	6843	-0.001	-0.0009	-0.0009	-0.00093	-93.3333
14 day	7164	6676	7243	10.2922	10.3286	10.323	14	7027.667	-0.0014	-0.0013	-0.0014	-0.00137	-136.667
28 day	7533	7204	7030	10.2919	10.3284	10.323	28	7255.667	-0.0017	-0.0015	-0.0018	-0.00167	-166.667
1 yr	0	0	0	0	0	0							

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.50 Delvo 12 oz

7/14/2017

w/cm =	0.5		Sand % water =	0.617	start	7:15 AM
PC =	0	type III	Rock % water =	0.000	batch	7:34 AM
RS =	564				stop	7:49 AM
Komp =	0					
FA =	0					

Moisture Content

Sand :	Wt (lb)		
Pan	0.49	Mc =	0.617
Pan + wet Sand	2.12		
Pan + dry Sand	2.11		
Aggregates :			
Pan	0.39	Mc =	0.000
Pan + wet Agg	2.99		
Pan + dry Agg	2.99		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

	Theoretical	Weight	Volume
Portland Cement		0.0	0.00
Rapid Set Cement		564	3.14
Komponent		0	0.00
Fly Ash		0	0.00
Water		282.0	4.52
Rock		1772.6	10.60
Air Entrapped 2%		0.0	0.54
DCI-chemical part		0.0	0.00
Sand		1346.2	8.20
	Sum	3964.77	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1772.6	196.95	lb
Fine Aggregate, Dover Sand		1354.5	150.50	lb
Water		298.4	33.15	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	ml	0.1	222.40	lb
Glenium (MRWR)	oz	0.0	80.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note:

Concrete Temperature	0
Air Temperature	0
Humidity	0
Air Content	0
Slump	0
Unit Weight Pot Empty	0
Unit Weight Pot Full	0

Expected Unit Wt		146.84
Measured	0	0.00
Difference	%	100.00

Unit Weight: 0 lb/ft.^3

Time	Compressive Strength (psi)			Shrink (in/in)			time	f'c	1	2	3	avg	strain
	#1	#2	#3	#1	#2	#3							
3 hr	3581	3797	3967	10.3350	10.3056	10.3091	0.125	3781.667	0.0000	0	0.0000	0	0
6 hr	4601	4768	4497	10.3347	10.3052	10.309	0.25	4622	-0.0003	-0.0004	-0.0006	-0.00043	-43.3333
24 hr	5381	4752	5239	10.3343	10.3048	10.308	1	5124	-0.0007	-0.0008	-0.0010	-0.00083	-83.3333
3 day	5565	5708	5832	10.3343	10.3047	10.308	3	5701.667	-0.0007	-0.0009	-0.0010	-0.00087	-86.6667
7 day	6428	6294	6129	10.334	10.3046	10.308	7	6283.667	-0.0010	-0.001	-0.0010	-0.001	-100
14 day	6426	6783	6694	10.3339	10.3044	10.308	14	6634.333	-0.0011	-0.0012	-0.0014	-0.00123	-123.333
28 day	7147	7101	6423	10.3334	10.3037	10.307		6890.333	-0.0016	-0.0019	-0.0018	-0.00177	-176.667
1 yr	0	0	0	0	0	0							

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Appendix III: Batch Sheets for RECOVER®

Rapid Set, 0.45 recover 4 oz

8/9/2016

w/cm =	0.45		Sand % water =	2.419	start	7:00 AM
PC =	0	type III	Rock % water =	0.325	batch	7:18 AM
RS =	564				stop	7:46 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.49	Mc =	2.419
Pan + wet Sand	4.3		
Pan + dry Sand	4.21		
Aggregates :			
Pan	0.58	Mc =	0.325
Pan + wet Agg	3.67		
Pan + dry Agg	3.66		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1778.3	197.59	lb
Fine Aggregate, Dover Sand		1454.8	161.64	lb
Water		238.3	26.48	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Recover Retarder	oz	0.0	2.51	oz
Glenium (MRWR)	oz	0.0	45.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note: 45mL Glenium added for workability

Concrete Temperature	59	Expected Unit Wt		148.55
Air Temperature	0	Measured	36.58	146.32
Humidity	2.3	Difference	%	1.50
Air Content	0			
Slump	2"			
Unit Weight Pot Empty	7.76	Unit Weight:	159.04	lb/ft.^3
Unit Weight Pot Full	44.34			

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg	strain
3 hr	4365	4420	4700	10.2733	10.2223	10.2594	0.125	4495	0.00000	0.00000	0.0000	0.00000	0
6 hr	4970	5055	4855	10.2730	10.2220	10.2591	0.25	4960	-0.0003	-0.00030	-0.0003	-0.00030	-30
24 hr	6110	5825	6257	10.2726	10.2217	10.2589	1	6064	-0.0007	-0.00060	-0.0005	-0.00060	-60
3 day	6855	6980	6940	10.2725	10.2216	10.2587	3	6925	-0.0008	-0.00070	-0.0007	-0.00073	-73.3333
7 day	7300	7595	8195	10.2724	10.2215	10.2586	7	7696.667	-0.0009	-0.00080	-0.0008	-0.00083	-83.3333
14 day	7965	8235	0	10.2724	10.2215	10.2589	14	8100	-0.0009	-0.00080	-0.0005	-0.00073	-73.3333
28 day	8355	8070	8060	10.2722	10.2213	10.259	28	8161.667	-0.0011	-0.00100	-0.0007	-0.00093	-93.3333
1 yr													

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.45 recover 20 oz

8/9/2016

w/cm =	0.45		Sand % water =	2.419	start	8:00 AM
PC =	0	type III	Rock % water =	0.325	batch	8:20 AM
RS =	564				stop	8:40 AM
Komp =	0					
FA =	0					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.49	Mc =	2.419
Pan + wet Sand	4.3		
Pan + dry Sand	4.21		
Aggregates :			
Pan	0.58	Mc =	0.325
Pan + wet Agg	3.67		
Pan + dry Agg	3.66		

Sand SG=	2.63	SSD:	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD:	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

	Theoretical	Weight	Volume
Portland Cement		0.0	0.00
Rapid Set Cement		564	3.14
Komponent		0	0.00
Fly Ash		0	0.00
Water		253.8	4.07
Rock		1772.6	10.60
Air Entrapped 2%		0.0	0.54
DCI-chemical part		0.0	0.00
Sand		1420.4	8.65
	Sum	4010.74	27

		1 yd	3	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	62.67	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1778.3	197.59	lb
Fine Aggregate, Dover Sand		1454.8	161.64	lb
Water		238.3	26.48	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Recover Retarder	oz	0.0	12.53	oz
Glenium (MRWR)	oz	0.0	60.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Note:60mL Glenium added for workability

Concrete Temperature	58	Expected Unit Wt		148.55	
Air Temperature	77	Measured	36.7	146.80	
Humidity	83	Difference	%	1.18	
Air Content	2.3				
Slump	3"				
Unit Weight Pot Empty	7.76	Unit Weight:	159.57	lb/ft.^3	
Unit Weight Pot Full	44.46				

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg	strain
3 hr	4370	4485	4355	10.232	10.2391	10.2309	0.125	4403.333	0.00000	0.00000	0.0000	0.00000	0
6 hr	5065	5460	5360	10.2316	10.2390	10.2306	0.25	5295	-0.0004	-0.00010	-0.0003	-0.00027	-26.6667
24 hr	6370	5815	5955	10.2316	10.2386	10.2304	1	6046.667	-0.0004	-0.00050	-0.0005	-0.00047	-46.6667
3 day	7105	6720	7080	10.2313	10.2385	10.2303	3	6968.333	-0.0007	-0.00060	-0.0006	-0.00063	-63.3333
7 day	7700	7820	7715	10.2311	10.2382	10.2300	7	7745	-0.0009	-0.00090	-0.0009	-0.00090	-90
14 day	7940	7435	7575	10.2306	10.2381	10.2298	14	7650	-0.0014	-0.00100	-0.0011	-0.00117	-116.667
28 day	7990	7595	7740	10.2304	10.2377	10.229	28	7775	-0.0016	-0.00140	-0.0015	-0.00150	-150
1 yr													

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great

Glenium Increased for better workability

Increased water content yields better paste

Rapid Set, 0.45 recover 40 oz

8/9/2016

w/cm =	0.45		Sand % water =	2.419	start	9:55 AM	
PC =	0	type III	Rock % water =	0.325	batch	10:00 AM	
RS =	564				stop	10:20 AM	
Komp =	0						
FA =	0						

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.49	Mc =	2.419
Pan + wet Sand	4.3		
Pan + dry Sand	4.21		
Aggregates :			
Pan	0.58	Mc =	0.325
Pan + wet Agg	3.67		
Pan + dry Agg	3.66		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

	Theoretical	Weight	Volume
Portland Cement		0.0	0.00
Rapid Set Cement		564	3.14
Komponent		0	0.00
Fly Ash		0	0.00
Water		253.8	4.07
Rock		1772.6	10.60
Air Entrapped 2%		0.0	0.54
DCI-chemical part		0.0	0.00
Sand		1420.4	8.65
	Sum	4010.74	27

		1 yd	3	cu ft	
Portland Cement		0.0	0.00	lb	
Rapid Set Cement		564.0	62.67	lb	
Komponent		0.0	0.00	lb	
Fly Ash		0.0	0.00	lb	
Coarse Aggregate, #67		1778.3	197.59	lb	
Fine Aggregate, Dover Sand		1454.8	161.64	lb	
Water		238.3	26.48	lb	
Air Ent. Admixture	oz	0.0	0.00	ml	
Recover Retarder	oz	0.0	25.07	oz	Note: 50mL Glenium added for workability
Glenium (MRWR)	oz	0.0	50.00	ml	
DCI (Accel w/ water)	oz	0.0	0.00	ml	

Concrete Temperature	59	Expected Unit Wt		148.55	
Air Temperature	77	Measured	36.49	145.96	
Humidity	83	Difference	%	1.74	
Air Content	2.10%				
Slump	1"				
Unit Weight Pot Empty	7.76	Unit Weight:	158.65	lb/ft.^3	
Unit Weight Pot Full	44.25				

Time	Compressive Strength (psi)			Shrink (in/in)									
	#1	#2	#3	#1	#2	#3	time	f'c	1	2	3	avg	strain
3 hr	4005	4225	4245	10.2403	10.2081	10.2350	0.125	4158.333	0.00000	0.00000	0.0000	0.00000	0
6 hr	5055	5205	5185	10.2392	10.2077	10.2346	0.25	5148.333	-0.0011	-0.00040	-0.0004	-0.00063	-63.3333
24 hr	6225	6135	6195	10.2391	10.2073	10.2343	1	6185	-0.0012	-0.00080	-0.0007	-0.00090	-90
3 day	6900	6635	6660	10.2389	10.2072	10.2341	3	6731.667	-0.0014	-0.00090	-0.0009	-0.00107	-106.667
7 day	7030	7310	6900	10.2388	10.2072	10.2341	7	7080	-0.0015	-0.00090	-0.0009	-0.00110	-110
14 day	7105	6865	7445	10.2386	10.2072	10.2338	14	7138.333	-0.0017	-0.00090	-0.0012	-0.00127	-126.667
28 day	7425	7695	7545	10.2381	10.2064	10.232	28	7555	-0.0022	-0.00170	-0.0028	-0.00223	-223.333
1 yr													

Curing: Environmental Chamber

Curing notes and mix comments: An external vibrating table was used to improve cylinder consolidation though consolidation was not great
Glenium Increased for better workability
Increased water content yields better paste

Appendix IV: Batch Sheets for Set Time Testing

Rapid Set, control batch

2/9/2018

w/cm =	0.45		Sand % water =	1.977	start			
PC =	0	type III	Rock % water =	0.000	batch			
RS =	564				stop			
Komp =	0							
FA =	0							
Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5		
Rock SG=	2.68	SSD=	0.86	DRUW =	101.0			
H2O SG=	1.0							
C SG=	3.15							
RS SG=	2.88							
Komp SG	2.88							
FA SG=	2.58							

Moisture Content

Sand :	Wt (lb)		
Pan	0.49	Mc =	1.977
Pan + wet Sand	4.1		
Pan + dry Sand	4.03		
Aggregates :			
Pan	0.58	Mc =	0.000
Pan + wet Agg	3.81		
Pan + dry Agg	3.81		

	Theoretical	Weight	Volume
Portland Cement		0.0	0.00
Rapid Set Cement		564	3.14
Komponent		0	0.00
Fly Ash		0	0.00
Water		253.8	4.07
Rock		1772.6	10.60
Air Entrapped 2%		0.0	0.54
DCI-chemical part		0.0	0.00
Sand		1420.4	8.65
	Sum	4010.74	27

		1 yd	1	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	20.89	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1772.6	65.65	lb
Fine Aggregate, Dover Sand		1448.5	53.65	lb
Water		250.5	9.28	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.00	lb
Glenium (MRWR)	oz	0.0	30.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Rapid Set, 0.45 recover 4 oz

2/13/2018

w/cm =	0.45		Sand % water =	1.977	start		
PC =	0	type III	Rock % water =	0.000	batch		
RS =	564				stop		
Komp =	0						
FA =	0						

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Moisture Content

Sand :	Wt (lb)		
Pan	0.49	Mc =	1.977
Pan + wet Sand	4.1		
Pan + dry Sand	4.03		
Aggregates :			
Pan	0.58	Mc =	0.000
Pan + wet Agg	3.81		
Pan + dry Agg	3.81		

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	1	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	20.89	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1772.6	65.65	lb
Fine Aggregate, Dover Sand		1448.5	53.65	lb
Water		250.5	9.28	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Recover Retarder	oz	0.0	24.71	ml
Glenium (MRWR)	oz	0.0	30.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Rapid Set, 0.45 Delvo 2 oz

2/15/2018

w/cm =	0.45		Sand % water =	1.796	start		
PC =	0	type III	Rock % water =	0.000	batch		
RS =	564				stop		
Komp =	0						
FA =	0						

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Moisture Content

	Wt (lb)		
Sand :			
Pan	0.49	Mc =	1.796
Pan + wet Sand	3.89		
Pan + dry Sand	3.83		
Aggregates :			
Pan	0.57	Mc =	0.000
Pan + wet Agg	3.91		
Pan + dry Agg	3.91		

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	1	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	20.89	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1772.6	65.65	lb
Fine Aggregate, Dover Sand		1445.9	53.55	lb
Water		253.2	9.38	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Delvo	oz	0.02	12.35	ml
Glenium (MRWR)	oz	0.0	30.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml

Rapid Set, 0.45 0.1% citric batch

2/15/2018

w/cm =	0.45		Sand % water =	1.796	start
PC =	0	type III	Rock % water =	0.000	batch
RS =	564				stop
Komp =	0				
FA =	0				

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.68	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3.15					
RS SG=	2.88					
Komp SG	2.88					
FA SG=	2.58					

Moisture Content

Sand :	Wt (lb)		
Pan	0.49	Mc =	1.796
Pan + wet Sand	3.89		
Pan + dry Sand	3.83		
Aggregates :			
Pan	0.57	Mc =	0.000
Pan + wet Agg	3.91		
Pan + dry Agg	3.91		

Theoretical	Weight	Volume
Portland Cement	0.0	0.00
Rapid Set Cement	564	3.14
Komponent	0	0.00
Fly Ash	0	0.00
Water	253.8	4.07
Rock	1772.6	10.60
Air Entrapped 2%	0.0	0.54
DCI-chemical part	0.0	0.00
Sand	1420.4	8.65
Sum	4010.74	27

		1 yd	1	cu ft
Portland Cement		0.0	0.00	lb
Rapid Set Cement		564.0	20.89	lb
Komponent		0.0	0.00	lb
Fly Ash		0.0	0.00	lb
Coarse Aggregate, #67		1772.6	65.65	lb
Fine Aggregate, Dover Sand		1445.9	53.55	lb
Water		253.2	9.38	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Citric Acid Retarder	lb	0.0	0.02	lb
Glenium (MRWR)	oz	0.0	30.00	ml
DCI (Accel w/ water)	oz	0.0	0.00	ml