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THE EFFECTS OF TEMPERATURE ON COMPRESSIVE STRENGTH OF RAPID SETTING CONCRETE

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THE EFFECTS OF TEMPERATURE ON THE COMPRESSIVE STRENGTH
OF RAPID SETTING CONCRETE

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[redacted]

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Abstract

Rapid setting concrete using Calcium Sulfoaluminate (CSA) cement has been around since the 1960's to meet the need for construction projects with limited time frames. These projects range from quick foundation work to rapid highway repair. However, little research has been done on CSA cement; specifically, there have been few studies on the effects of temperature on the compressive strength and workability of this type of cement.

This study examines the mixing and curing temperature aspects of CSA rapid setting concrete. By controlling the batching and curing temperature independently, we can see what effect each has on both the early and late age strength properties. A study of past research on the subject will provide a starting point for the investigation. A set of laboratory experiments conducted under controlled conditions will provide data for analysis and conclusions.

The four main objectives of this study are: develop a catalog of variables and characteristics relevant to rapid setting concrete; create mix designs based around the above variables and form samples for testing; measure the compressive strength, slump, air content and other characteristics of each mix; compile and compare the results obtained and present the best possible combination for overall strength and workability. This research will provide insight into the effects of temperature on the properties of CSA rapid setting cements.

1.0 Introduction

1.1 Summary of Problem

Rapid setting concrete has been around since the early 1900's, and has been used in projects where there is a narrow time frame and setting time is limited. Rapid setting concrete has been a source of study since its inception due to its chemistry and complex physical properties. Originally designed for a variety of applications such as highway pavements, bridges, runways, tunnels, precast, sidewalks, and floors, the cement also has the added benefit of being able to be prepared in conventional mixer equipment.

The trademarked product Rapid Set©, a calcium sulfoaluminate cement, was developed by CTS Cement Manufacturing Corporation and has been providing quick solutions to time-sensitive projects since the 1960's. Successful projects include the Chicago Midway Airport pavement and the San Diego Qualcomm Stadium renovation. This cement will serve as the testing product in this study.

Normal Portland cement concrete workability and strength change at the extremes of the concrete placement temperature spectrum. On the one hand, having a colder temperature when mixing helps increase workability and ease of placement; however, early strength gains are diminished if the temperature is too low during the curing process. On the other hand, if there is a high temperature when mixing, the concrete gains early strength more easily at the cost of ease of placement and workability time. Add to this the complexity of additional variables such as the use of rapid setting cement and admixtures, and one can see the importance of having ideal conditions when pouring concrete.

1.2 Objective of Research

The objective of this research is to determine how temperature during the mixing and curing phases influences the compressive strength of CSA cement. By determining what effect temperature has on this cement, users of Rapid Set© and other CSA cements will have a better understanding of the possible overall strength and workability in various curing conditions. In addition, this research will provide a reference for ideal temperature conditions for this type of cement.

1.3 Scope of Research

The testing program implemented in this study is designed to investigate all aspects of temperature's effects on CSA cement. The primary variables for testing are mixing temperature, curing temperature, strength of the mix design, and the use of admixtures (Glenium 7500 and citric acid). From these variables, mix designs can be developed to investigate each of these parameters. Test samples can then be created and subjected to various mixing and curing conditions, and the properties of each recorded. From the compressive strength results, the data can be analyzed to find any trends that occur with respect to the mixing and curing temperatures.

To gain a complete look at the effects of temperature on the final product, the following tests will be performed: slump cone test, air content test, unit weight measurement, and set temperature.

2.0 Background

A review of past research and field practices allows us to understand the behavior of both fast setting and traditional Portland concretes. It will provide a basic understanding of the state of rapid setting CSA cements. This section will examine what role temperature plays in the field and how it is managed based on the ambient conditions. A review of ordinary Portland cement will provide a comparison to rapid setting cement. Finally, a look at both early and recent studies on rapid setting cements will be discussed.

2.1 Controlling Temperature in the Field

In general, it is known that too high of a temperature can have an adverse effects on Portland concrete's performance. Increased rate of hydration, thermal stresses, higher incidence of shrinkage and cracking, and decreased long term strength are a few effects of curing at higher temperatures. A compilation and study of data from the Texas Rigid Pavement database has shown that there are an increased number of rigid pavement failures as the air temperature increases (Schindler et al. 2002).

Curing at a range of 140°F to 158°F has been shown to cause a serious loss of durability (Taylor, 1997). This can be partly due to microcracking, but also from an effect known as delayed ettringite formation. Ettringite are crystals that form in the early stages of cement's hydration, and provide strength to the concrete. If the heat during the curing process is too high, either applied externally or due to the heat of hydration of the cement, the formation of the ettringite crystals is delayed until the concrete is set, then crystals form, expand, and can cause cracking in the concrete. Because of this, it is common practice in the field to limit the temperature at which placed concrete is cured, either by pouring in a cooler season or limiting exposure to heat.

If an increased rate of hardening is needed, heat may be applied using saturated steam at atmospheric pressure, known as "steam curing." Manufacturers of precast members commonly take advantage of the steam curing process to expedite the curing phase of the structural members. The steam provides a source of heat to speed up the hydration of the cement without drying out the concrete. Other methods can also be used to achieve this elevated-temperature curing.

On the other hand, if curing in hot weather conditions, it may be necessary to cool the concrete to prevent the loss of durability discussed above. The main problems of concreting in hot weather are loss of moisture and workability time. Higher temperatures means there are increased water requirements to maintain slump, decreased setting time, and increased risk of plastic shrinkage, as well as lower ultimate strength (Mindess et al. 1981). Mindess suggests an optimal temperature range of 50 to 60°F or lower for large mass concrete to prevent thermal cracking. The temperature can be regulated by controlling the temperature of the aggregates, and the overall concrete temperature can be estimated using the following equation:

$$T_{\text{concrete}} = \frac{H(T_aW_a + T_cW_c) + T_aW_{wa} + T_wW_w}{H(W_a + W_c) + W_{wa} + W_w}$$

This equation from Mindess takes into account the temperature (T), specific heat (H), and weight fraction (W) for the cement (c), aggregate (a), aggregate moisture (wa), and water (w). The equation shows how the heat of the water plays a large role in the overall temperature of the concrete, given its high specific heat and small weight fraction. Using ice is another viable option for mixing concrete in hot weather, as the heat of the concrete is absorbed in the melting ice. The above equation can modified to include ice and is written as follows:

$$T_{\text{concrete}} = \frac{H(T_aW_a + T_cW_c) + T_aW_{wa} + T_wW_w - F_iW_i}{H(W_a + W_c) + W_{wa} + W_w + W_i}$$

In this equation, W_i is the weight of ice and F_i is the latent heat of fusion. The cement temperature is not of much concern; its specific heat and weight fraction are not substantial enough to affect the overall temperature in a noticeable way. Cooling or heating cement powder is impractical and rarely if ever performed in the field. Other steps can be taken to lower the temperature of the mix such as storing materials in the shade or covering the aggregates with white reflective sheeting.

The opposite is true when curing in cold weather conditions. If the ambient temperature during curing is low, alternative steps should be taken to prevent the freezing of the concrete. Heating of the aggregates is possible, as well as adding heated water to the mix. Fresh placed concrete should be allowed to harden and dry before being exposed to freezing conditions to ensure damage to the concrete does not occur. The table below gives recommended concrete temperatures for cold-weather curing to prevent deleterious effects due to freezing temperatures:

Table 1 - Recommended Concrete Temperatures (°F) for Cold-Weather Curing (Mindess et al. 1981)

Condition of Placement and Curing	Size of Section		
	Thin	Moderate	Mass
Minimum Temp of Fresh Concrete, as Mixed			
Above 32°F Ambient	60.8	55.4	50
- 40 to 32°F Ambient	64.4	60.8	55.4
Below -40°F Ambient	69.8	64.4	60.8
Minimum Temp, as Placed	55.4	50	44.6
Max Allowable Drop in Temp	82.4	71.6	62.6

Since high-late strength is important for longevity of concrete, curing at warmer temperatures could call for the addition of admixtures to offset the long term strength reduction. This may also be necessary on large, thick slabs where the internal temperature can reach relatively high readings when compared to the outer layers. One study showed that additives such as fly ash can be added to the concrete mix, resulting in various strength results (Kobayashi, 1979). Other additives can be used as well to aid in the strength gain at various temperatures.

The amount of time available for concrete placement is very important in the field because it generally dictates how well the concrete is placed and finished. In general, the maximum mixing time is dependent on the temperature. Higher temperatures result in increased slump loss, rapid setting, and decreased workability, but lower temperatures allow more time for concrete to be placed. For example, at a mixing temperature of 70°F it is reasonable to assume 1 hour for mixing and placing for ordinary Portland cement. With every rise/drop of 5°F there is a decrease/increase of fifteen minutes of workable time with a Portland cement based concrete (Nilson et al. 2004). So at 90°F there is essentially no time for the placement of concrete.

On average, seventy percent of concrete's strength will be gained in the first week after placing; however around thirty percent of the strength can be lost due to premature drying or allowing the concrete temperature to drop past 40°F in the initial few days (Nilson et al. 2004). An average of seven days of curing is needed for regular Portland concrete during which temperature and moisture content should be monitored. In cold weather, it is common practice to heat the water, and occasionally the aggregates to protect the concrete from strength loss. Insulation, add-mixtures, and in some cases, external heat, can be applied in some applications.

In some construction scenarios, delaying the setting time of the concrete is necessary. Retarders are occasionally used, delaying the hydration of the cement, and allowing for greater workability and increased working time. Citric Acid is a common agent used to achieve this retarding effect. A study was performed to examine the effects of citric acid on the hydration of Portland cement. The research found that 0.1% wt/cement accelerates the hydration, while amounts greater than 0.1% wt/cement retards the hydration (Singh et al. 1986). Used in the proper amount, citric acid can delay the set up time of the concrete and allow more time for placement and finishing. The study showed no adverse effects on the ultimate strength of the concrete with the use of citric acid. Citric acid is also a retarder for CSA cements though there is very little information concerning its behavior.

2.2 Temperature and Portland Cement

Although traditional rapid setting concrete has been used since the early 1900's, few studies have been performed on the effects of temperature on the strength properties. There are fewer, if any, studies discussing temperature and calcium sulphoaluminate (CSA) rapid setting cement. In order to provide a starting point for the research, it is necessary to study past research done on ordinary Portland cement. From the studies' results, we can compare and contrast the results of using Portland versus CSA cement.

Several studies have been done on regular Portland cement's relationship with temperature. Some have found that curing at different temperatures resulted in different compressive strengths. One study showed how concrete mixed with Portland cement that was wet-cured at 86°F (30 °C) shows higher strength at early ages, but lower strength at later ages compared to the same concrete wet cured at 68°F (2°C) (Neville, A.M., 1990). A similar study looked at long term strength of regular Portland cement mixes, and found that Portland concrete wet-cured under isothermal conditions at a temperature of 68°F had a higher strength beyond 28 days than the samples that were cured at 104 to 160°F (Al-Kaisi, 1989).

In a similar study of temperature effects, Eren (2002) performed a complete study of the influence of temperature on 100% ordinary Portland cement, and obtained the results listed in Table 2:

Table 2 – Portland Cement Compressive Strength at Five Curing Temperatures (Eren, 2002)

Cube Compressive Strength						
Concrete Type	Age (days)	Compressive Strength (psi)				
		Curing Temperature (°F)				
		43	68	95	140	176
100% OPC	1	333	3156	3989	4510	5482
	3	2603	5359	5163	5272	5670
	7	4880	6882	5946	5823	6272
	28	7288	9104	7070	6475	7367
	90	8803	10101	7665	7476	8078

This research subjected each sample to wet curing conditions at the designated temperatures. Reviewing the results in the table, it can be seen that the work by Eren confirms the research discussed previously. In particular, increasing temperature increases early age strength. Also, during the 28 day and 90 day late age periods, there is an ideal temperature of 68°F (20°C) for higher strength gains around at 28 days and 90 days. The plotted results can be seen below in Figure 1:

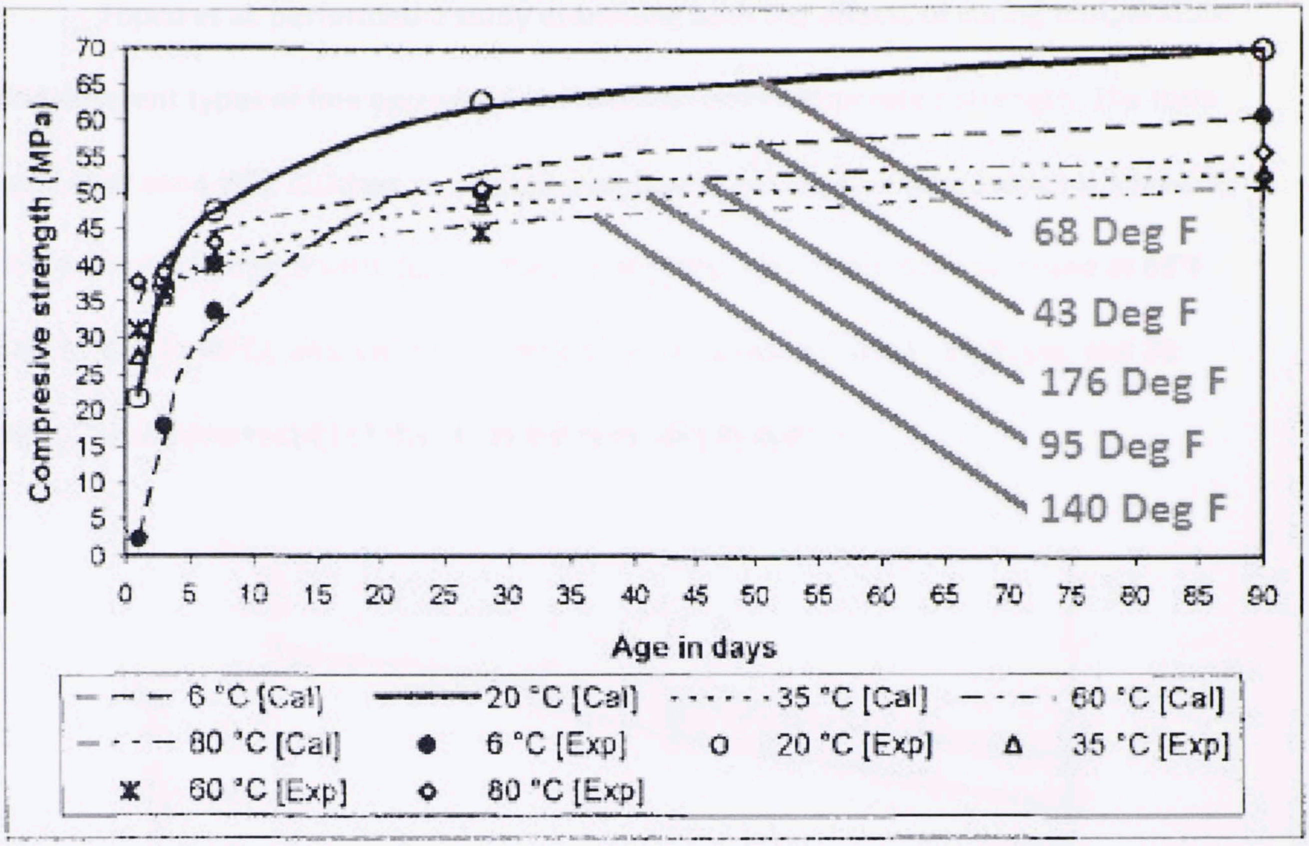

Figure 1 - Portland Strength at Various Curing Temperatures (Eren 2002)

The graph shows the various curing conditions for the samples and the strength gain of each. The 68°F mix performed the best out of the group, followed by the lowest curing temperature of 43°F and the highest curing temperature of 176°F. One advantage to this study is that it tested a wide range of curing temperatures. It is important to consider a spectrum of reasonable temperatures the concrete may be subjected to in order to get a more complete view of temperatures effects. One limitation of the results is there are relatively few data points, forcing the author to interpolate the data lines between the points. Second, the mixing temperature is not considered in this study, which may affect the overall strength of the concrete.

Topcu et al. performed a study examining both the effects of curing temperature and different types of fine aggregate on Portland cement concrete's strength. The tests used river sand (RS), crushed stone (CS), and Type III Portland cement, which is a type of finely ground Portland with quick setting properties. Specimens were air-cured at 68°F (20°C), 104°F (40°C), and 140°F(°C). Samples were taken at 6 hours, 18 hours, and 28 days. The plotted results of the study can be found in Figure 2.

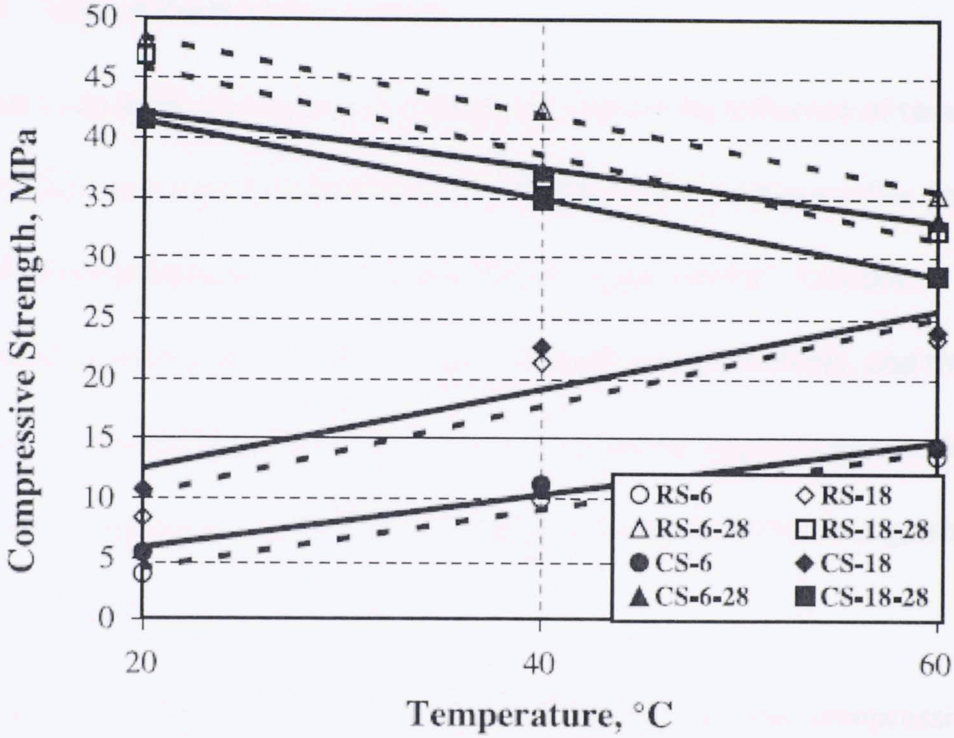

Figure 2 - Temperature vs Compressive Strength (Topcu et al. 2005)

The results for the high early strength Portland Type III cement mimic what was found for regular Portland cement in that increasing the curing temperature increases early strength. This can be seen by the upward trend or positive slope of the lowest linear fit lines. In addition, the study shows increasing temperature decrease the 28 day strength of the concrete. This can be seen by the downward trend, or negative slope of the upper linear fit lines. As for the two fine aggregates, the results are more clear with the specimens that used the crushed stone (CS) as a fine aggregate. The authors believe this to be due to the stronger bonding characteristics between the cement and the crushed stone are stronger than with the river sand (RS). The limitation to this study is it only takes into account three curing temperatures, and does not have many data points for each of the samples.

2.3 Types of Rapid Setting Cements

There has been extensive research carried out on the influence of temperature on typical concrete using Portland cement; However, there are few studies done on cements that are considered “rapid hardening” or “rapid setting”. Calcium sulfoaluminate cements fall into the category of rapid setting cements, and there is little to no research done discussing temperature’s effect on this type of cement. Before covering the studies done on this type of cement, it is important to distinguish the differences between the types of cement.

Cement considered “rapid setting” is one that acquires high compressive strength in a short amount of time. In general, several thousand psi within three hours of hydration. The first difference between Type I Portland cement and calcium sulfoaluminate cement is that CSA cement is ground down into finer particles that ordinary cement. This smaller particle size means more surface area, which in turn means more contact with water molecules and thus faster hydration and strength gain.

The second difference between Portland cement and CSA cement is the chemical composition. Table 3 shows the chemical makeups of different Portland cements and Rapid Set©, a type of CSA cement.

Table 3 - Chemical Composition of Portland and CSA Cements

ASTM TYPE	C_3S	C_2S	C_3A	C_4AF	$C\underline{S}$
I	59	15	12	8	2.9
II	46	29	6-8	12	2.8
III	60	12	12-15	8	3.9
IV	30	46	5-7	13	2.9
V	43	36	4-5	12	2.7
	$C_4A_3\underline{S}$	C_2S	C_3A	C_4AF	$C\underline{S}$
Rapid Set©	30	45	0	2	15

Note that Rapid Set©, as with other CSA cements, does not have C3A while Portland has 4-15%. CSA also has a higher CS and much lower C4AF. And finally CSA has C4A3S and no C3S.

The hydration process is different between the two types of cement. Ordinary Portland cement initially gains strength with the hydration of C_3S in the early stages, followed by the hydration of C_2S at later ages. The rapid setting cement gains strength when the calcium sulfoaluminate, C_4A_3S, reacts with gypsum, CS, to form ettringite (Bescher et al.). As discussed earlier, ettringite are crystals that form from hydration and provide structure and strength to the concrete.

Rapid Set© is a CSA cement used for testing in this research. Rapid Set© is a trademark product of CTS Cement Manufacturing Corporation developed in 1960. This hydraulic cement is very versatile and is known for its high strength, low shrinkage, and impressive durability. The uses for Rapid Set© include highway and runway repairs, bridge repairs, structures, rapid setting grout, and many other uses where high early strength is needed. The product can reach strengths of 2800 psi in one hour.

Various types of cement such as magnesium phosphate cement, jet cement, or geopolymeric cement were used for their quick-setting abilities, but were very costly (Srinivasan, 2003). These types of cement were also prone to unusual behavior problems such as extreme stickiness, segregation, or flash setting which causes sub-optimal conditions for mixing (Ramseyer, 1999). Rapid Set© cement will be used for this research because of its stable properties and reliability.

2.4 Early Studies with Rapid Setting Cements

As with any research, it is important to look at older research to build upon past knowledge. Davey (1931) performed an early testing of rapid setting cements in his article entitled "Temperature of Maturing of Concrete with Rapid-Hardening Cement." Although the study is dated, it provides reliable information on the topic of interest. In the early uses of rapid hardening cement, it was often a mystery why test specimens would vary in strength despite consistent materials, water content, time of mixing, and method of placement. It was determined that the only factor that could contribute to these changes is the curing temperature.

In order to check this theory, Davey developed a testing regimen that would test the compressive strength of nine inch by three inch cylindrical concrete samples. The test looked at a concrete mix that utilized rapid setting cement with the chemical composition shown in Figure 3. The testing began with the creation of a uniform mix design for each of the samples. After the mix design was created, test specimens were prepared on three different days. Each sample was made in thin metal tins with slip-on lids. The curing conditions were controlled by placing the molded specimens into water tanks that are heated or cooled to the appropriate test temperature. The molds were sealed with tape to ensure that no water came into contact with the samples as to adversely affect the results. In order to maintain the correct temperature during the compression test process, the author constructed a water jacket rig with the adjusted temperature as seen in Figure 4.

(d) Chemical Analysis.

SiO_2	20·25
Al_2O_3	6·13
Fe_2O_3	2·59
TiO_2	0·38
CaO	64·50
MgO	0·36
Na_2O	0·35
K_2O	0·74
SO_3	2·20
Loss on Ignition	2·57
	100·07

Figure 3 - Chemical Composition of Cement Used by Davey, 1931

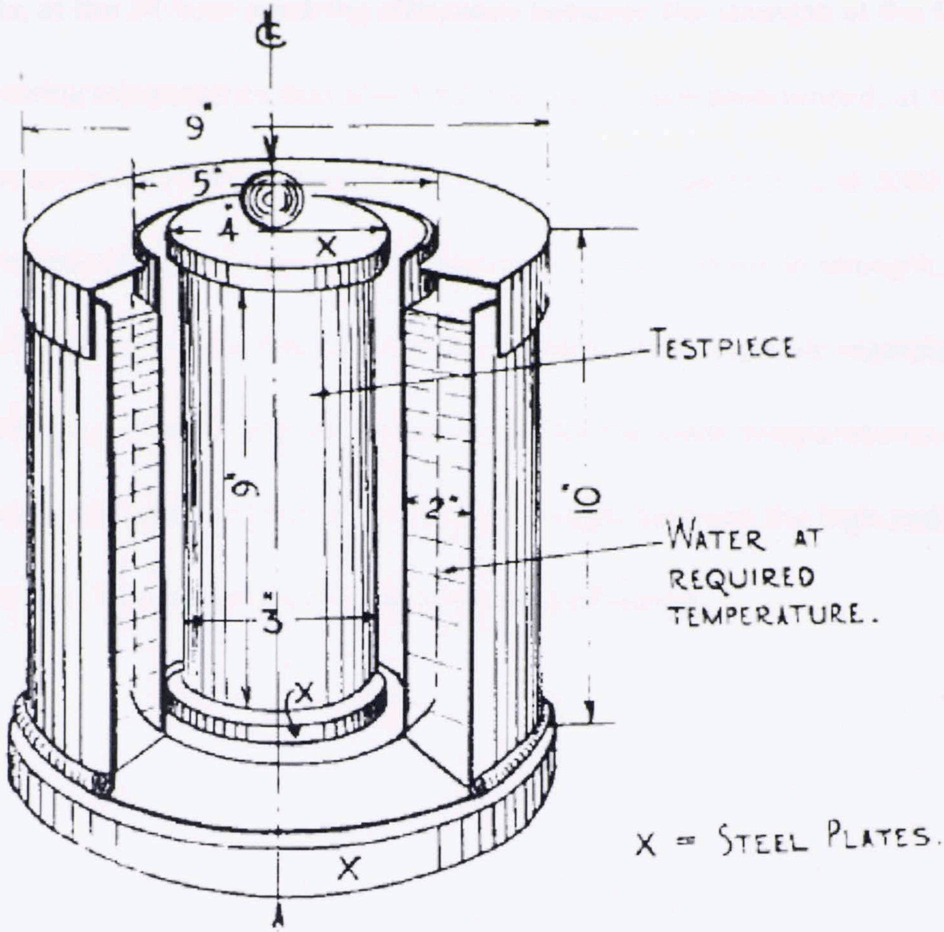

Figure 4 - Water Jacket Used to Maintain Temperature during Testing

After curing for an appropriate length of time, the specimens were removed, de-molded, and tested to find the compressive strength. The table of the summarized compression test results can be found in Table 4. The ambient temperature during mixing was recorded for each of the days, and remained fairly constant. The third day's temperature was 6.3°F lower than the first two days, which, in Davey's opinion, may account for the slightly lower strengths of the specimens.

To get a better understanding of the test results, the average strength was plotted against time at the various temperatures and can be found in Figure 5. Looking at the results, at the 24 hour mark the difference between the strength at the highest and lowest curing temperature was about 900 psi. Even more pronounced, at the three day mark the same difference in temperature yielded a change of around 2000 psi. The more mature specimens at the seven day mark were more uniform in strength, however, and there was little difference in the strength of each sample regardless of curing temperature. Overall, the study concluded that the lower temperatures did not attain high-early strength, and the difference in strength between the high and low temperatures was less pronounced after seven days of curing.

Results of Strength Tests.

Series.	Temperature of concrete at time of moulding.		Age at test: 24 hours. Crushing strength, lb. per sq. inch.		Mean temperature during curing period.		3 days. Crushing strength, lb. per sq. inch.		Mean temperature during curing period.		7 days. Crushing strength, lb. per sq. inch.		Mean temperature during curing period.	
	° C.	° F.			° C.	° F.			° C.	° F.			° C.	° F.
A (made Feb. 10, 1931)	18	64·4	174 133	*154*	6	43	905 916	*911*	6	43	2,930 3,145	*3,038*	6	43
			672 620	*646*	15·5	60	2,580 2,262	*2,421*	15·7	60·3	3,280 3,220	*3,260*	15·7	60·3
			688 717	*703*	18	64·4	2,272 2,268	*2,270*	17·2	63	3,070 3,085	*3,078*	17·2	63
			1,190 1,200	*1,195*	25	77	2,485 2,711	*2,598*	24·7	76·5	2,820 3,470	*3,145*	25·3	77·5
B (made Feb. 11, 1931)	18	64·4	120 *	*120*	6	43	777 758	*768*	6	43	2,920 2,882	*2,901*	6·1	43·1
			584 561	*573*	15·7	60·3	2,680 2,435	*2,558*	15·8	60·4	* 3,285	*3,285*	15·7	60·3
			625 625	*625*	17	62·6	2,640 2,325	*2,483*	16·8	62·2	2,662 3,040	*2,851*	17·2	63
			1,055 1,055	*1,055*	24	75·2	2,640 2,282	*2,461*	25·3	77·5	3,525 2,980	*3,253*	25·2	77·4
C (made Feb. 13, 1931)	14·5	58·1	111 120	*116*	6	43	630 716	*673*	6	43	2,730 2,490	*2,610*	6·2	43·2
			510 555	*533*	15·6	60·1	2,175 1,760	*1,968*	15·8	60·4	2,730 2,708	*2,719*	15·7	60·3
			568 552	*560*	16·8	62·2	2,150 2,100	*2,125*	16·9	62·4	2,886 2,550	*2,718*	17·1	62·8
			1,260 1,380	*1,320*	27	80·6	2,362 2,340	*2,351*	25	77	3,580 3,280	*3,430*	25	77

* Specimens damaged during handling.

Table 4 - Results of Strength Test (N. Davey, 1931)

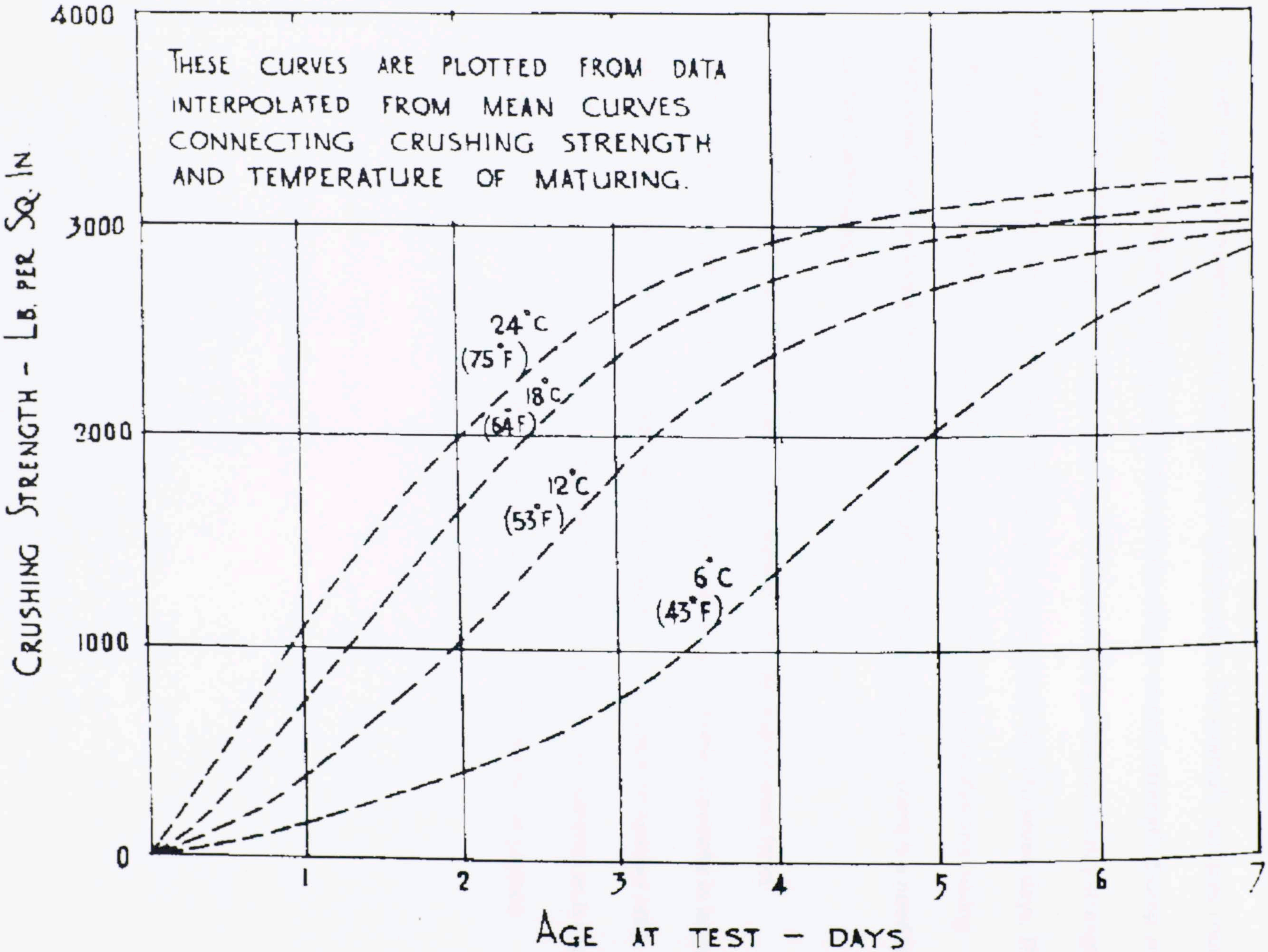

Figure 5 - Compressive Strength vs Curing Time (N. Davey, 1931)

Although Davey's study was fairly conclusive, more research is needed in order to get a more complete view of the effects of temperature. For example, samples could be made at varying mixing temperatures to see the effects on early strength. Slump and workability should be accounted for, and and it is customary to find the 28-day strength to determine the overall strength of the concrete; this test only went to seven days. This research was also published in 1931 which is relatively dated. New codes and mixing techniques and testing protocols have been developed since then, so there is a need for updated information.

Another study by Troxel et al. in 1965 looked at the heat generated from different types of cements. Much of the heat generated by concrete, especially in large mass concrete, depends on the temperature of placement, the water-to-cement ratio, and the cement content. However, a large factor that affects the heat generation is the type of cement used in the mix. Figure 6 shows a graph of temperature rise plotted against the age of concrete for several types of cement:

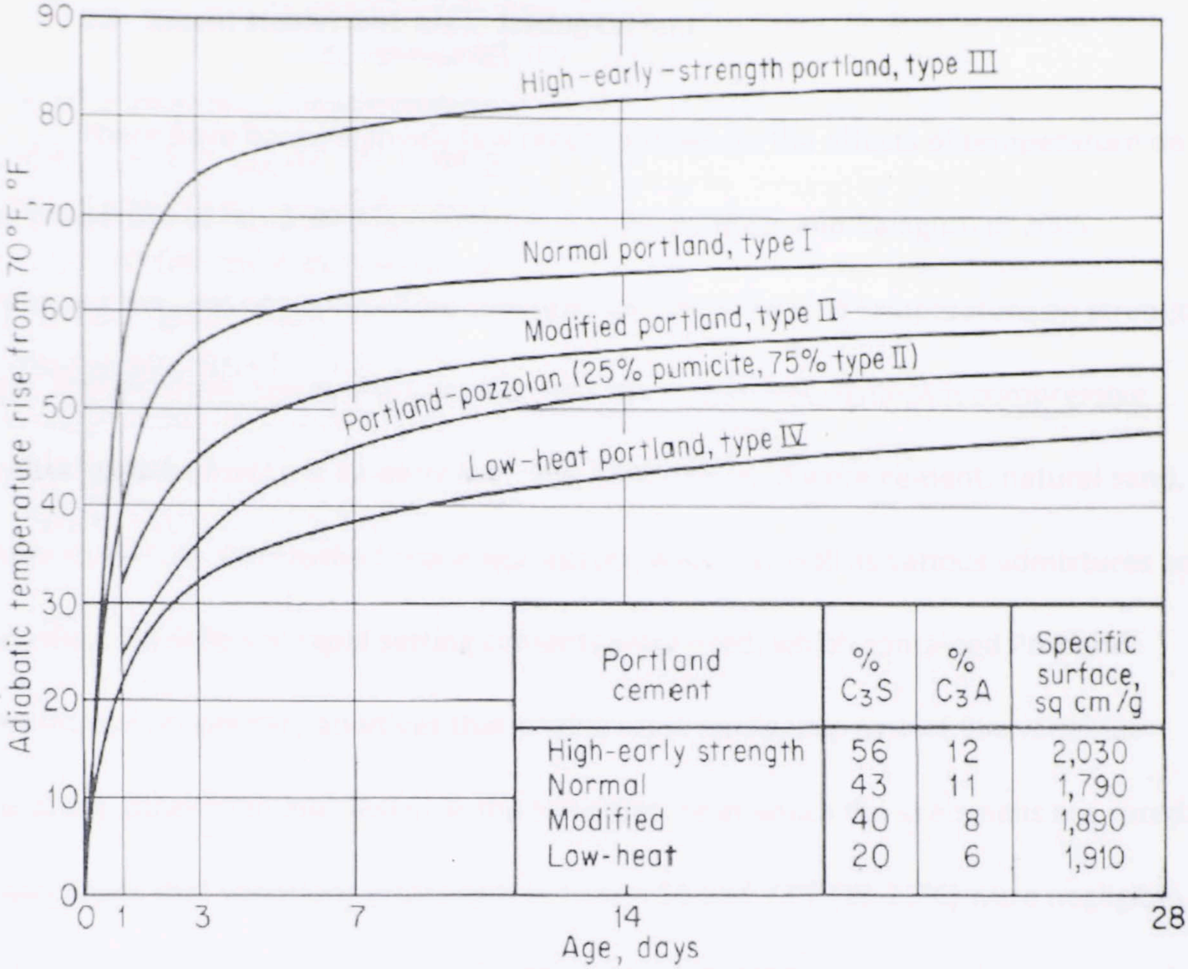

Figure 6 - Type of Cement and Adiabatic Temperature Rise (Troxel et al. 1965)

The specimens used in this test were protected against loss or gain of heat so that the adiabatic heat could be monitored without external influence. It is apparent from the graph that the total heat is greatest for rapid setting, high early strength cement. The heat generated is closely related to the compound composition of the cement (Troxel et al. 1965). In this case, for the high early strength Type III Portland cement, the larger amount of tricalcium aluminate (C_3A) serves to increase the adiabatic heat. This knowledge can be used to compare to rapid setting CSA cements, such as the Rapid Set© product.

2.5 Recent Studies with Rapid Setting Cement

There have been relatively few recent studies on the effects of temperature on the properties of rapid setting concretes. A study by Najm and Balaguru in 2005 discussed the uses of rapid setting concrete, and the effects of temperature on strength gain. In their study, the authors developed 3 mixes that met significant compressive strength requirements at an early age. The materials used were cement, natural sand, 9-mm maximum size crushed stone aggregates, water, as well as various admixtures and retarders. Six different rapid setting cements were used, which contained Portland cement and proprietary additives that enable rapid hardening. One of five variables discussed, other than mix design, is the temperature at which the specimens are cured. It was found that variations in strength between 55 and 73°F (13-23°C) were negligible, while the temperature range between 46 and 55°F (8-13°C) experienced an exponential drop in strength. As a result, it was concluded that normal concrete placement only be performed at temperatures higher than 50°F (10 °C) to ensure that the high early strength gains of the rapid setting Portland cement are utilized.

A study done by Yang et al. in 2001 looked at the hydration of rapid setting cement after heat curing. The type of cement used was a rapid setting cement with a similar chemical make up to the one used in the study by Davey, shown in Figure 3. The major difference between this study and others done on quick-setting cements is that this study applies external heat to the curing concrete during the first twelve hours only, followed by curing at room temperature. The major focus of the study was to observe the time of hydration of the various components of the cement, as well as note any expansion of the cements due to the heat application. In terms of expansion, the rapid setting cement exhibited the most expansion when heat cured at 100°F for 12 hours, then cured at ambient temperature for a total time of two years. The expansion can be seen below in the plot in Figure 7.

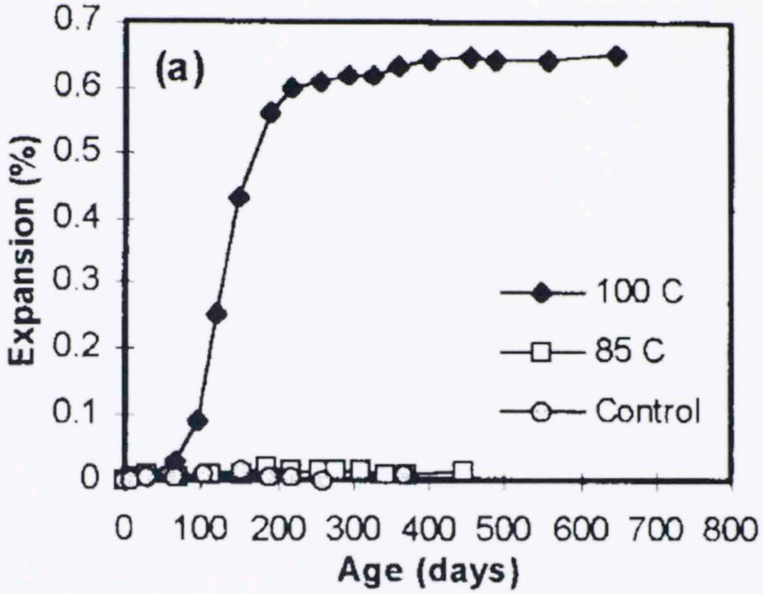

Figure 7 - Expansion of Rapid Setting Cement after Heat Curing for 12 Hours (Yang et al. 2001)

In addition to the increased expansion of the cements, the study found the increased curing temperatures of 85 and 100 degrees Celsius increased the hydration of the cement components. The four main anhydrous cement minerals that were affected were alite, belite, C_3A, and ferrite. The hydration of these components forms ettringite crystals, which add strength to the cement but cause expansion and can lead to cracking. This is one explanation for the increased expansion of the rapid setting cement at 100°F. This may have been an example of delayed ettringite formation.

These studies will serve as a starting point in the observation of temperature's effects on CSA cement. By taking note of the unexplored variables and inconsistencies in past research, it is possible to expand upon past knowledge and formulate a new approach to looking at the subject. The following sections will discuss the current research as it applies to temperature and Rapid Set© concrete.

3.0 Testing Regimen

3.1 Mixing and Curing Variables

In any research, it is important to control the variables in an experiment in order to obtain a clear and unbiased solution. In this research, the primary variables we are concerned with include:

1) Mixing temperature
2) Curing temperature
3) Strength of concrete
4) Admixtures (Glenium 7500 and citric acid)

Each of these variables is a key component in the overall strength and initial workability of the concrete, and will be discussed individually in the following sections.

3.1.1 Mixing Temperature

For this research, temperature is the primary variable of concern in both the mixing and curing stage. The mixing temperature is important to consider when looking at the early and ultimate strength of a concrete mix. It is common on construction sites in different climates around the world to experience a wide range of ambient temperatures throughout the placement and curing process. Varying the mixing temperature from the curing temperature for this study was implemented to simulate this variability. For example, concrete being placed in the middle of the night will be subjected to a lower temperature during the mixing stage followed by an increase in temperature as the morning and mid-day heat arrives. Another example would be if a certain project begins in the mid-day where the temperature is warmer, only to be followed by an extended cold front in the evening and following days during curing. For this research, mixing temperatures of 40, 60, and 80 degrees Fahrenheit will be used.

In order to ensure that the proper thermal conditions were met, preparations were made to set up the ideal conditions for each particular temperature range. For the purposes of measuring the thermal differences between tests, an infrared thermometer, as seen in Figure 8, was used to read both the temperature of the mixes and equipment before use. The thermometer in use to measure the temperature of the mixer can be seen in Figure 9.

Figure 8 - Infrared Digital Thermometer

Figure 9 - Measuring Temperature of Mixer Using Infrared Thermometer

The initial mixing conditions proved to be more difficult to control than the curing conditions. Along with measuring the precise temperature of the materials being used in the mix, records must be kept of the equipment used in the mixing process as well as the ambient temperature. Before each batch was started, the temperature of the mixing equipment had to be adjusted to the required mixing degree range. For the various temperature mixing ranges, either ice or buckets of warm water were added to the mixer, which then rotated to either chill or warm the machine for approximately five minutes. Once this time elapsed, a reading was made of the internal and external surfaces of the mixer using the digital infrared thermometer. Ice or warm water was added as needed to adjust the temperature of the mixer to within a reasonable range for the mix, and the measured temperature was recorded on the mix design sheet, which can be found in Appendix A.

The temperature of the mixing material, including the aggregates, water, and cement, was also adjusted to be within a reasonable range for the designated test. This was accomplished by storing the materials in their respective curing environments controlled to the correct temperature. Figure 10 shows the testing of the water temperature for a mix. To cool the material to 40°F for mixing, the buckets of rock, sand, cement, and water were placed in an industrial freezer, seen in Figure 11, and allowed to chill overnight. For the 60°F mixing temperature, the material was placed in the curing chamber at Fears Laboratory, controlled to 60°F via the thermostat. The 80°F mixing range the material was allowed to sit overnight indoors in the laboratory, where the nighttime temperature during the summer months was around eighty degrees.

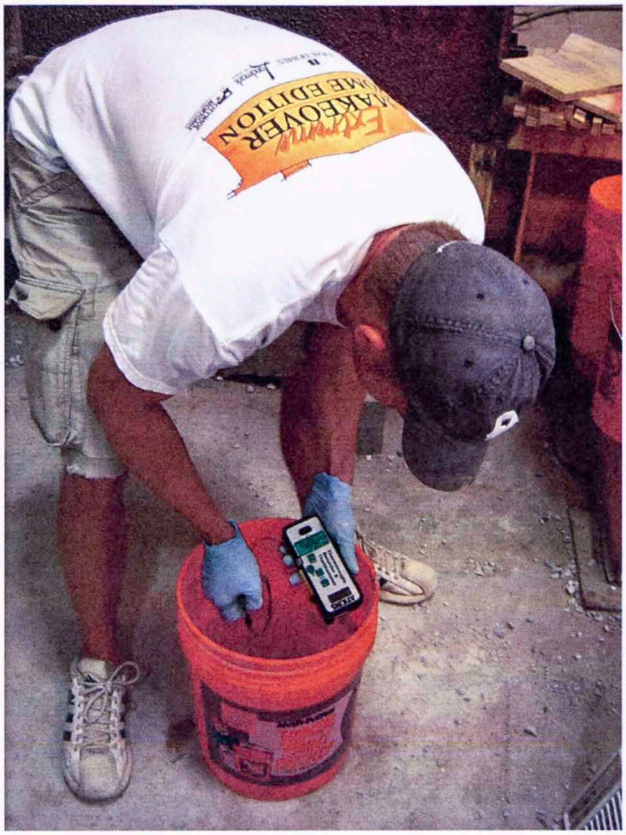

Figure 10 - Adjusting the Mixing Water Temperature

Figure 11 - Industrial Freezer for Aggregates and Samples

3.1.2 Curing Temperature

The second main variable considered in the scope of this research is the curing temperature. This variable is very important as it is held constant for the subsequent 28 days. In each of the curing scenarios, the specimens were placed in a water bath to ensure proper heat distribution throughout the curing process. For the 40°F curing condition, small round metal water basins were loaded into the industrial freezer, as seen in Figure 12. These basins were then filled with water and allowed to cool overnight to reach the target forty degrees. Due to the confined space in the freezer and heat of hydration of the concrete immediately following mixing, ice was added to the basins to safeguard against the heat transfer effect of the warming concrete cylinders. A thermocouple reading was made during the first 24 hours to verify that the water remained around forty degrees.

For the 60°F curing condition, small oval stock tanks were placed in the curing chamber that was controlled to 60°F, seen in Figure 13. Blue plastic basins were also utilized when space was limited in the larger tanks. Using the same principle as before, the specimens were placed in the water with just the top portion of the cylinders exposed to the air. Small portions of ice were added initially to balance the heat given off by the fresh samples.

Figure 12 - Water Basins in Freezer for Forty Degree Curing

Figure 13 - Small Stock Tanks for Sixty Degree Curing

For both the 80° F and 100° F baths, large round stock tanks were utilized to cure the specimens. The proper water temperature was achieved with the use of stock tank heaters and water pumps for circulation. To maintain the precise temperature, an electric thermostat control unit was plugged into the water heaters. The unit would take a reading of the water temperature by means of a thermometer submerged in the water, and would turn the water heater on or off depending if the target temperature was met or not. For the eighty degree tank, a stock tank heater was used in conjunction with a water cooling unit to reach a suitable thermal range. Two water pumps were used in both of the large tanks to circulate the heated water and maintain an even temperature throughout.

To make sure that the ground did not affect the internal temperature of the large tanks, each stock tank was placed on a sheet of insulating foam. To further protect the specimens from heat transfer, the test cylinders were placed on top of a sheet of plywood that was raised off the floor of the tank by concrete blocks. Finally, large pieces of housing insulation were wrapped around the body to prevent heat from escaping. The schematic of the large basins and the heat circulation can be seen in Figure 14. Another advantage of using the large stock tanks to cure the samples is increased consistency between the specimens. With such a large body of water, fluctuations in temperature are reduced.

Figure 15 shows a picture of one of the stock tanks with the insulation wrapped around the body. Figure 16 shows a stock tank heater on the left and a water pump for circulation on the right.

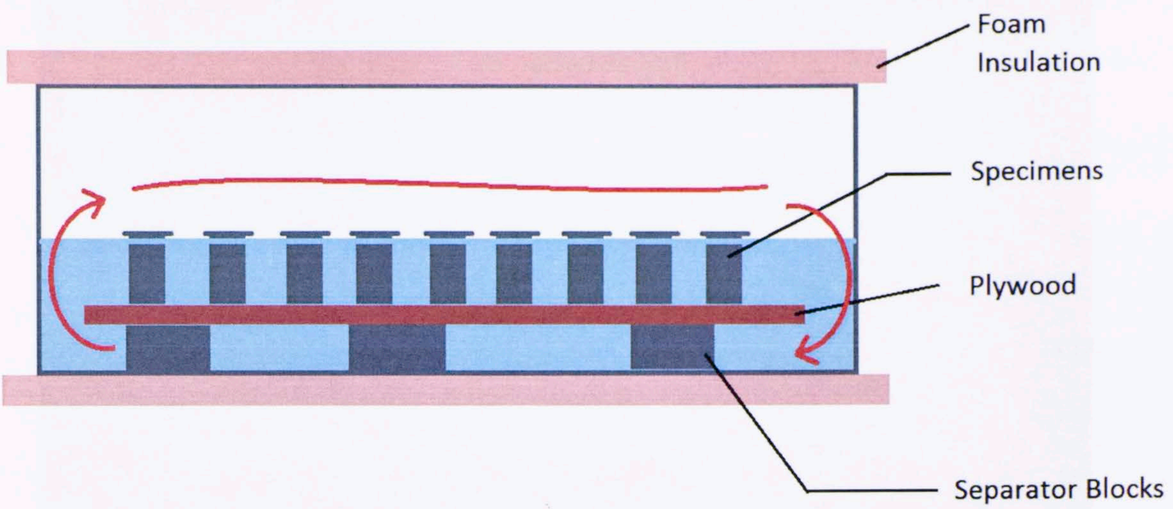

Figure 14 – Cross-Section of the Curing Basin

Figure 15 - Stock Tanks for Curing

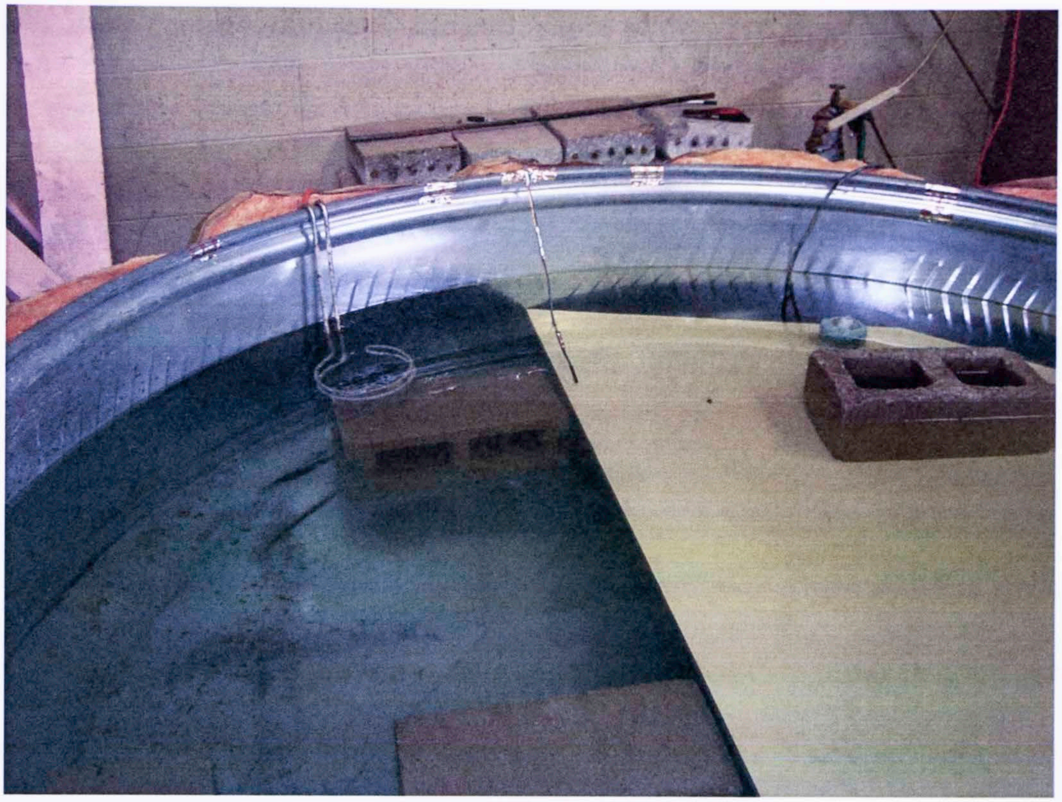

Figure 16 - Water Heater and Pumps

For each of the water baths, the top of the cylinders were exposed to the air and not submerged in the water. Full submersion was not desired since the fresh specimens were placed in the curing baths immediately after finishing. If the tops of the fresh mixed concrete cylinders were submerged, they would be adversely affected by the contact with the water and would skew the compression results. To account for this, foam insulation was placed over the top of the basins. Through an understanding of thermodynamics and heat transfer, it can be seen that the relatively large body of water at the warmer temperature will heat the enclosed air to roughly the same temperature as the water, given proper insulation. To verify this, a thermometer was stuck through the foam insulation and the enclosed air was, in fact, very close to the temperature of the water. The difference in temperature of the air and water was therefore deemed negligible. Later compression tests showed failure of the concrete cylinders occurred on both the upper and lower portion of early strength tests, which indicates temperature exposure was homogenous throughout the cylinder during the curing process. Although the specimens were not truly 'water cured' by definition, the curing process achieved the intended result of even heat distribution to the cylinders.

3.1.3 High and Low Strength Concrete

Another variable that was considered was to compare a high and low strength mix design. It is necessary to consider both ranges of strength in order to get a complete understanding of how Rapid Set© is affected by temperature. Some projects, such as highways and structures, require higher performance and stronger concrete. Other projects may not need such a strong mix such as when a budget limits the amount of material available to use, or when live loads are relatively small, such as a sidewalk. By examining both a high and a low strength mix, we can also determine if the paste volume influences the sensitivity to the mixing and curing temperatures. It is thought that higher cement concentration will react more to temperature than a lower concentration. Table 5 and Table 6 show an example low and high strength mix design, respectively.

Table 5 - Low Strength Mix Design

w/c=	0.52						
cement =	611						
Type =	Rapid Set						
Air Entrain	0						
Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5	
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0		
H2O SG=	1.0						
C SG=	3						
Latex SG=	1						

			1 yd	2.3	cu ft
Cement	Rapid Set		611.0	52.05	lb
Coarse Aggregate, #67			1772.6	151.00	lb
Fine Aggregate, River Sand			1225.2	104.37	lb
Water			341.5	29.09	lb
Air Ent. Admixture		oz	0.0	0.00	ml
Plasticizer Admix.		oz	0.0	0.00	ml
(HRWR) ADVA Cast		oz	0.0	0.00	ml
DCI (Accel)		oz	0.0	0.00	ml
Latex (Acryl 60)		lbs	0.0	0.00	lbs
Glenium 7500		Oz	79.8	201.00	ml

	Theoretical Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Table 6 – High Strength Mix Design

w/c=	0.45
cement =	675
Type =	Rapid Set
Air Entrain	0

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft
Cement	Rapid Set	675.0	57.50	lb
Coarse Aggregate, #67		1772.6	151.00	lb
Fine Aggregate, River Sand		1205.8	102.72	lb
Water		327.4	27.89	lb
Air Ent. Admixture	oz	0.0	0.00	ml
Plasticizer Admix.	oz	0.0	0.00	ml
(HRWR) ADVA Cast	oz	0.0	0.00	ml
DCI (Accel)	oz	0.0	0.00	ml
Latex (Acryl 60)	lbs	0.0	0.00	lbs
Glenium 7500	Oz	91.7	231	ml

Theoretical	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Differences can be seen between the two mix designs. First, the stronger mix has a lower water to cement ratio. The theoretical water to cement ratio that will completely hydrate Rapid Set© cement is 0.44. Any additional water added to the mix past this ratio serves to reduce the strength of the overall mix because the cement is already fully hydrated. For stronger mixes, a water to cement ratio of 0.45 was used to ensure complete cement hydration. For the low strength mixes, a water to cement ratio of 0.52 was used.

The second way the varying strengths were achieved was to adjust the cement and aggregates in the mix design. For the stronger mixes, 675 lb/yd^3 of cement were used compared to the 611 lb/yd^3 used in the weaker mixes. The higher content of cement provides more adhesion between the concrete components and thus results in higher strength. Sand was used as a replacement for the lower cement portions as per the mix design calculations.

3.1.4 Admixtures (HRWR)

The use of a High Range Water Reducer (HRWR) is necessary to use with Rapid Set© in some situations to allow enough time for placing the concrete and getting a finish before the concrete sets and makes the placement and finishing much more difficult. In the initial testing phases, citric acid was used to increase workability but didn't provide the results as needed. A discussion of these findings can be found in the results section.

Glenium 7500 is a modern, carboxolate superplasticizer that works as a water reducing admixture. When used in high doses, it can add enough workability and slump to qualify as self-consolidating concrete. Glenium 7500 aids in workability yet still allows for fast setting and improved early age compressive strength results. Glenium 7500 meets ASTM C 494 Type A and Type F water reducing, admixtures. The amount of Glenium used varied mix to mix depending on the visual flow ability of the mixing concrete, but did not exceed the maximum 15 oz/cwt recommended by the manufacturers.

3.2 Concrete Mixture Design

After outlining the constants and variables of focus for the research, mix designs were developed to study the variables individually. For example, by holding the mixing temperature at a certain level and varying the curing temperature, we can assess the environment's thermal influence on the curing concrete. By repeating the same set of experiments but using high strength concrete instead of low strength, we will be able to study the effects of temperature on two separate mix designs. Table 7 summarizes the total tests specimens to be created at the various strengths and temperatures.

Table 7 - Test Specimens

	Low Strength												High Strength											
Mixing Temp (°F)	40				60				80				40				60				80			
Curing Temp (°F)	40	60	80	100	40	60	80	100	40	60	80	100	40	60	80	100	40	60	80	100	40	60	80	100
Comp. Strength	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Air Content	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Slump (in)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

The Absolute Volume Method was utilized in the creation of each mix design. The calculations for material in each mix were determined by first examining a known one cubic yard mix and its components and then reducing to a smaller, more reasonable volume for use in the experiment. The mix designs for each of the experiments can be found in Appendix A.

It should be noted mix 1 through mix 6b are included in Appendix A; they only served as initial tests using citric acid as a retarder before the use of Glenium 7500. A discussion of citric acid is included as a reference and a justification for the use of Glenium in its place, and the results of these mixes will be discussed in the results and discussion section.

The order and numbering of the mix designs was developed so that the even numbers represent the high strength mixes and the odd numbers represent the low strength mixes. For the temperatures, the order that the mixes were completed in was decided by the availability of equipment and the availability of room for curing. For example, the industrial freezer was received towards the end of the research process, so the mixes at 40°F were completed later in the process.

4.0 Batching, Curing, and Testing

4.1 Batching Procedure

Given the extremely fast setting time of Rapid Set© cement and the precise temperature demand of each of the mixes, a working team of at least three or more students was required for each mixing process. The students helped in the creation of the cylinder molds, performing some of the testing procedures and bucketing material for the next day.

The first step in creating each of the mixes was to bucket and prepare the material the day before mixing by using the mix designs as discussed earlier, including rock, sand, water, and cement. A picture of the bucketing process can be seen in Figure 17, and the labeled buckets can be seen in Figure 18. The use of a front end loader was necessary given the amount of material needed for mixing. This preparation the day before was necessary in order for materials to reach their designated temperature in the respective controlled environment. The exact material for each mix was then measured out the morning of batching once the water content of the aggregates had been determined. The buckets were then kept in their respective temperature controlled environment to ensure that the specified mixing temperature was met while maintaining their moisture content. Temperatures of the corresponding mixing material, as well as the temperature of the mixer, can be found on the mix design sheets in Appendix A.

Figure 17 - Bucketing Aggregate Using a Front End Loader

Figure 18 - Bucketed Material with Labels

The type of mixer used in this research is a Stone Mixer, Model 95 CM, shown in Figure 19. In preparation for the mixing process, 26 cylinder molds were lubricated with diesel oil and placed near the mixer, as seen in Figure 20. The 26 cylinders were used for each of the allotted time slots, as well as two extra cylinders as extras. The Glenium was measured out at this time to the nearest milliliter.

Batching procedures followed ASTM C 192, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory." This included wetting down the equipment used prior to use, including the mixer, wheelbarrow, trowels, scoops, and testing equipment. The batching procedure was carried out as follows. Once the mixer was turned on, the rock and sand were added to the mixer and allowed to mix to a relative homogeneous state. A quarter to half of the water for the mix was then added and time was given to allow the aggregates to be sufficiently coated. The bucket of cement was then added, followed by the remainder of the water. At this point, the timer was started. The graduated cylinder of Glenium 7500 was finally added to the mix.

Because of the quick setting time of Rapid Set©, the mixing and resting time was different from ASTM C 192. Instead of mixing for three minutes, resting for three minutes, and mixing for a final two minutes, there was only one continuous cycle of mixing for two minutes total. This allowed the components to be fully incorporated but not allow for any hardening within the mixer, and allow ample workability for placing in the cylinder molds and for running the tests.

Figure 19 - Mixer Used for Batching

Figure 20 - Cylinder Molds and Material Ready for Batching

4.2 Curing Procedure

Once the mixing was complete, the sample of concrete was poured into a clean wheelbarrow. The prepared cylinders were then prepared in the following manner, following ASTM C 31. One-third of the cylinder was filled with the fresh concrete and tamped or "rodded" using a steel rod for a count of 25. The remaining two thirds were completed in the same manner, and then the tops were smoothed using a concrete trowel. For each mix, 26 total cylinders were prepared. Figure 21 shows the cylinder molds being filled, and Figure 22 shows the rodding process. The final troweling procedure is shown in Figure 23.

The specimens were then placed in their respective curing environments, depending on the required curing temperature. For a thorough discussion of the curing conditions please refer to the "Curing Temperature" section in the Testing Regimen portion of the paper. For the 40 degree temperature, the cylinders were placed in small basins of ice water in the industrial freezer. For the 60 degree curing, the samples were placed in medium stock tanks in the temperature controlled curing chamber. Finally the 80 and 100 degree samples were placed in their respective large stock tanks, controlled to the proper temperature. A picture of the samples being loaded into the industrial freezer for curing can be seen in Figure 24.

Given the quick early strength gains of Rapid Set©, it was necessary to tailor a compressive strength testing regimen that focused on both early strength and late strength of the samples. It was decided that a reasonable strength graph could be plotted from the following testing times: 1 hour, 3 hour, 6 hour, 9 hour, 24 hour, 7 day, 14 day, and finally 28 day. The specimens were kept in the curing environment up until it was time for the compression testing.

Figure 21 - Filling Cylinder Molds

Figure 22 - Tamping Cylinders

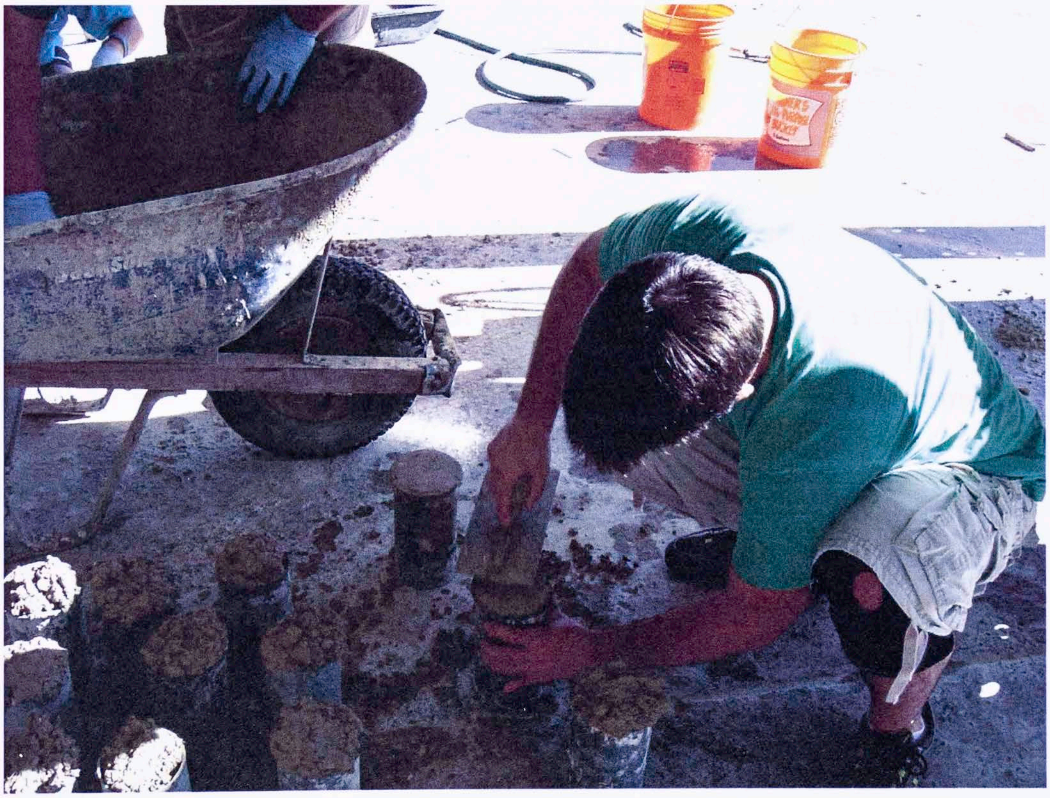

Figure 23 - Troweling Samples

Figure 24 - Placing Samples in Curing Freezer

4.3 Tests Performed

Several tests were carried out in order to assess the performance of each of the mixes. It is important to not only consider the overall strength of the concrete product but to consider the workability of the mix. The following tests were performed:

1) Temperature
2) Slump
3) Air Content
4) Unit Weight
5) Compression Test

4.3.1 Temperature

Temperature is the primary design variable in this investigation, so tracking the temperature of the mix right out of the mixer was very important. This helps to indicate how quickly the concrete will set up, and the workability of the mix. For example, a warmer mix right out of the mixer indicates that the heat of hydration process has begun, and decreased slump and therefore decreased workability can be expected.

For recording the temperature, ASTM C 1064 "Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete" was followed. The temperature during the early stages of testing was recorded using a standard analog cooking thermometer. A thermocouple was acquired for the later testing and provided much more accurate temperature readings of the fresh concrete. The temperature readings for each of the mixes can be found on the mix design and results in the Appendix. Figure 25 shows the measuring of the fresh concrete temperature using both an analog and digital thermometer.

Figure 25 - Taking Temperature Using a Thermocouple and Analog Thermometer

4.3.2 Slump

In addition to measuring the strength of the concrete, other factors should be compared between the mixes such as workability. This characteristic is found using the concrete slump test following ASTM C 143, a simple test that measures the plasticity of a fresh batch of concrete. This variable is affected by the amount of HRWR that was added to the mix, and the temperature of the concrete (i.e. how far along the concrete is in the hydration process). Slump is the best indicator for workability and was therefore used as a guide to adjust the amount of Glenium 7500 in the following mixes. Figure 26 and Figure 27 show the process of measuring slump.

Figure 26 - Rodding Concrete in the Slump Cone

Figure 27 - Measuring the Resulting Slump

4.3.3 Air Content

Air content is determined as soon as the mix is removed from the mixer. ASTM C 231 "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method" was followed. This test reports how much entrapped air may exist inside voids in the aggregate particles. Entrapped air is unavoidable in mixes, but should be measured and generally falls around the range of 2 percent air content. The air content meter can be seen in Figure 28.

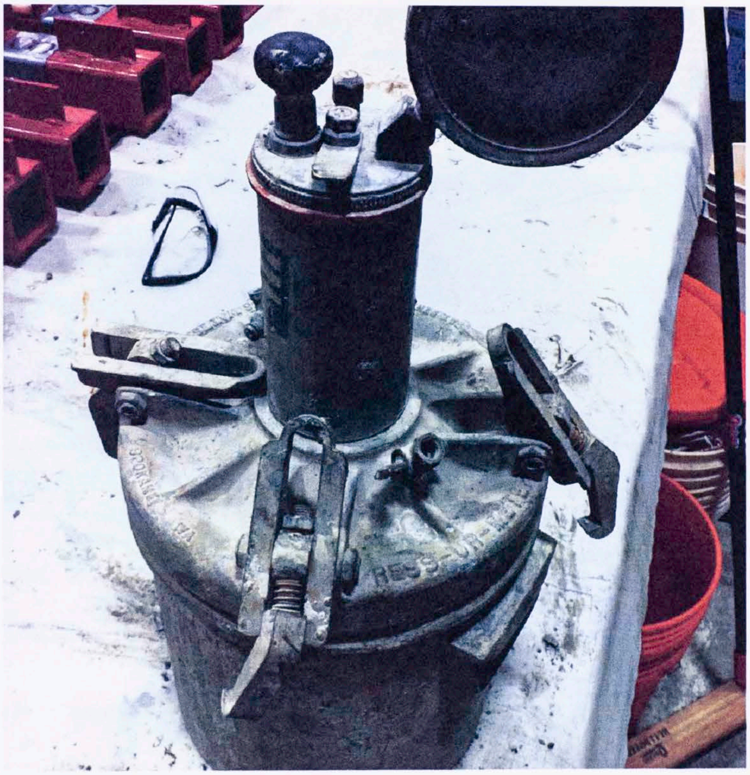

Figure 28 - Air Content Meter

4.3.4 Unit Weight

The unit weight is determined using the same sample from the previous air content test. ASTM C 138 "Standard Test Method for Unit Weight, Yield, and Air Content

(Gravimetric) of Concrete" was followed for the procedure to determine unit weight. Once the unit weight is found, it can be checked against the theoretical unit weight which serves as a gage to determine if the proper mixing procedures were followed within reason. The pot from the air content test, shown in Figure 29, was weighed on the scale, and then checked against the theoretical unit weight.

Figure 29 - Air Content Pot Used for Unit Weight

4.3.5 Compression Strength

After the specimens had cured for the allotted time, three samples were removed from their respective curing conditions, and were extracted from their plastic molds using compressed air as seen in Figure 30.

The test used to determine strength was the compression test, which was carried out in accordance with ASTM C 39 "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" as well as ASTM C 1231 "Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders". The testing equipment used for this test was a Forney® LC-1 concrete testing machine, serial # 965054, which was last calibrated on April 14, 2010. Loading and removing a specimen from the Forney can be seen in Figure 31 and Figure 32, respectively.

The size of the cylinders used were four inches by eight inches, and the strength of each cylinder, given in pounds per square inch, was determined by dividing the load at failure by the top surface area of the cylindrical specimen.

Figure 30 - Removing a Sample from Cylinder Mold Using a Compressed Air

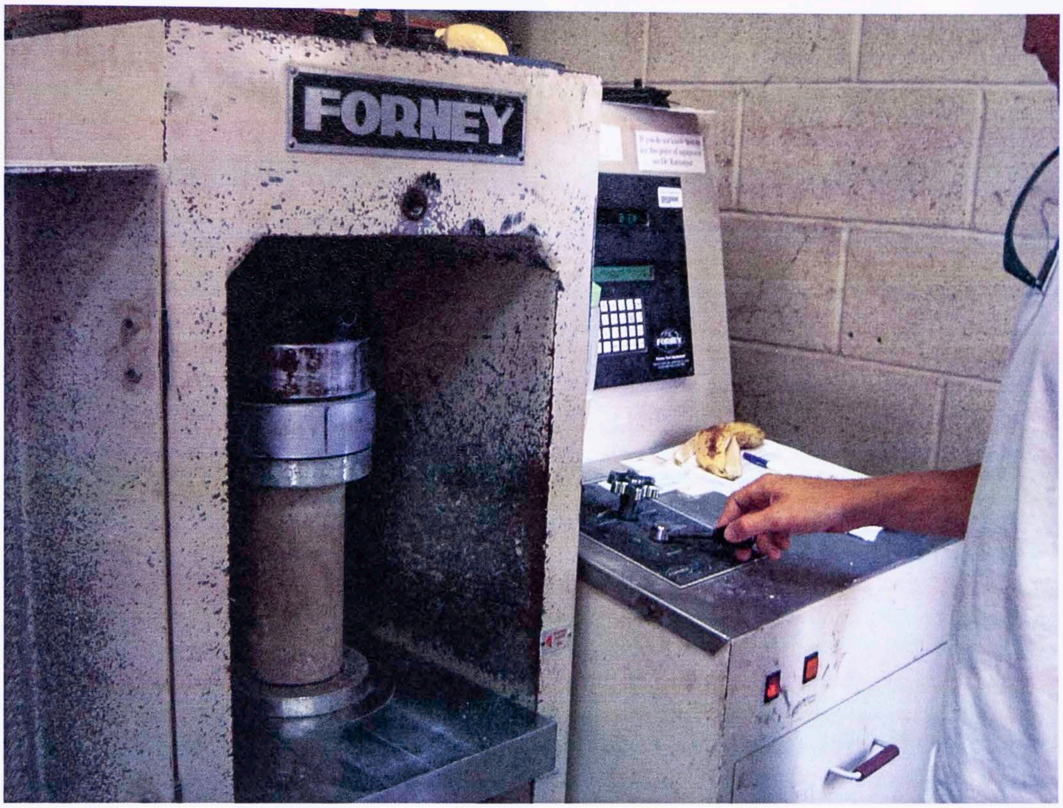

Figure 31 - Loading a Specimen Using the Forney LC-1 Testing Machine

6.6 Schedule of Work

Table 8 summarizes the schedule of the research process. Most of the work was completed in one year, with a bulk of the research being performed in the [illegible] of 2010. The [illegible] work on the mixing temperature of [illegible] was done in [illegible] the thesis writing [illegible] of 2010, with [illegible] to the [illegible] review process.

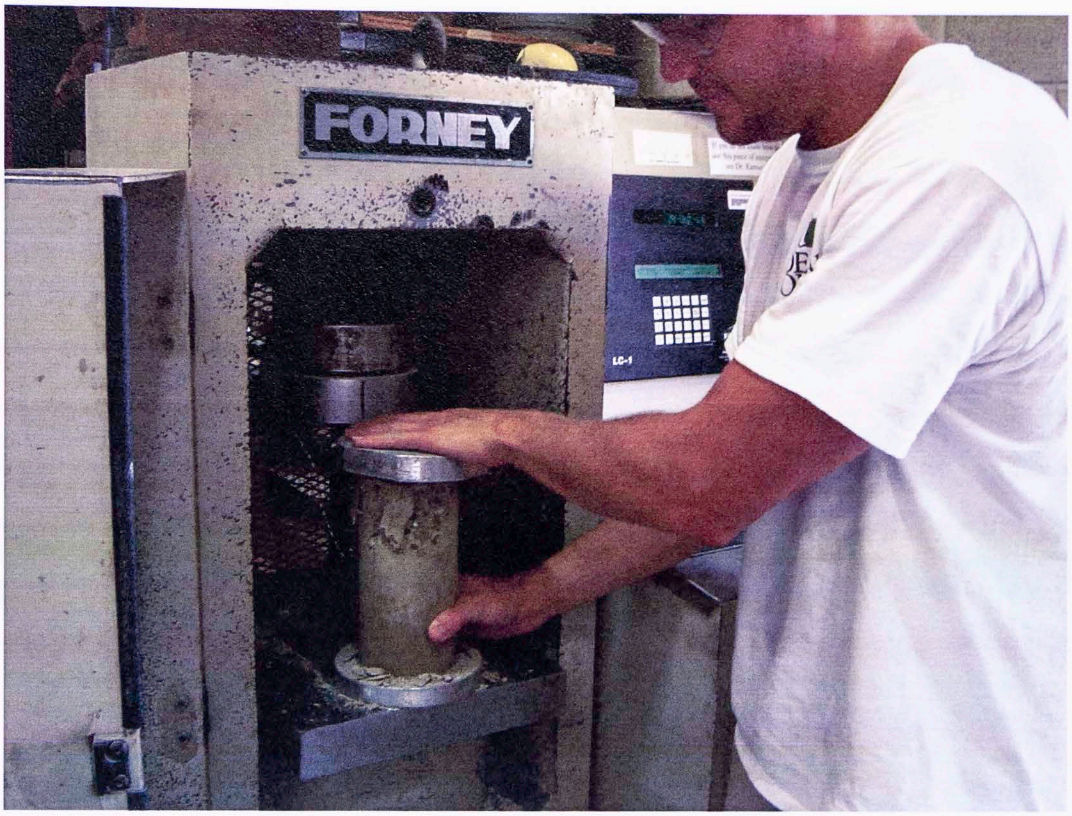

Figure 32 - Removing a Failed Specimen from the Forney

4.4 Schedule of Work

Table 8 summarizes the schedule of the research process. Most of the work was completed in one year, with a bulk of the manual labor performed in the summer of 2010. This was ideal as the mixing temperature of 80°F was easy to maintain. Most of the thesis writing was competed in the fall of 2010, with additions to the literature review portion.

Table 8 - Schedule of work

2010	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Literature Review	■	■	■							■	■
Create Mix Designs			■								
Gather material				■	■						
Mix				■	■	■	■				
Cure				■	■	■	■	■			
Test Samples				■	■	■	■	■			
Data Analysis								■	■		
Compose Thesis								■	■	■	
Thesis Defense											■

5.0 Test Results

This section will discuss the findings of the research. The first thing that can be seen from most of the presented data is the consistency between tests. Definite trends can be observed between the low and high strength mixes, which is a good sign that consistent mixing and curing procedures were followed, and improves confidence in the results.

5.1 Failure Modes

The failure load of each specimen increased as curing time increased, which was to be expected. The mode of failure was also very different between the early and late age samples. Cylinders cured within 24 hours mostly failed in a partial slant shear near the top or bottom of the cylinder, and the majority of the cylinder stayed intact. On the other hand, around the 28 day curing time the cylinders generally failed more completely in a columnar type failure. Figure 33 shows an example failure after six hours and Figure 34 shows a more complete failure after 28 days.

Figure 33 - Cylinder Failure after 6 Hours

Figure 34 - Cylinder Failure after 28 Days

5.2 Tabulated Compression Results

Once all the cylindrical specimens were tested in compression, the results were compiled and tabulated. For the early mixes, test batches were made to gauge the overall strength of the mix design as well as test the properties of the citric acid. These earlier tests were not tested at 28 days because it was determined the mixes were not meeting the early strength requirements. A compression test was performed on at least the one hour and 24 hour mark for evaluation.

The results for the initial tests using citric acid as a retarder are included here for comparison of early strength gains, and the results can be seen below. Table 9 through Table 14 include the mix number, the mixing and the curing temperature, and the compressive strengths of each of the three samples taken at the allotted times.

5.2.1 Tests Using Citric Acid

Table 9 - Compressive Strength Mix 1 – Mix 80°F, Cure 100°F, Citric Acid

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	2631	2680	2454	2588
3 hr	3602	3450	4006	3686
6 hr	4046	4015	3950	4004
9 hr	3957	4178	4128	4088
24 hr	4765	4744	4794	4768

Table 10 - Compressive Strength Mix 3 – Mix 80°F, Cure 100°F, Citric Acid

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	98	183	727	336
3 hr	3376	3361	3782	3506
6 hr	4009	4358	4205	4191
9 hr	4460	4716	4732	4636
24 hr	5196	5228	5195	5206
7 day	6035	6353	6381	6256

Table 11 - Compressive Strength Mix 4 – Mix 80°F, Cure 100°F, Citric Acid

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	143	218	423	262
3 hr	3915	3987	4062	3988
6 hr	4746	4706	4948	4800
9 hr	4948	4926	4975	4950
24 hr	6010	5873	5973	5952
7 day	6791	6836	7068	6898

Table 12 - Compressive Strength Mix 5 – Mix 60°F, Cure at Ambient Temperature, Citric Acid

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
2 hr	169	590	590	450
4 hr	3342	3594	3603	3513
24 hr	4894	5066	4982	4980

Table 13 - Compressive Strength Mix 6 – Mix 60°F, Cure at Ambient Temperature, Citric Acid

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
2 hr	892	902	1022	939
4 hr	4412	4456	4623	4497
24 hr	4894	5066	4982	4980

Table 14 - Compressive Strength Mix 6b - Mix 60°F, Cure at Ambient Temperature, Citric Acid

Time	Compressive Strength (60 m, ambient)			
	#1	#2	#3	AVG
1 hr	193	259	471	308
3 hr	4347	4222	4119	4229
6 hr	4897	5115	4881	4965
24 hr	6042	6135	6441	6206

Mix 1 was a low strength mix that was created using no additives to gauge the strength and workability of the mix design. Mix 2 was a high strength mix that also did not use any additives. These mixes returned a slump of one inch and zero inches, respectively, and were barely workable. Mix 2 was extremely dry and deemed unusable; therefore, no samples or compression results were obtained. As a result, Mix 2 has been left out of the test results and discussion, but serves as a starting point and an indicator that a retarder or water reducer was needed to increase workability, especially in the high strength mix design. For a complete view of additives used and the resulting slumps, refer to Appendix C.

Mixes 3 and 4 are the low and high strength mixes that utilized the citric acid as a retarder, and were cured at 100°F. For comparison, Mixes 5 and 6 were batched with citric, but then allowed to cure at ambient room temperature under a thermal blanket. Mix 6b was the same as Mix 6, except using half of the citric amount. Refer to the analysis section for further discussion of citric acid use. The following section will summarize the results from the use of Glenium 7500 as an additive.

5.2.2 Tests Using Glenium 7500

Mix #1 through #6b show that it was found that the use of citric acid was not achieving the required strength gain in the early curing stage. Glenium 7500 was chosen to use as a high range water reducer in place of the citric acid, as the product allows for greater workability without compromising overall strength of the concrete mix. Table 15 through Table 38 summarize the results from the tests using Glenium 7500 as a HRWR.

Table 15 - Compressive Strength Mix 7 – Mix 60°F, Cure 100°F, Low Strength

Time	Compressive Strength (psi)			
	#1	**#2**	**#3**	**AVG**
1 hr	1254	1735	1644	1544
3 hr	2659	2338	2550	2516
6 hr	3218	3283	3153	3218
9 hr	3234	3328	3465	3342
24 hr	3603	3457	3775	3612
7 day	3895	3675	3764	3778
14 day	4243	4222	4078	4181
28 day	4294	3869	4227	4130

Table 16 - Compressive Strength Mix 8 – Mix 60°F, Cure 100°F, High Strength

Time	Compressive Strength (psi)			
	#1	**#2**	**#3**	**AVG**
1 hr	2687	2844	2607	2713
3 hr	3408	3581	3616	3535
6 hr	4206	4076	3909	4064
9 hr	4324	4437	4421	4394
24 hr	4784	4854	4934	4857
7 day	5209	4759	5391	5119
14 day	5243	5418	5405	5355
28 day	6310	6182	5819	6104

Table 17 - Compressive Strength Mix 9 – Mix 80°F, Cure 100°F, Low Strength

Time	Compressive Strength (psi)			
	#1	**#2**	**#3**	**AVG**
1 hr	1740	2122	2091	1984
3 hr	3401	2882	3489	3257
6 hr	3860	3945	3906	3904
10 hr	4495	4416	3834	4248
24 hr	4576	4660	4458	4565
7 day	5058	5165		5111
14 day	6242	5370	5147	5586
28 day	6833	6559	5539	6310

Table 18 - Compressive Strength Mix 10 - Mix 80°F, Cure 100°F, High Strength

Time	Compressive Strength (psi)			
	#1	**#2**	**#3**	**AVG**
1 hr	2698	3026	3038	2920
3 hr	4760	5004	4964	4909
6 hr	5317	4969	5491	5259
9 hr	5300	5658	5889	5616
24 hr	5753	5835	6188	5925
7 day	6535	7030	6724	6763
14 day	7253	6856	7114	7074
28 day	7339	8362	8200	7967

Table 19 - Compressive Strength Mix 11 - Mix 80°F, Cure 80°F, Low Strength

Time	Compressive Strength (psi)			
	#1	**#2**	**#3**	**AVG**
1 hr	1837	2098	1977	1970
3 hr	3320	3296	3250	3289
6 hr	4173	3758	3852	3927
9 hr	4136	4229	4265	4210
24 hr	4528	4525	4802	4618
7 day	5545	5152	5491	5396
14 day	5395	5790	5258	5481
28 day	6005	6210	6024	6080

Table 20 - Compressive Strength Mix 12 - Mix 80°F, Cure 80°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	2206	2701	2395	2434
3 hr	3742	3584	3466	3597
6 hr	3867	4116	4321	4101
9 hr	4560	4533	4377	4490
3 day	5604	5776	5728	5703
7 day	6207	6024	6014	6082
14 day	6253	6217	6400	6290
28 day	7071	7351	6353	6925

Table 21 - Compressive Strength Mix 13 – Mix 60°F, Cure 80°F, Low Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	1297	1549	1584	1476
4 hr	3146	2971	3019	3046
6 hr	3121	3377	3404	3301
9 hr	3563	3648	3961	3724
24 hr	4092	4378	4015	4162
7 day	4350	4791	4733	4625
14 day	5527	4974	5418	5306
28 day	6003	5745	5965	5905

Table 22 - Compressive Strength Mix 14 - Mix 60°F, Cure 80°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	1943	2426	2535	2301
4 hr	4186	4265	4078	4176
6 hr	4329	4533	4393	4418
9 hr	4783	4760	4934	4826
24 hr	5180	5440	5219	5280
7 day	6360	6551	6127	6346
14 day	6933	6852	6696	6827
28 day	7469	7603	6950	7341

Table 23 - Compressive Strength Mix 15 - Mix 80°F, Cure 60°F, Low Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	1358	1318	1082	1253
4 hr	2123	2094	2028	2082
6 hr	2137	2919	1988	2348
9 hr	2671	3142	3295	3036
24 hr	3552	3244	3850	3549
7 day	4703	4593	4603	4633
14 day	4900	4891	4510	4767
28 day	5494	4966	4060	4840

Table 24 - Compressive Strength Mix 16 Mix 80°F, Cure 60°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	1534	1722	1705	1654
4 hr	2319	3193	2924	2812
6 hr	3525	3026	3632	3394
9 hr	3411	3299	3252	3321
24 hr	4304	4530	4792	4542
7 day	5816	5497	5658	5657
14 day	4982	5327	5400	5236
28 day	5871	5375	5636	5627

Table 25 - Compressive Strength Mix 17 - Mix 60°F, Cure 60°F, Low Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
2 hr	1077	1377	1564	1340
3 hr				
5 hr	2647	2451	2817	2638
9 hr	2909	2537	2941	2796
24 hr	3998	3937		3968
7 day	5243	5356	4877	5158
14 day	5389	5254	5823	5489
28 day	5660	6190	5720	5856

Table 26 - Compressive Strength Mix 18 - Mix 60°F, Cure 60°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
2 hr	1911	1849	1784	1848
3 hr				
5 hr	3562	3508	3805	3625
9 hr	4590	4076	4038	4235
24 hr	4845	4743	5083	4890
7 day	6498	6551	6721	6590
14 day	6497	7019	6277	6598
28 day	7746	6575	6713	7011

Table 27 - Compressive Strength Mix 19 - Mix 40°F, Cure 100°F, Low Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	1719	2034	1894	1882
3 hr	3490	3721	3756	3656
6 hr	4315	4197	4319	4277
9 hr	4421	4501	4431	4451
24 hr	4276	4426	4574	4426
7 day	5187	4919	5193	5100
14 day	5134	5187	5348	5223
28 day	5233	5177	5317	5243

Table 28 - Compressive Strength Mix 20 - Mix 40°F, Cure 100°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	2640	2804	2917	2787
3 hr	3807	4012	3968	3929
6 hr	4479	4292	4652	4474
9 hr	4660	4342	4343	4448
24 hr	4872	4964	5039	4958
7 day	5709	5610	5851	5723
14 day	6312	6080	6088	6160
28 day	7283	6385	6758	6809

Table 29 - Compressive Strength Mix 21 - Mix 40°F, Cure 80°F, Low Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	1294	1276	1351	1307
3 hr	3112	3049	2823	2995
6 hr	3901	3840	3875	3872
9 hr	4192	4149	4256	4199
24 hr	4919	4921	4775	4872
7 day				
14 day	6720	6637	6447	6601
28 day	7413	7224	7226	7288

Table 30 - Compressive Strength Mix 22 - Mix 40°F, Cure 80°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr	1633	1868	2371	1958
3 hr	3936	4206	4456	4200
6 hr	4923	5223	4821	4989
9 hr	5718	5098	5575	5464
24 hr	6105	5674	6032	5937
7 day				
14 day	7924	8037	7908	7957
28 day	8418	8244	8666	8443

Table 31 - Compressive Strength Mix 23 - Mix 40°F, Cure 60°F, Low Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr				
4 hr	2206	2421	2499	2375
6 hr				
9 hr	3930	3931	3591	3817
24 hr	4818	4959	5034	4937
10 day	6887	6971	6718	6859
14 day	6678	7275	6842	6932
28 day	7278	7525	7542	7448

Table 32 - Compressive Strength Mix 24 - Mix 40°F, Cure 60°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr				
4 hr	3006	3377	3524	3302
6 hr				
9 hr	4953	4740	4283	4658
24 hr	5865	5558	5892	5771
10 day	7461	8134	7932	7843
14 day	7511	8752	8005	8089
28 day	8687	9148	8909	8915

Table 33 - Compressive Strength Mix 25 - Mix 40°F, Cure 40°F, Low Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr				
3 hr				
6 hr				
9 hr				
24 hr	1732	3016	2790	2513
7 day	5427	5440	5220	5362
14 day	5777	5653	5313	5581
28 day	5755	6078	6242	6025

Table 34 - Compressive Strength Mix 26 - Mix 40°F, Cure 40°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1 hr				
3 hr				
6 hr				
9 hr				
24	4321	3452	4297	4023
7 day	6974	6403	7030	6802
14 day	7246	7399	7415	7353
28 day	7590	7076	7945	7537

Table 35 - Compressive Strength Mix 27 - Mix 60°F, Cure 40°F, Low Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
2 hr	748	910	971	876
4 hr	2152	1878	1889	1973
7 hr	2293	2903	2305	2500
9 hr	2793	2765	2769	2776
24 hr	3724	3777	3778	3760
7 day	5610	5652	5356	5539
14 day	5516	5866	5211	5531
28 day	5442	6042	5636	5706

Table 36 - Compressive Strength Mix 28 - Mix 60°F, Cure 40°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
2 hr	1956	2152	1771	1960
4 hr	2682	2637	2823	2714
7 hr	3729	3667	3875	3757
9 hr	3403	3552	3634	3530
24 hr	4690	4910	4603	4734
7 day	6845	6794	6988	6876
14 day	6414	6957	7041	6804
28 day	7006	7674	7003	7228

Table 37 - Compressive Strength Mix 29 - Mix 80°F, Cure 40°F, Low Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1.5 hr	2160	1953	2080	2064
3 hr	2699	2854	2621	2725
8 hr	3470	3500	3400	3456
9 hr				
24 hr	3810	3487	2870	3389
7 day	3390	4310	3974	3891
14 day	3750	3622	3591	3654
28 day	4324	4646	3600	4190

Table 38 - Compressive Strength Mix 30 - Mix 80°F, Cure 40°F, High Strength

Time	Compressive Strength (psi)			
	#1	#2	#3	AVG
1.5 hr	2900	3170	2825	2965
3 hr	3681	3783	4138	3867
8 hr	4565	4347	3988	4300
9 hr				
24 hr	4382	5246	4935	4854
7 day	5586	4872	5246	5235
14 day	5150	5203	5344	5232
28 day	5177	4483	4746	4802

These tables represent all of the compressive strength data for each of the mixing and curing conditions. Present on some of the charts are blank spots; this is due to either not enough early strength, or time did not permit to break the samples. For example, in Table 33 and Table 34 for the 40°F mix and 40°F cure, the samples were not strong enough to be tested in the Forney for the first 24 hours. The following section will take a more in depth look at these results and plot this data graphically for analysis.

6.0 Data Analysis and Discussion

The tables presented in Chapter 5 summarize all of the data attained from the compression testing. In order to understand the trends and patterns that may be present, figures and graphs are needed to visualize the results. The two main variables of interest are the mixing and curing temperature; therefore, graphs were created to compare both.

Overall, the graphs give a satisfactory overview of the effects of changing the mixing and curing temperature on the ultimate strength of Rapid Set© concrete. Although there are several graphs provided in this section, they are important for finding trends and providing a reliability check for each of the tests. Comparing the high strength against the low strength graphs shows that the two strengths have similar trends. This gives an indicator that consistent batching and testing procedures were followed, and the results can be considered relatively accurate.

6.1 Early Strength Gains (24 hour)

Rapid Set© concrete was first developed for its quick setting time and very early strength gains. Some projects may require this early strength for situations where the set up time is a primary factor in the design or repair. A discussion of late strength gains will be found in the Section 6.2, but a closer analysis of the first 24 hour strength will be looked at further in this section.

In order to observe the early strength gains, the compressive strength of the samples were plotted in the first 24 hours to see the initial gains in more detail. In order to accurately view temperature's influence on the concrete, both the curing and mixing temperature will be held constant independently so one variable at a time can be considered. As such, two groups of graphs will be presented that reflect both the curing and mixing temperatures. Both the high and low strength graphs will be shown for comparison.

6.1.1 Curing Temperature, Early Age

The first set of graphs presented show each of the mixing temperatures with the curing temperature plotted as the variable. From this, comparing the curing temperature's influence on the early strength of the mix can be done. Figure 35 and Figure 36 show the tests performed at the highest mixing temperature of 80°F. In the high strength case, curing at 100°F resulted in the highest strength of the group. For the low strength mix, the 100°F and 80°F cures were almost identical. The 60°F mix had the lowest compressive strength out of both mixes, as can be seen in the graphs. These graphs show that a high curing temperature results in high initial strength. This pattern is similar to what was found with Portland cement in the background research.

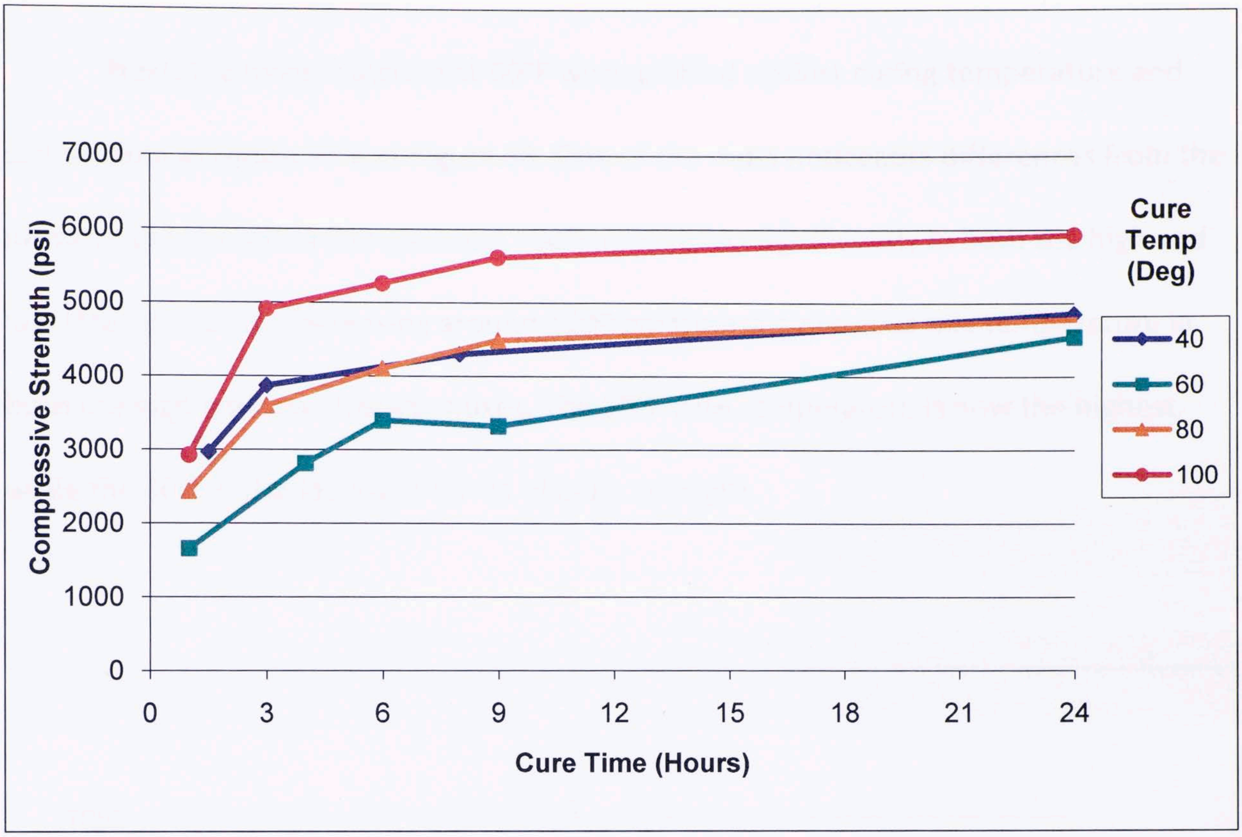

Figure 35 - Early Gains, High Strength, Mixed at 80°F

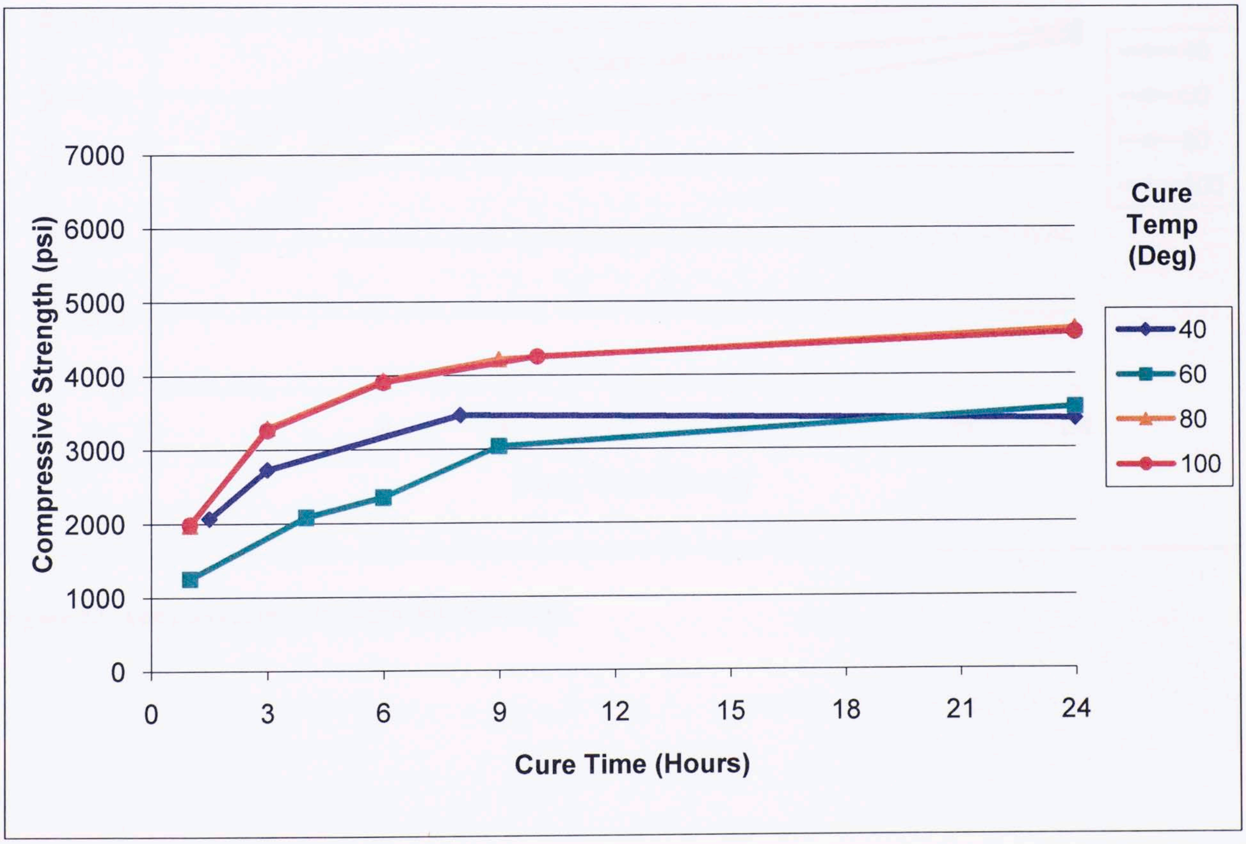

Figure 36 - Early Gains, Low Strength, Mixed at 80°F

Next, the mixes batched at 60°F were plotted against curing temperature and can be seen in Figure 37 and Figure 38. One of the most noticeable differences from the previous graphs is that the warmest 100°F cure drops significantly in both the high and low strength cases, decreasing around 1000 psi from the previous mix temperature in both the high and low strength mixes. The 80°F cure temperature is now the highest while the 40°F is the lowest in terms of early strength.

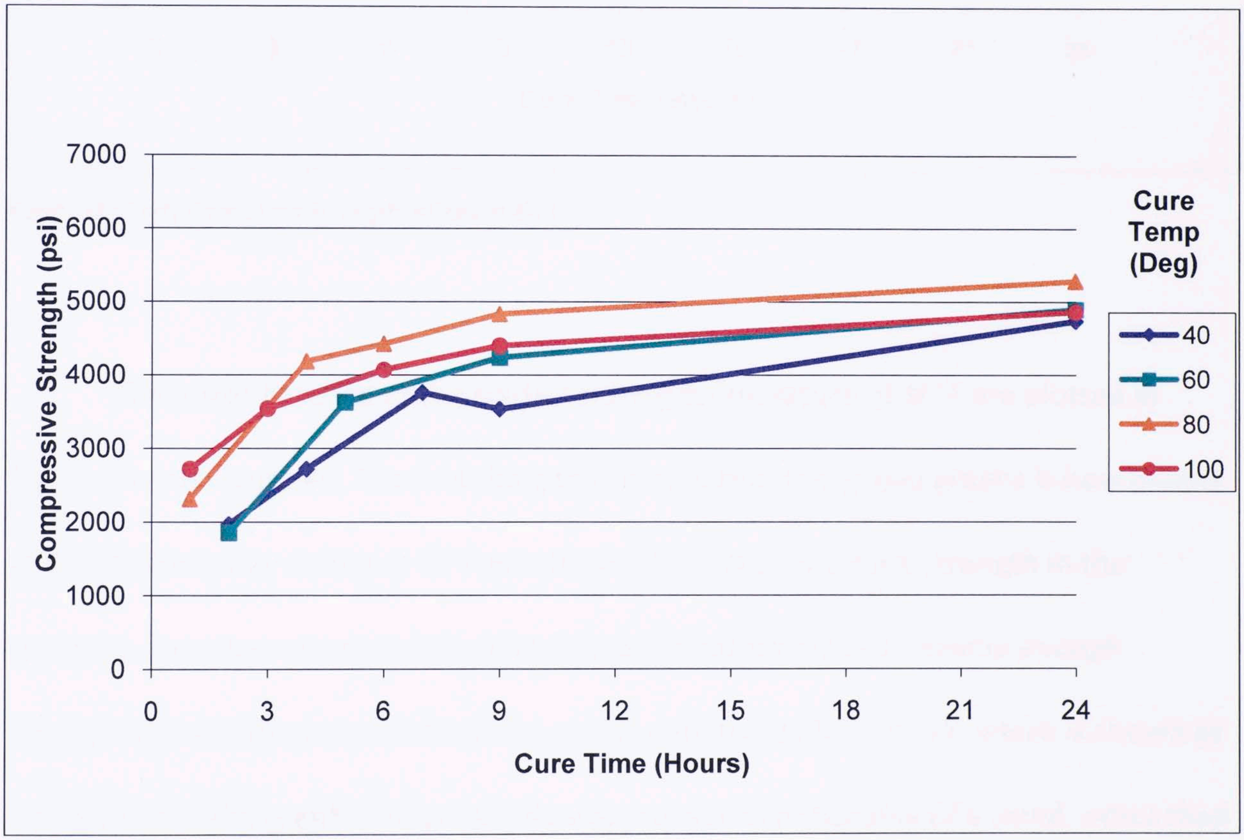

Figure 37 - Early Gains, High Strength, Mixed at 60°F

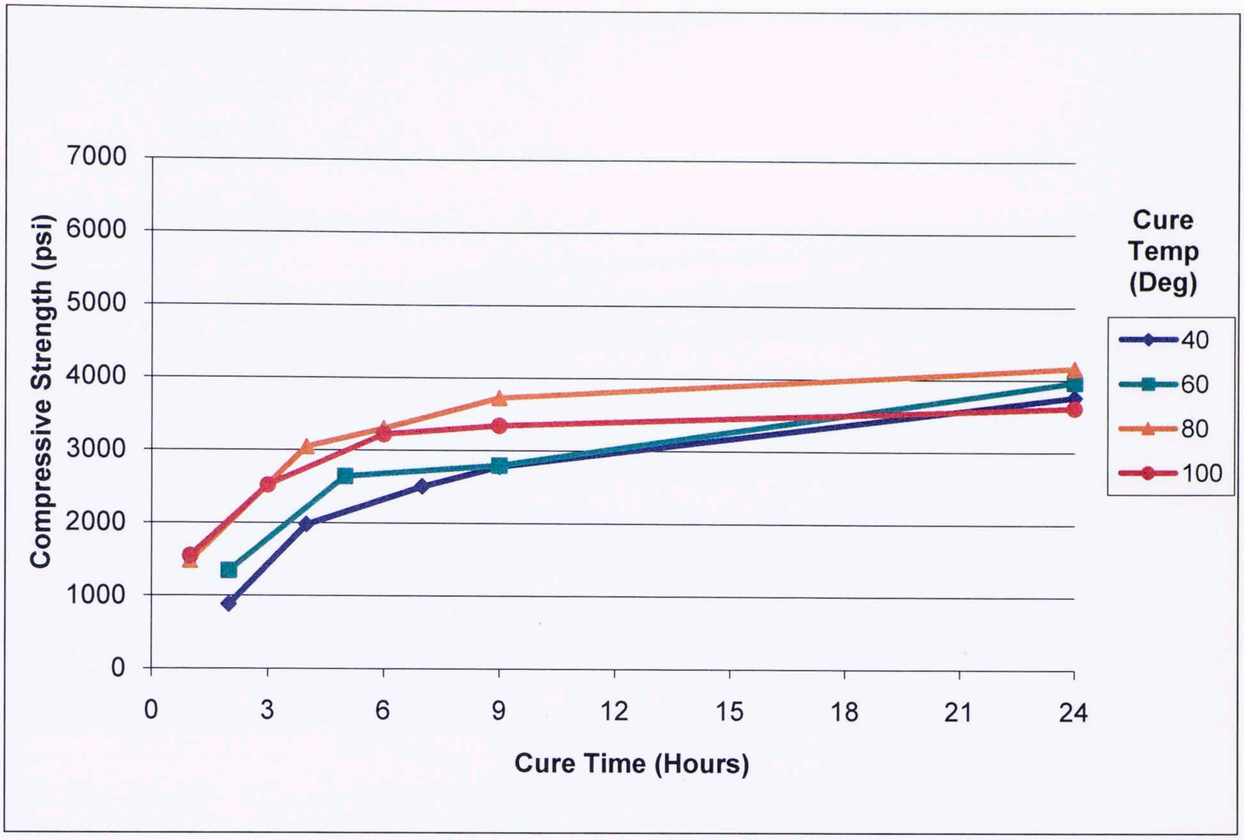

Figure 38 - Early Gains, Low Strength, Mixed at 60°F

The mixes batched at the coldest mixing temperature of 40°F are plotted in Figure 39 and Figure 40. The first thing that is apparent in the two graphs is how mixing at 40°F followed by curing at 40°F practically eliminates any early strength in the concrete. Samples mixed and cured at this temperature did not develop enough strength to even be removed from the molds until the 24 hour mark, which is shown as a single dot in the graph. The graphs do not present as noticeable of a trend, other than that the curing temperatures of 80°F and 100°F have a relatively high initial strength during the first hours of curing compared to the other curing temperatures.

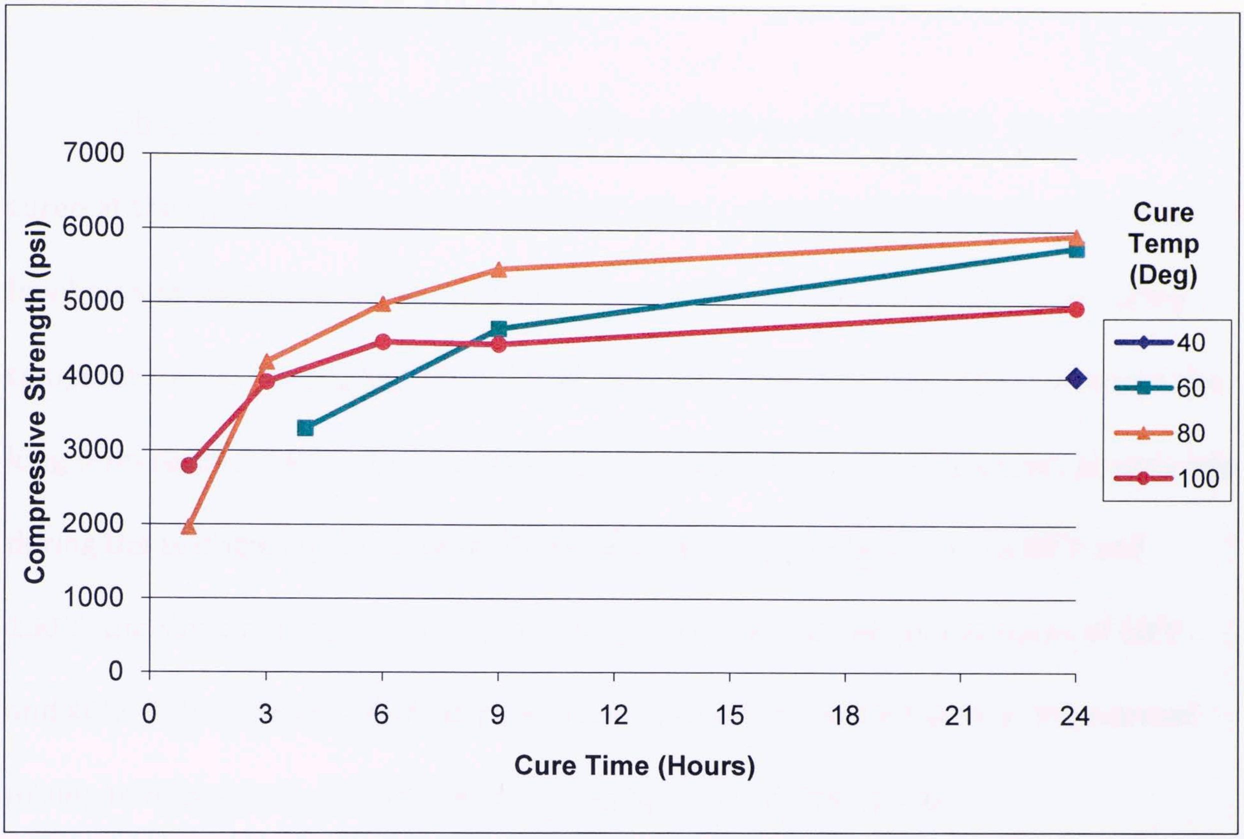

Figure 39 - Early Gains, High Strength, Mixed at 40°F

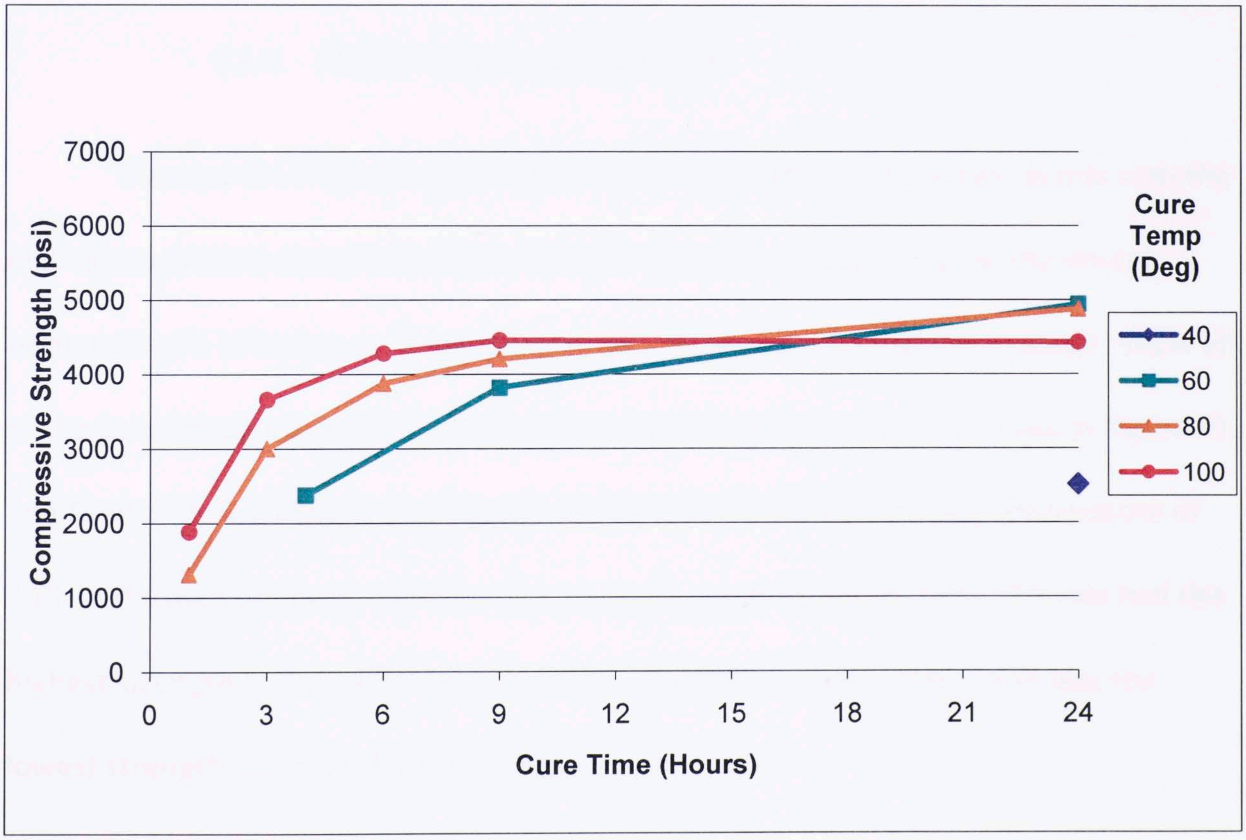

Figure 40 - Early Gains, Low Strength, Mixed at 40°F

Observations can be made about the results from these graphs. The concrete cured at the warmest temperature of 100°F shows a strong initial strength in the first few hours of curing, but show a definite drop in strength, relative to the other curing temperatures, as the mixing temperature decreases. This coincides with the data in the long term results graphs. It is also interesting to note the slope of the curves at early age during the first few hours of curing. At the warmer cure temperatures of 80°F and 100°F, the slope of the lines are steeper than the cooler curing temperatures of 60°F and 40°F. This slope indicated that the rate of hydration may be higher at the warmer mixing temperatures, and thus there is a greater rate of strength gain.

6.1.2 Mixing Temperature, Early Age

The next set of graphs presented show each of the curing temperatures with the mixing temperature plotted as the variable. From this, we can compare the mixing temperature's influence on the early strength of the mix. The first set of graphs show all of the samples cured at 100°F at the different mixing temperatures, as seen in Figure 41 and Figure 42. The high strength graph shows that the warmer mixing temperature of 80°F performed the best, while the low strength graph shows that the 40°F mix had the highest strength in the early hours of curing. The 60°F mixing temperature was the lowest strength out of both of the mixes.

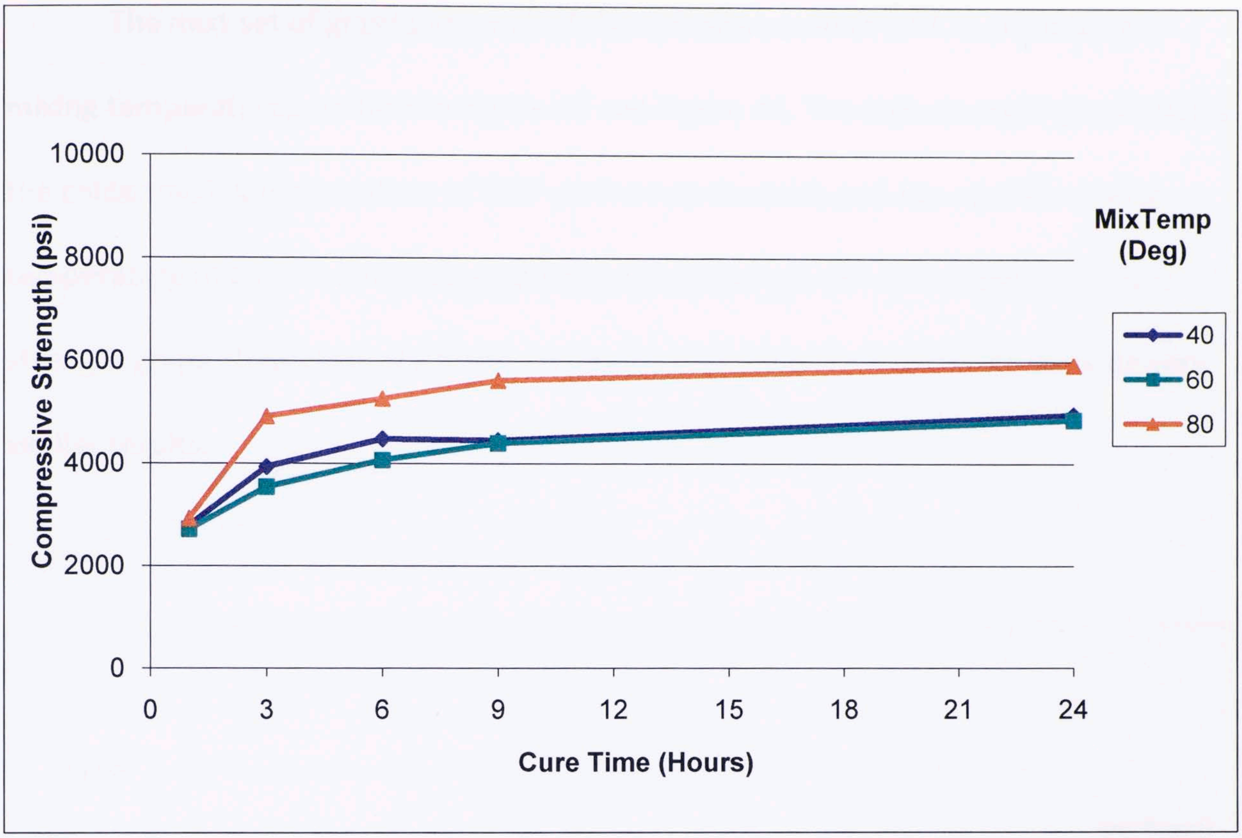

Figure 41 - Early Gains, High Strength, Cured at 100°F

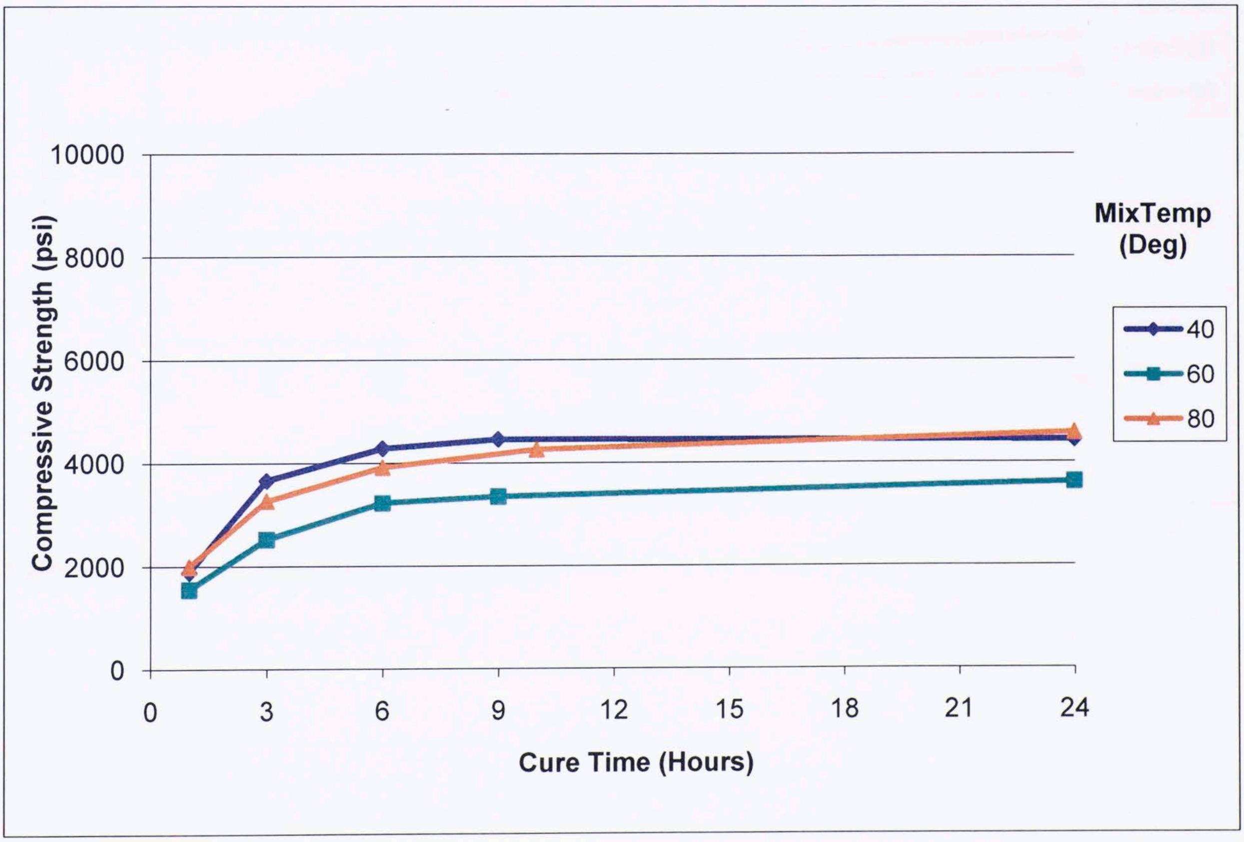

Figure 42 - Early Gains, Low Strength, Cured at 100°F

The next set of graphs show all of the samples cured at 80°F at the different mixing temperatures, as seen in Figure 43 and Figure 44. The high strength graph shows the colder mixing temperature of 40°F performed the best, and the warmer mixing temperature of 80°F had the lowest compressive strength out of the group. The low strength graph shows less of a trend, as can be seen from the trend lines showing very similar results.

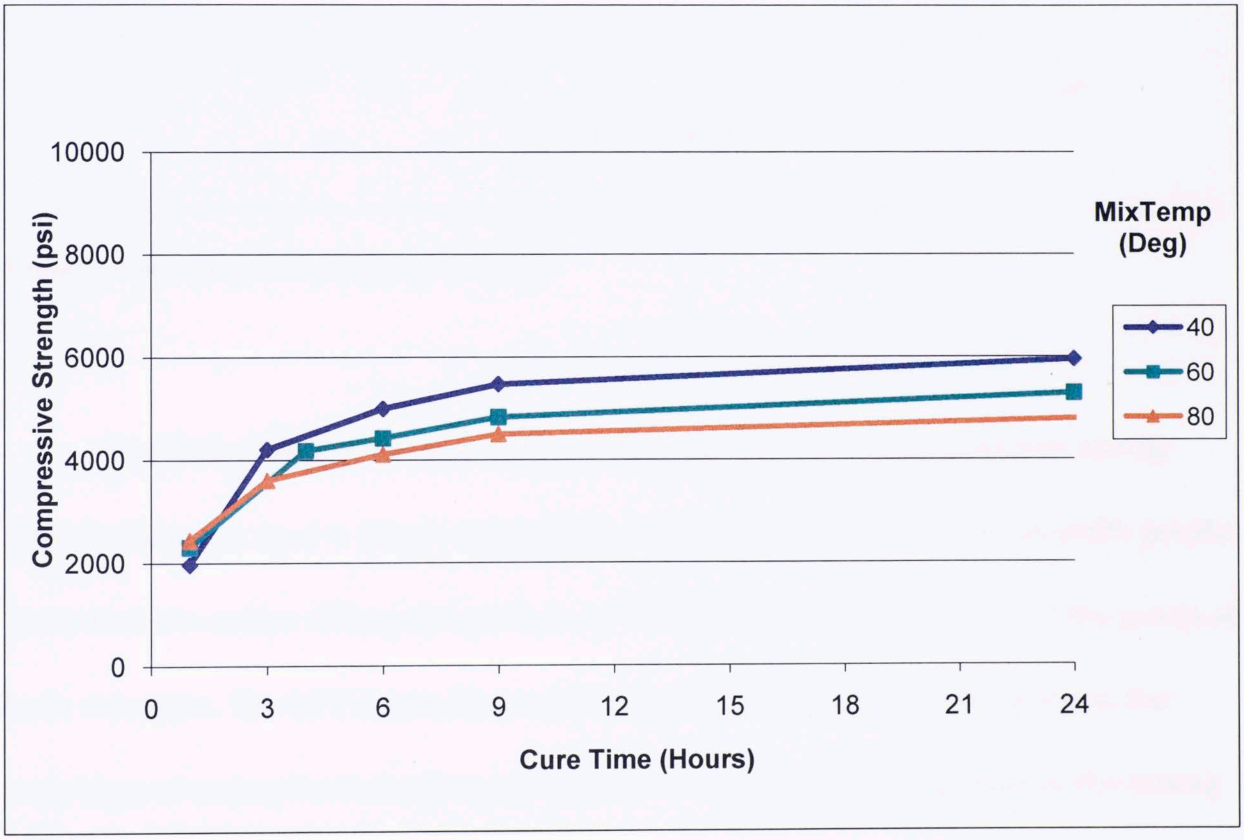

Figure 43 - Early Gains, High Strength, Cured at 80°F

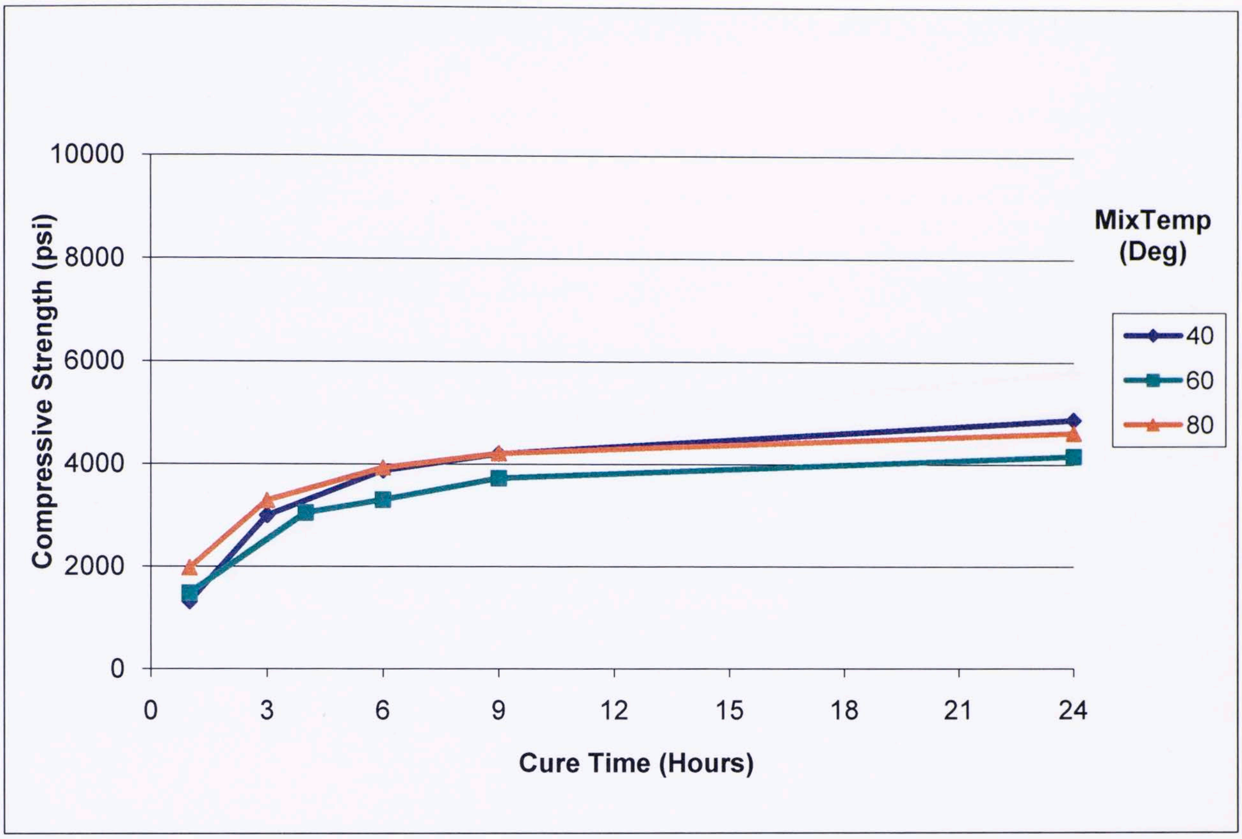

Figure 44 - Early Gains, Low Strength, Cured at 80°F

The following graphs show the samples cured at 60°F at the different mixing temperatures, as seen in Figure 45 and Figure 46. Both the high and low strength graphs show that the colder mixing temperature of 40°F performed the best out of the group at both strengths. The 80°F mixes returned the lowest strength out of the group in the early ages of curing for both strengths as well. It is important to note that as the mixing and curing temperatures decreased, there are fewer data points for each of the temperatures because the samples were not sufficiently strong enough to remove from the molds and test.

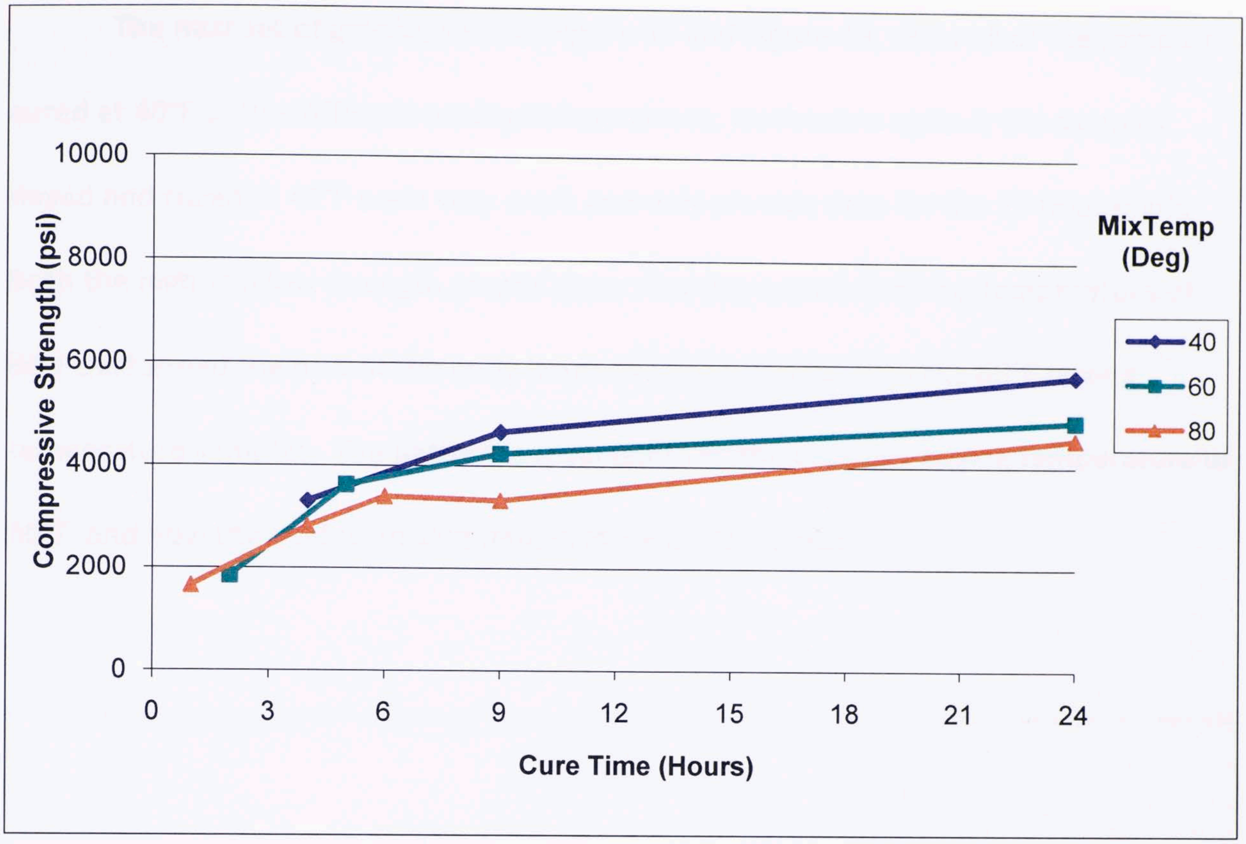

Figure 45 - Early Gains, High Strength, Cured at 60°F

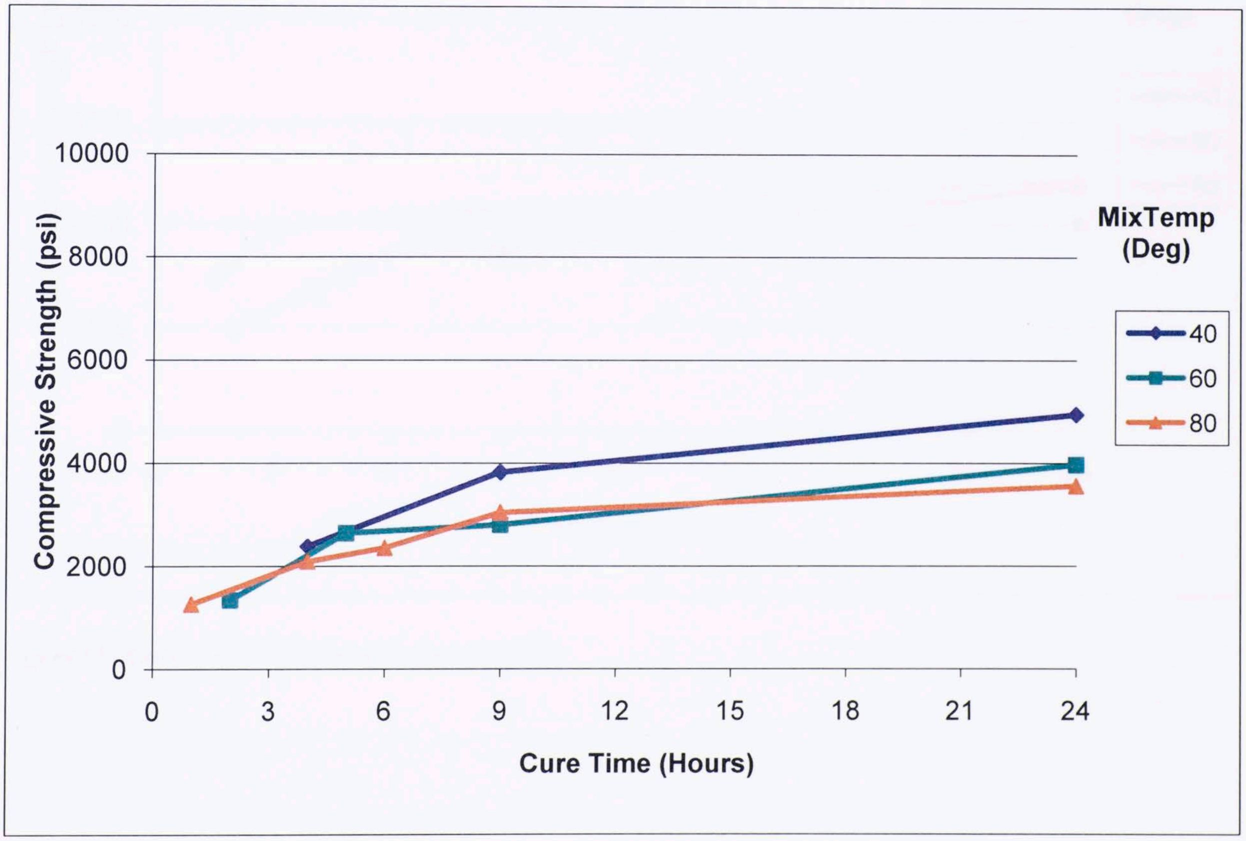

Figure 46 - Early Gains, Low Strength, Cured at 60°F

The next set of graphs, seen in Figure 47 and Figure 48, show all of the samples cured at 40°F at the different mixing temperatures. Noticeable again is the samples mixed and cured at 40°F were very weak and only provide data for the 24 hour mark. Both the high and low strength graphs show that the warmest mixing temperature of 80°F performed the best at the early hours of curing, followed by the 60°F mixing temperature samples. The pattern is reversed from the previous mixing temperature of 60°F, and now the coldest mixing temperature is the weakest.

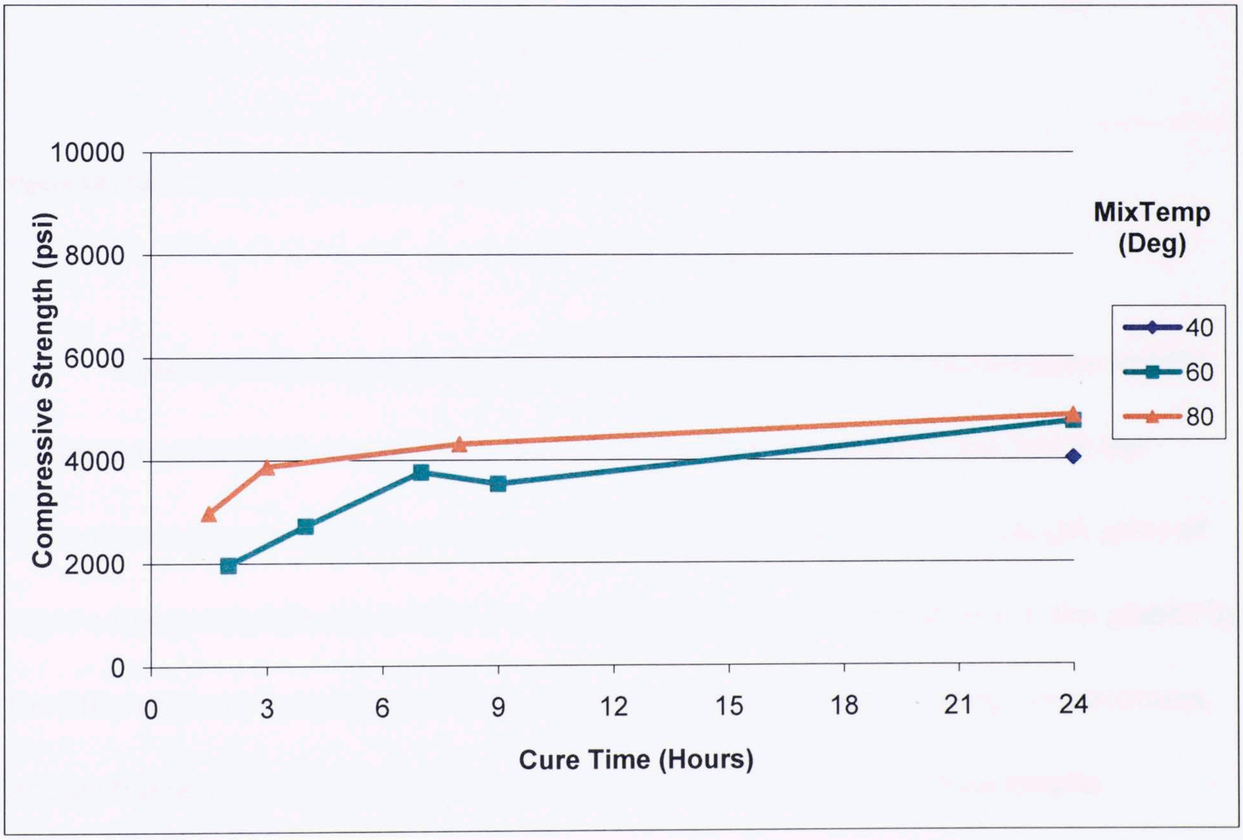

Figure 47 - Early Gains, High Strength, Cured at 40°F

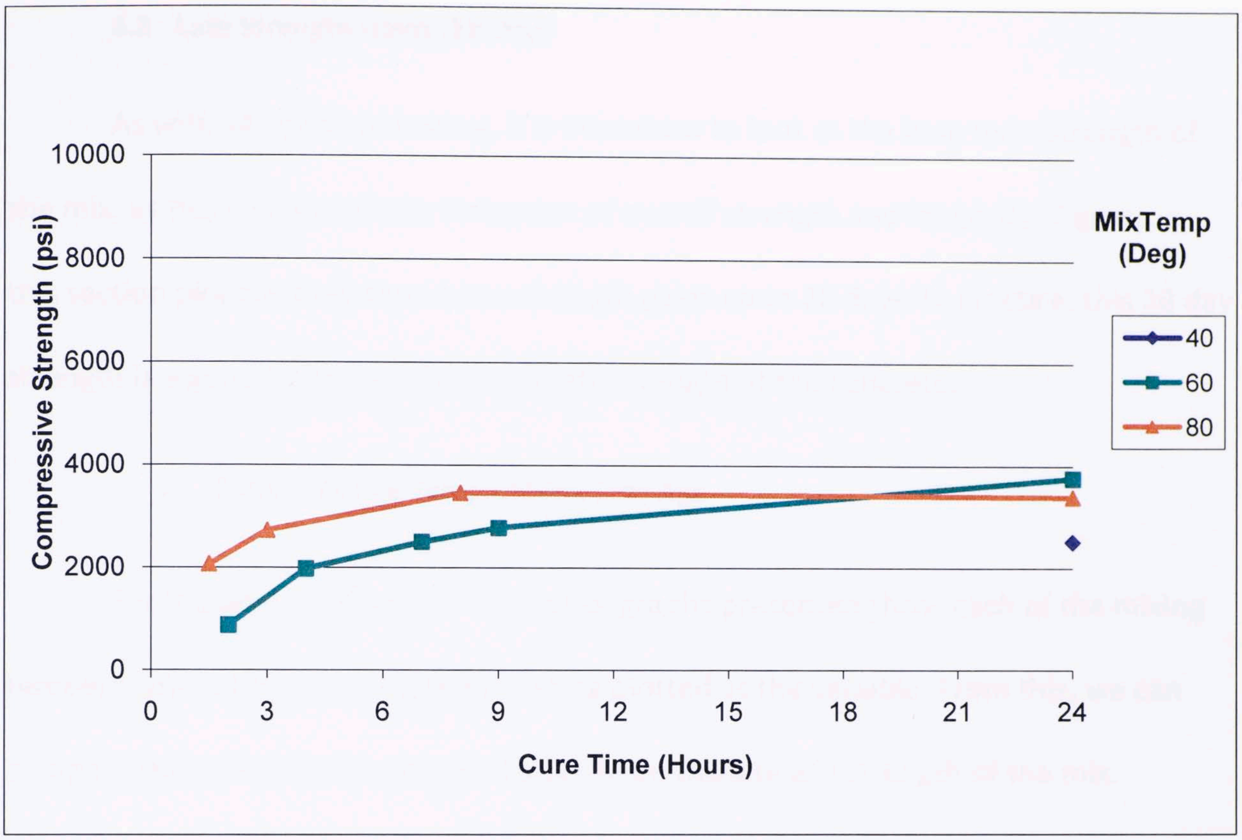

Figure 48 - Early Gains, Low Strength, Cured at 40°F

Looking at these graphs where the curing temperature is held constant and the mixing temperature is the variable, we can draw a few conclusions. The first is the mixing temperature appears to have less of an influence on the early strength gains of the rapid setting concrete mixes than the curing temperature. This is shown in the graphs by the little variance in compressive strength results for each of the mixing temperatures, and by the fact that there is no consistent trend between each of these graphs.

The second observation is that as the curing temperature decreases, the slopes of the lines in the early hour of curing decrease. This suggests that the rate of hydration and hardening probably decrease as the curing temperature decreases.

6.2 Late Strength Gains (28 Day)

As with all concrete testing, it is important to look at the long term strength of the mix, as this will provide an indication of overall strength and longevity. Figures in this section plot the long-term term strength gains up to 28 days. In practice, this 28 day strength is a good indicator of the ultimate strength of the concrete.

6.2.1 Curing Temperature, Late Age

For the late age data, the first set of graphs presented show each of the mixing temperatures with the curing temperature plotted as the variable. From this, we can compare the curing temperature's influence on the late age strength of the mix.

The results of the highest mix temperature, 80°F, can be found in Figure 49 and Figure 50. This shows one of the clearest trends out of the group. As the curing temperature decreases, so does the overall strength. The warmer curing temperatures of 80°F and 100°F have a strong initial increase in early strength, and then slowly but gradually gain strength over the long term. The cooler curing temperatures of 40°F and 60°F degrees also gain early strength rapidly, but tend to not develop strength past the seven day curing time. This pattern of higher curing temperature and higher strength differ from the patterns seen with Portland cement in the literature review, where the colder curing temperatures are stronger in the late age.

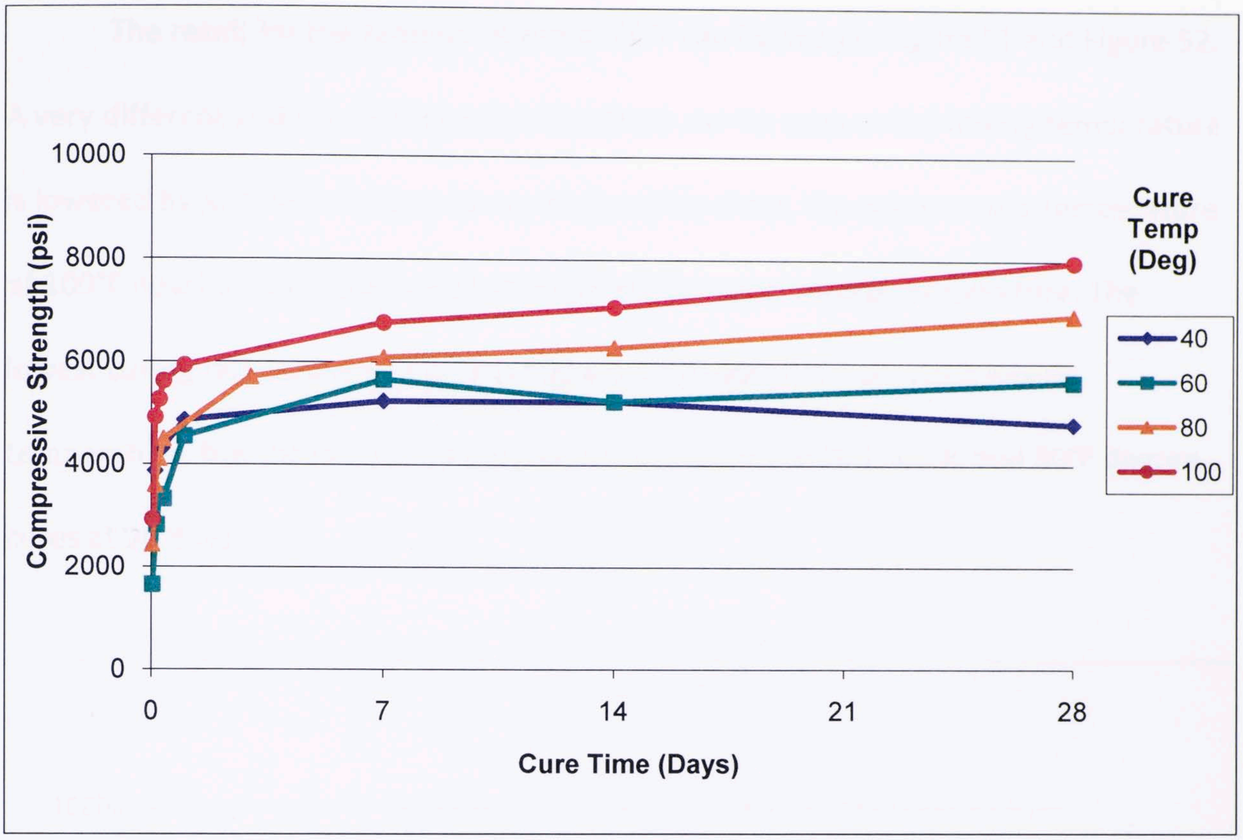

Figure 49 - Mix at 80°F, High Strength

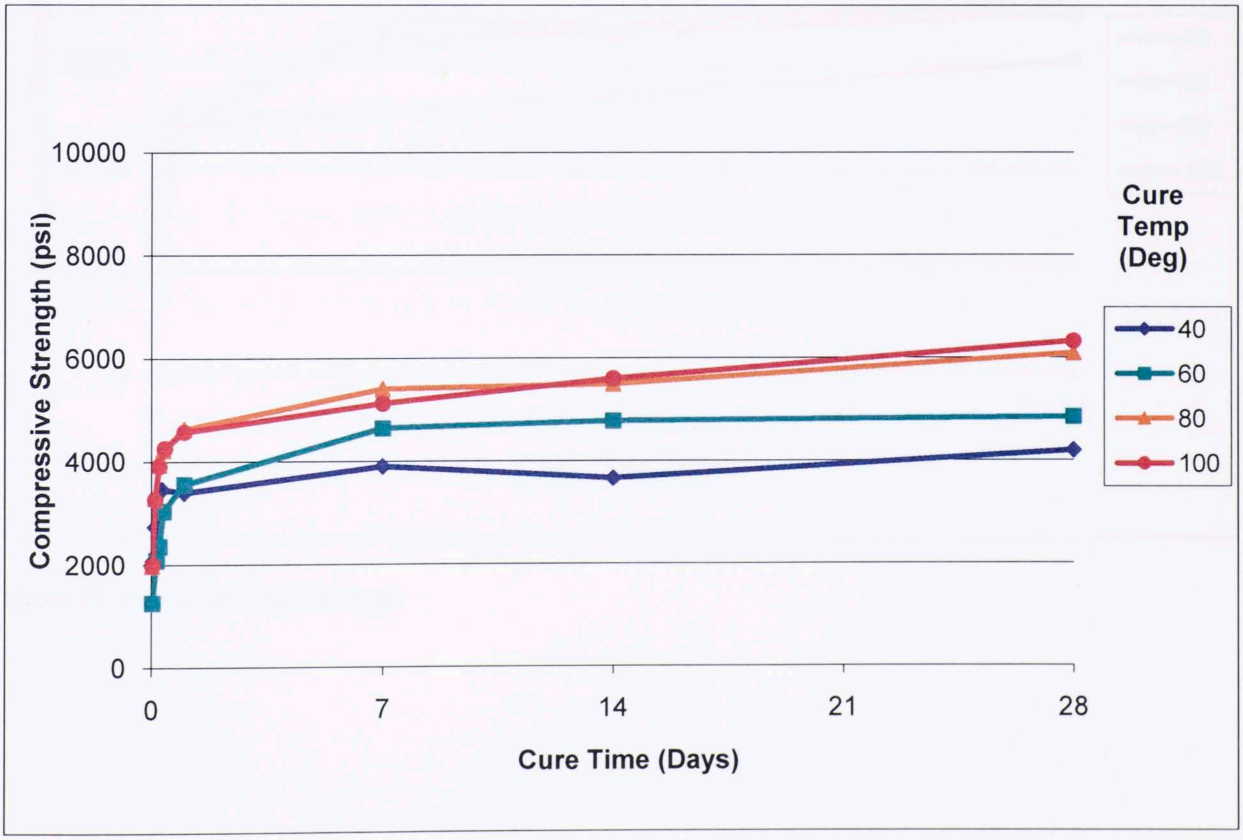

Figure 50 - Mix at 80°F, Low Strength

The result for the samples mixed at 60°F can be seen in Figure 51 and Figure 52. A very different and less distinguishable pattern can be seen as the mixing temperature is lowered by just 20°F. In contrast to the previous chart, the warmer cure temperature of 100°F now has the least overall strength at the cooler mixing temperature. The lowest curing temperature of 40°F is higher compared to the previous mixing temperature, but the results are very similar between the 40°F, 60°F, and 80°F degree cures at 28 days.

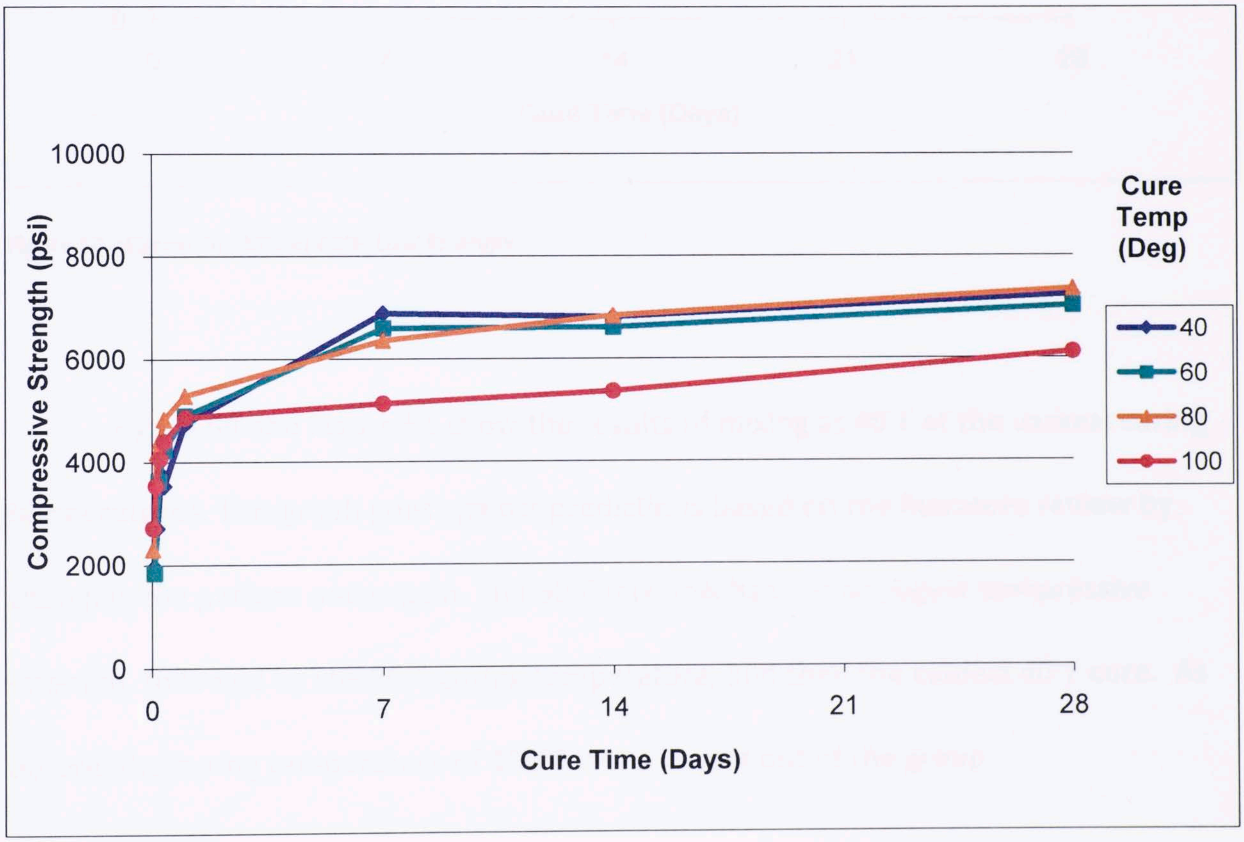

Figure 51 - Mix at 60°F, High Strength

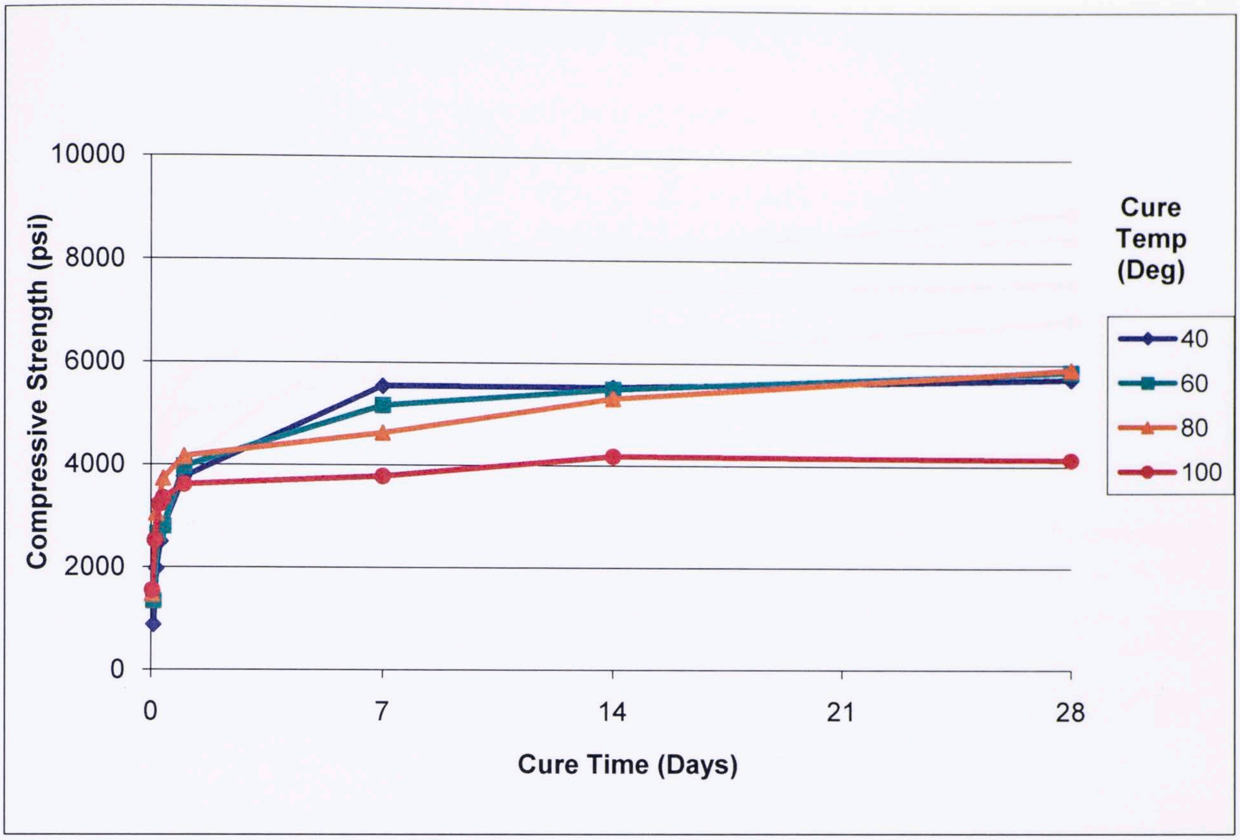

Figure 52 - Figure 36 - Mix at 60°F, Low Strength

Figure 53 and Figure 54 show the results of mixing at 40°F at the various curing temperatures. This graph goes against predictions based on the literature review by changing the pattern once again. The 60°F mix now has the strongest compressive strength, followed by the 80°F curing temperature, and then the coldest 40°F cure. As before, the curing temperature of 100°F is the lowest out of the group.

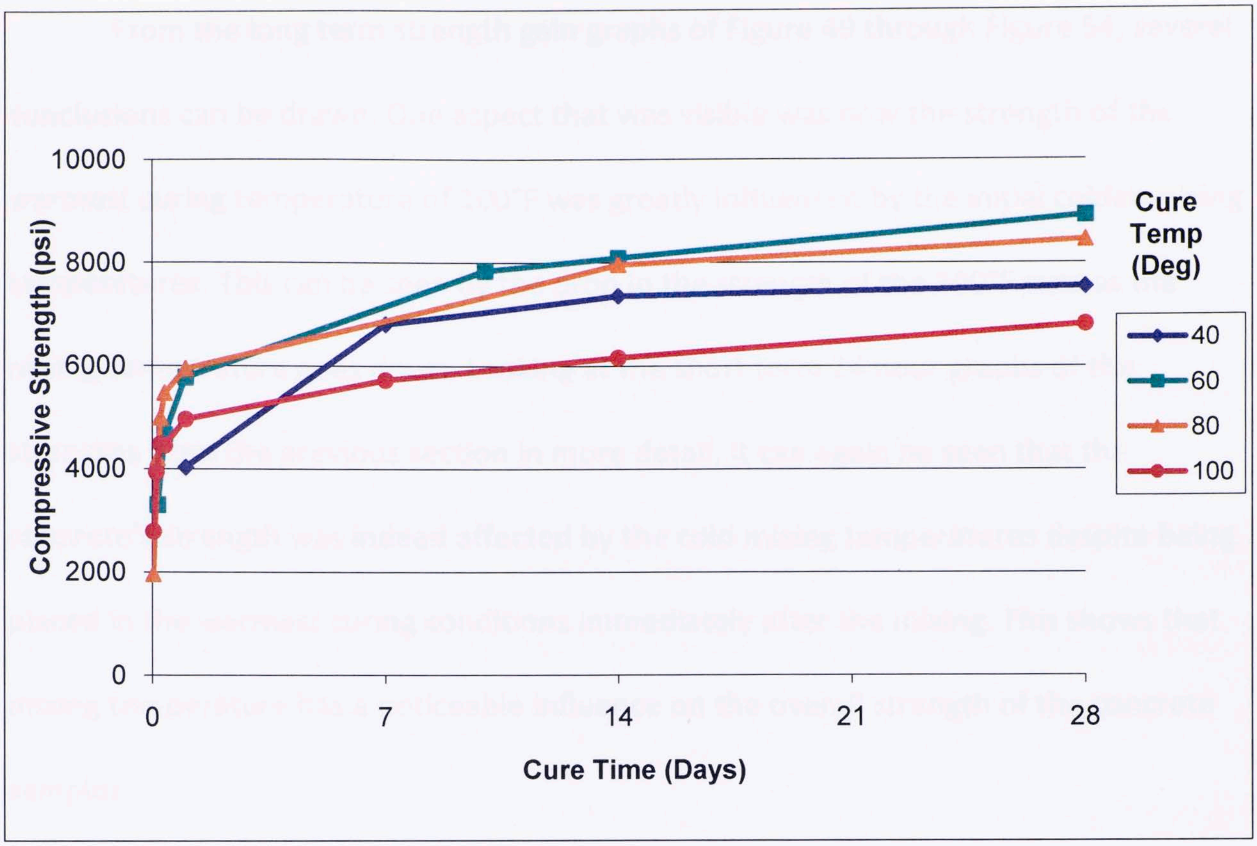

Figure 53 - Mix at 40°F, High Strength

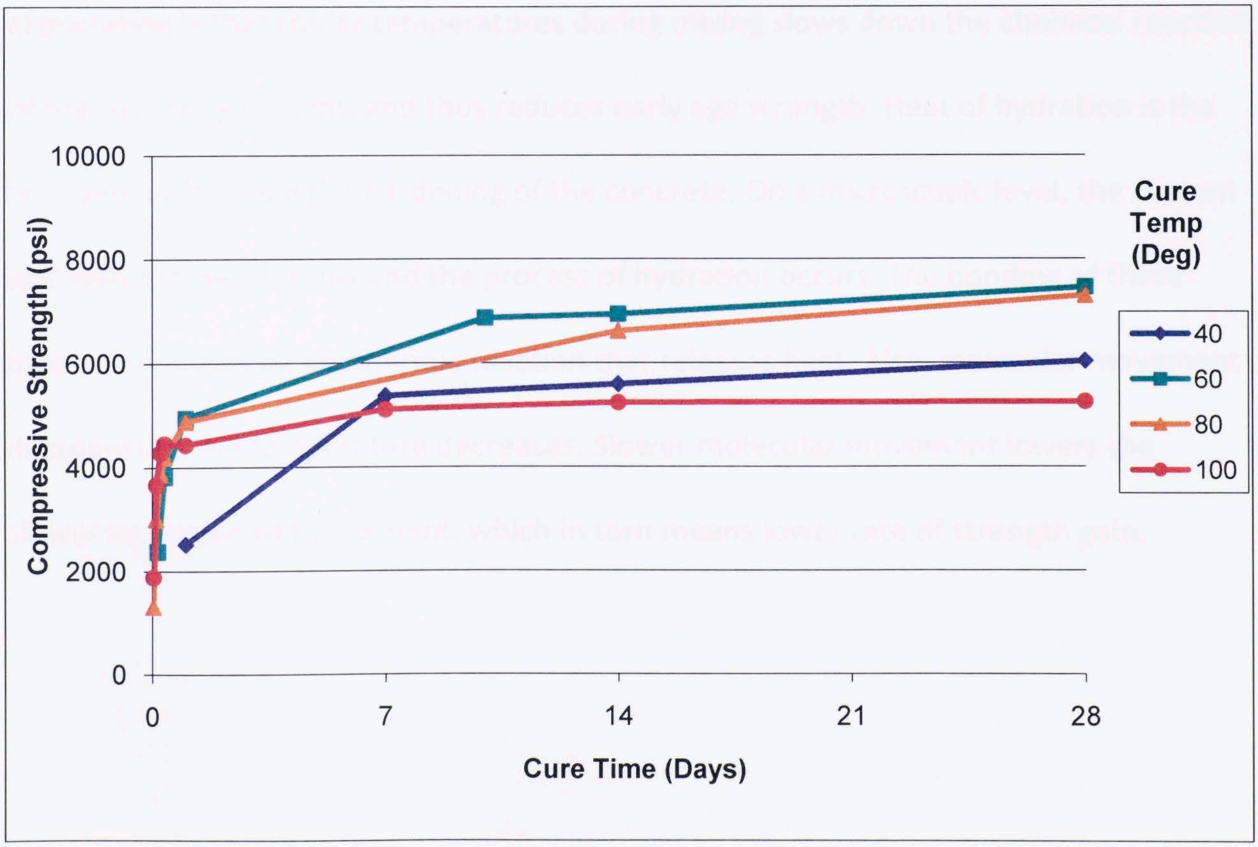

Figure 54 - Mix at 40°F, Low Strength

From the long term strength gain graphs of Figure 49 through Figure 54, several conclusions can be drawn. One aspect that was visible was how the strength of the warmest curing temperature of 100°F was greatly influenced by the initial colder mixing temperatures. This can be seen by the drop in the strength of the 100°F cure as the mixing temperature goes down. Looking at the short term 24 hour graphs of the strengths from the previous section in more detail, it can again be seen that the concrete's strength was indeed affected by the cold mixing temperatures despite being placed in the warmest curing conditions immediately after the mixing. This shows that mixing temperature has a noticeable influence on the overall strength of the concrete samples.

There could be several reasons for this phenomenon. The most reasonable explanation is that cooler temperatures during mixing slows down the chemical reaction of the hydrating cement, and thus reduces early age strength. Heat of hydration is the heat given off during the hardening of the concrete. On a microscopic level, the cement and water molecules mix and the process of hydration occurs. The bonding of these molecules causes an exothermic reaction that releases heat. Also, molecular movement decreases as the temperature decreases. Slower molecular movement lowers the slower hydration of the cement, which in turn means lower rate of strength gain.

6.2.2 Mixing Temperature, Late Age

The next step was to compare the mix temperatures while the curing temperature was held constant for the late age, 28 day curing time. This provides another means to analyze the data and discover any trends that may occur. Figure 55 to Figure 62 represent the four curing temperature conditions for both the low and high strength mixes, and plot the mixing temperatures for each.

The samples cured at 100°F shown in Figure 55 appear to show an unusual trend. The warmest mixing temperature of 80°F resulted in the highest strength, followed by the lowest mixing temperature of 40°F, and finally the mid-range 60°F mixing temperature returned the lowest strength of the group. This pattern is repeated in the low strength mix, shown in Figure 56. The warmest mixing temperature having the highest strength is unusual given the past trends that have been discussed. The results from this graph of 100°F curing temperature can be compared to the graphs of other curing temperatures for comparison.

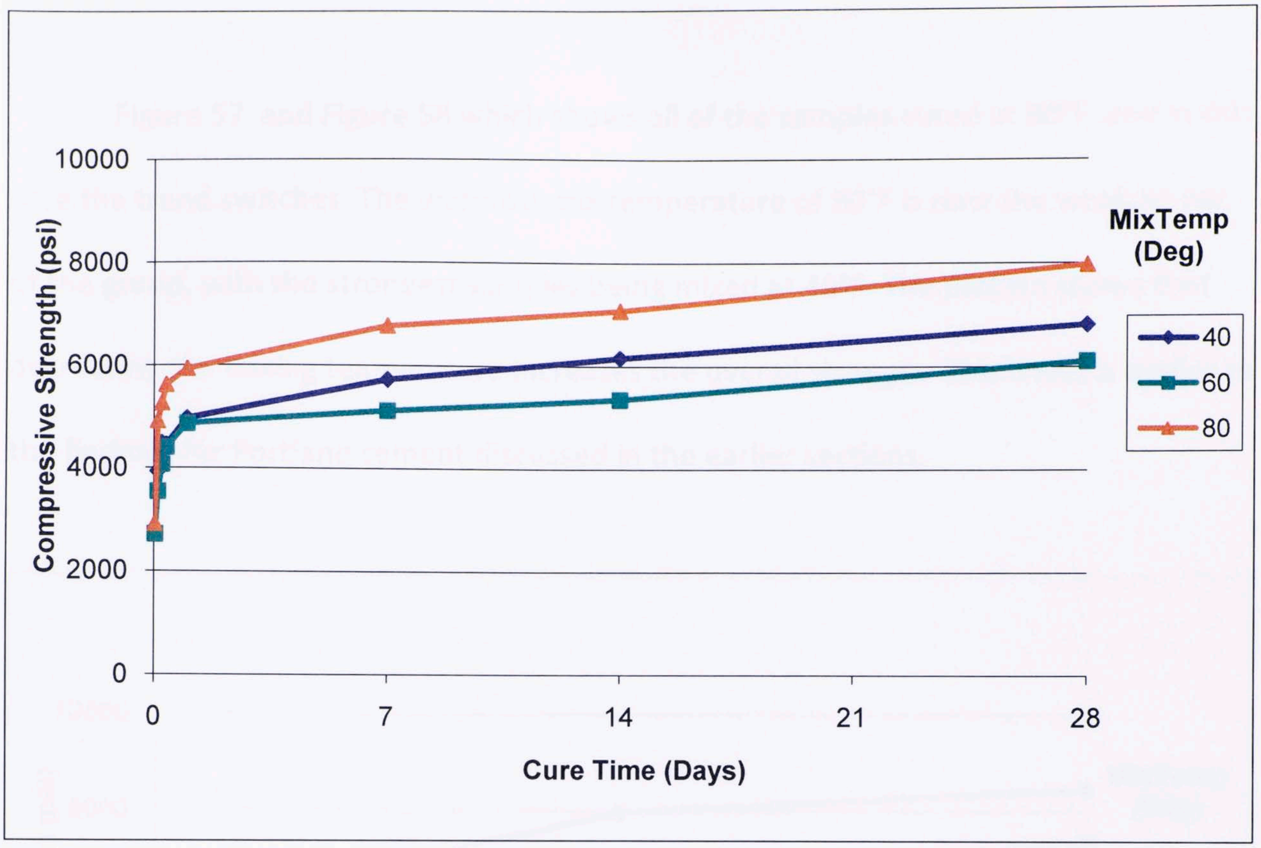

Figure 55 - Samples Cured at 100°F, High Strength

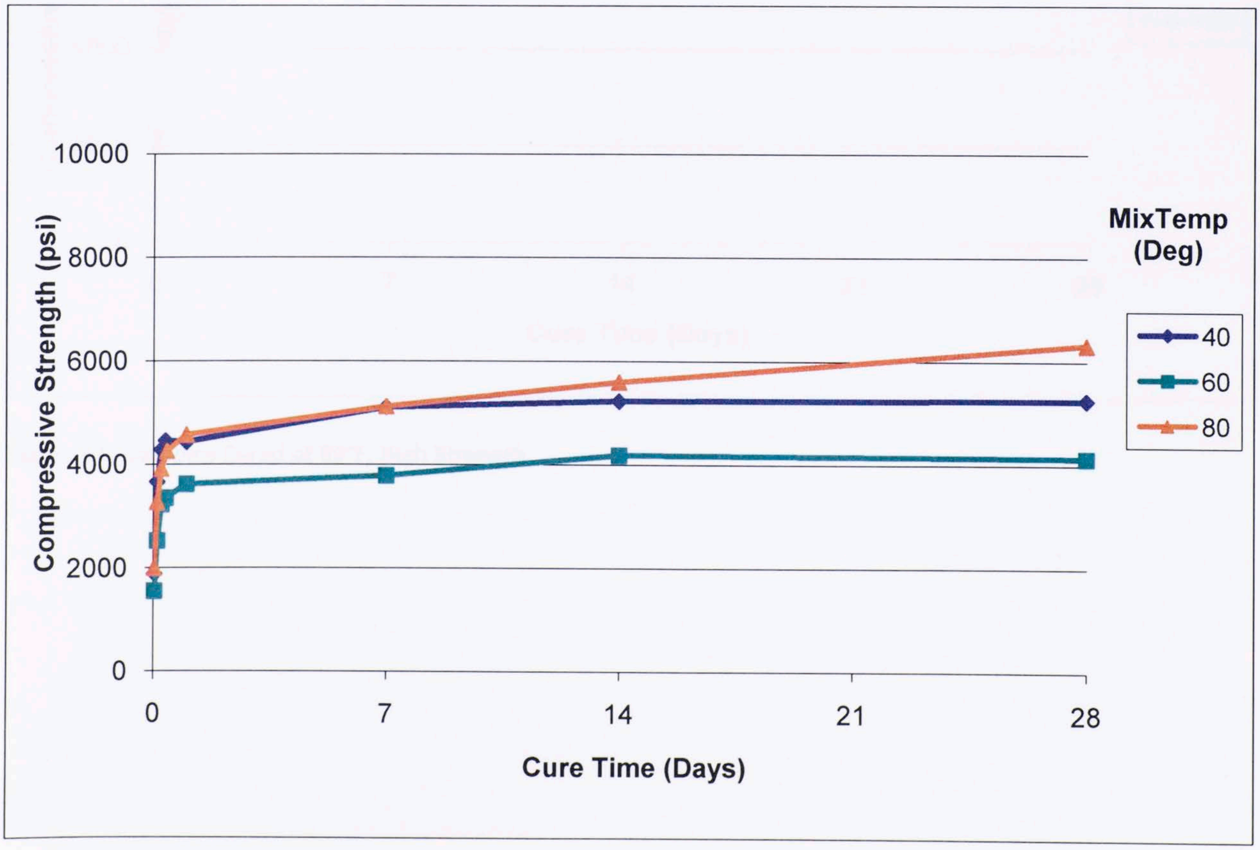

Figure 56 - Samples Cured at 100°F, Low Strength

Figure 57 and Figure 58 which shows all of the samples cured at 80°F, and in this case the trend switches. The warmest mix temperature of 80°F is now the weakest out of the group, with the strongest samples being mixed at 40°F. The pattern shows that decreasing the mixing temperature increases the overall strength. This trend is similar to the findings for Portland cement discussed in the earlier sections.

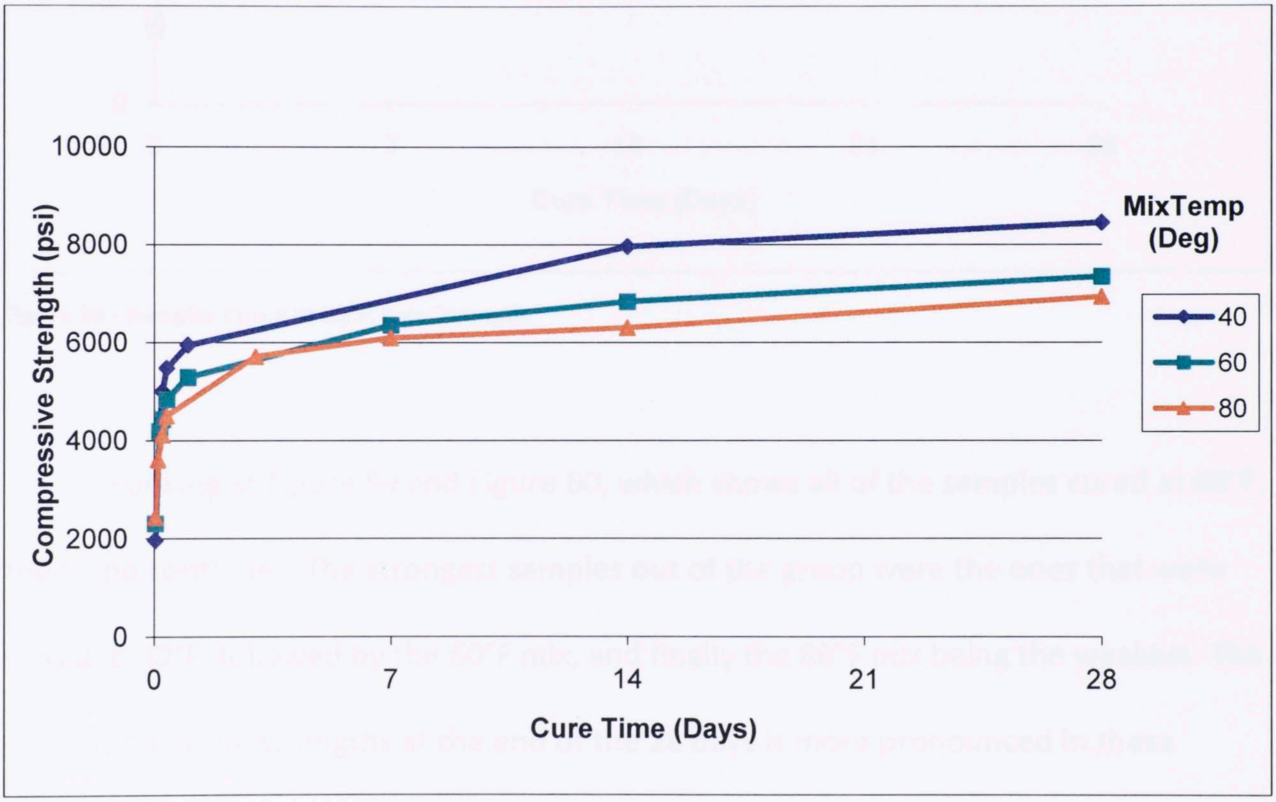

Figure 57 - Samples Cured at 80°F, High Strength

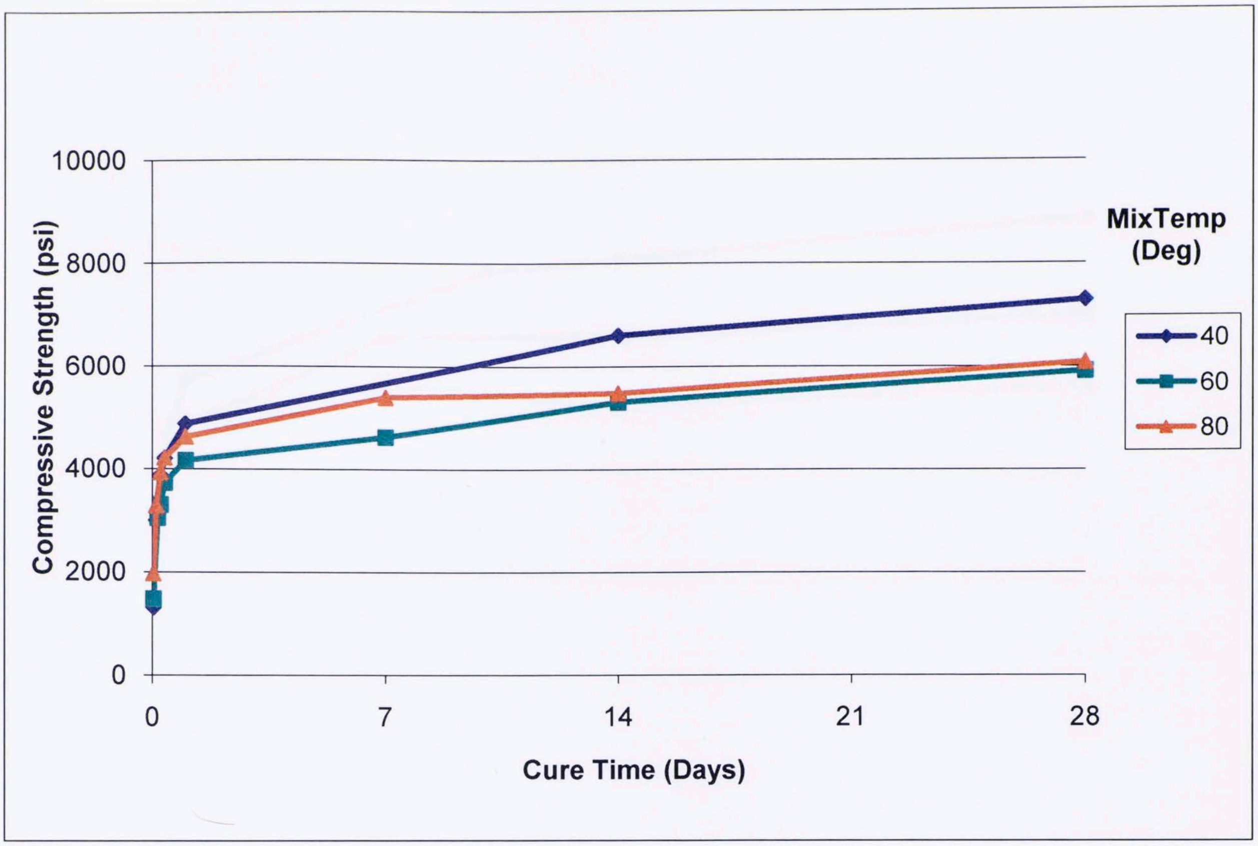

Figure 58 - Samples Cured at 80°F, Low Strength

Looking at Figure 59 and Figure 60, which shows all of the samples cured at 60°F, the trend continues. The strongest samples out of the group were the ones that were mixed at 40°F, followed by the 60°F mix, and finally the 80°F mix being the weakest. The separation of the strengths at the end of the 28 days is more pronounced in these graphs as well. Where the trend lines are closely bunched in the previous graphs at 80°F, the trend lines are now more dispersed by the 28th day for the 60°F cure. The pattern again shows that decreasing the mixing temperature increases the overall strength.

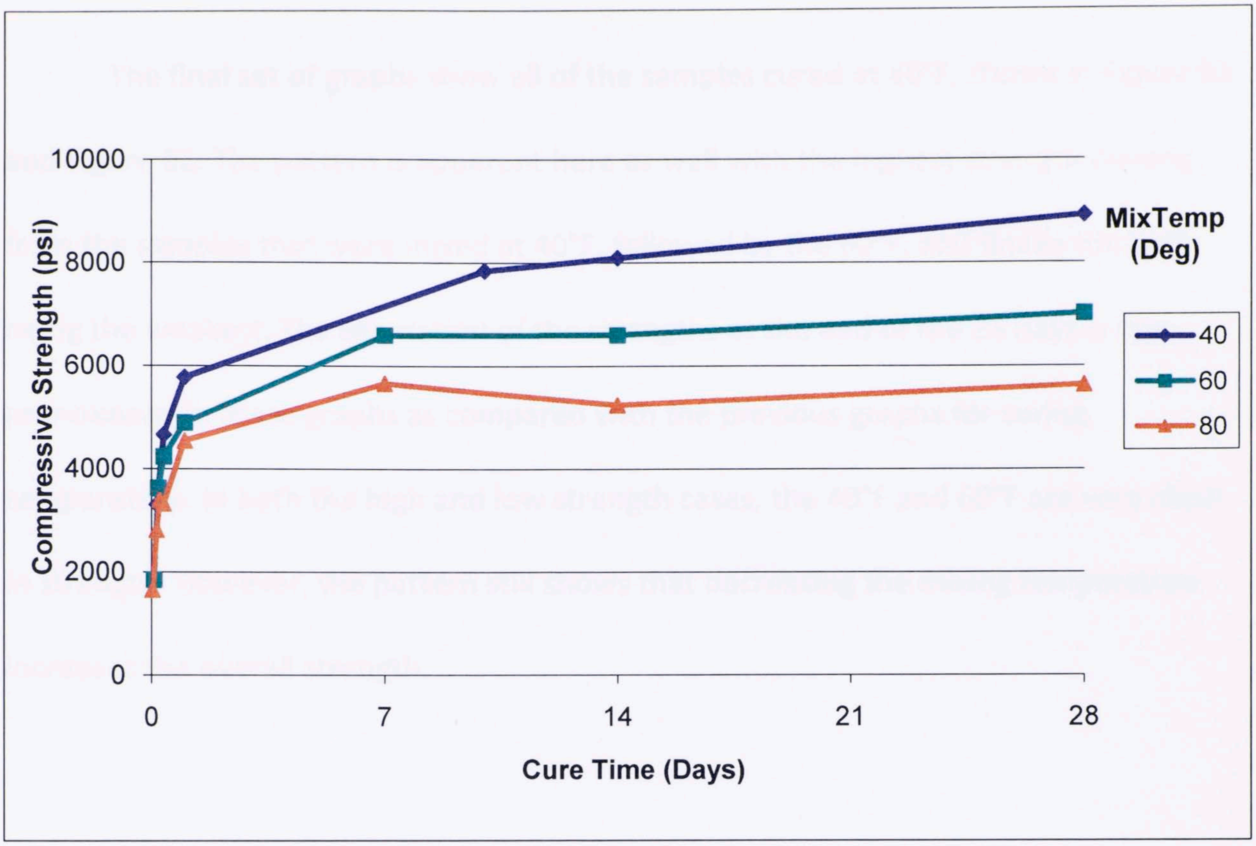

Figure 59 - Samples Cured at 60°F, High Strength

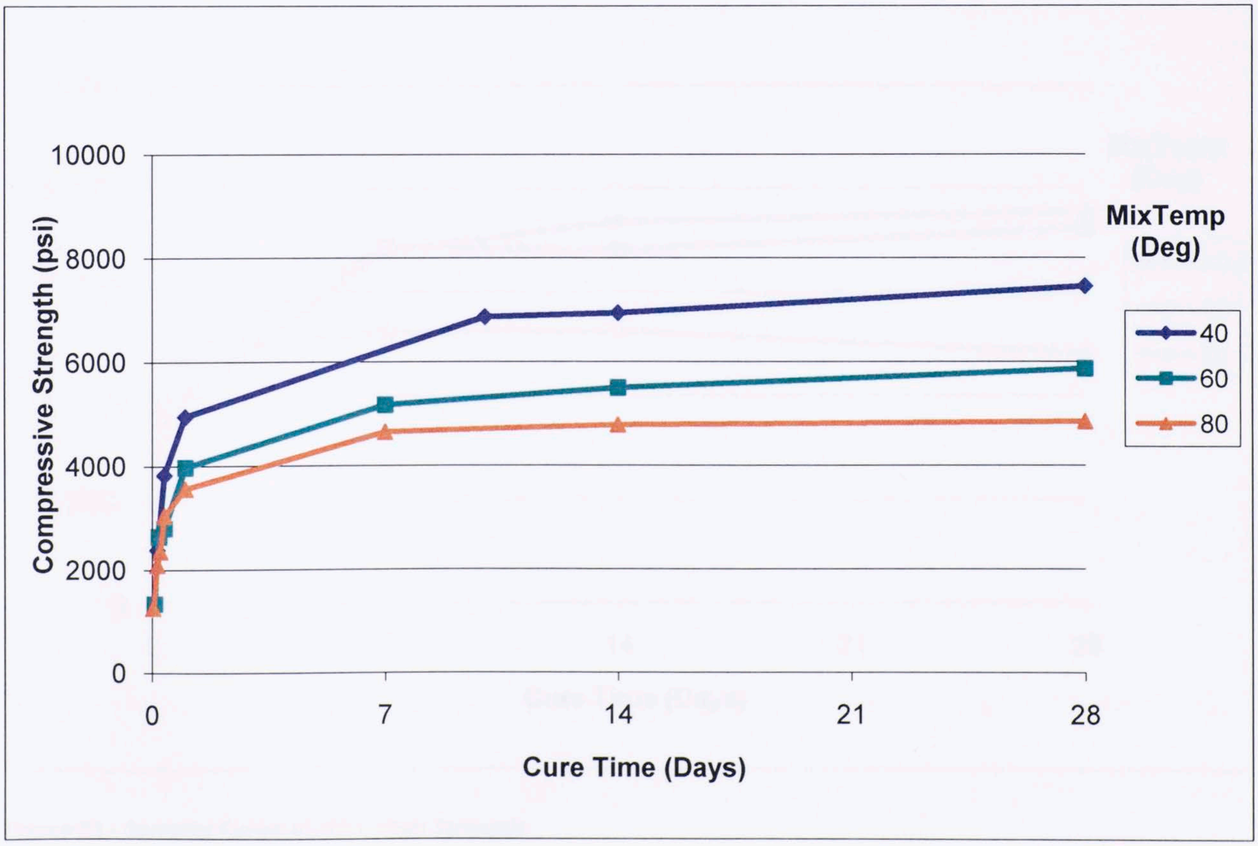

Figure 60 - Samples Cured at 60°F, Low Strength

The final set of graphs show all of the samples cured at 40°F, shown in Figure 61 and Figure 62. The pattern is apparent here as well with the highest strength coming from the samples that were mixed at 40°F, followed by the 60°F, and finally the 80°F being the weakest. The separation of the strengths at the end of the 28 days is less pronounced in these graphs as compared with the previous graphs for curing temperature. In both the high and low strength cases, the 40°F and 60°F are very close in strength. However, the pattern still shows that decreasing the mixing temperature increases the overall strength.

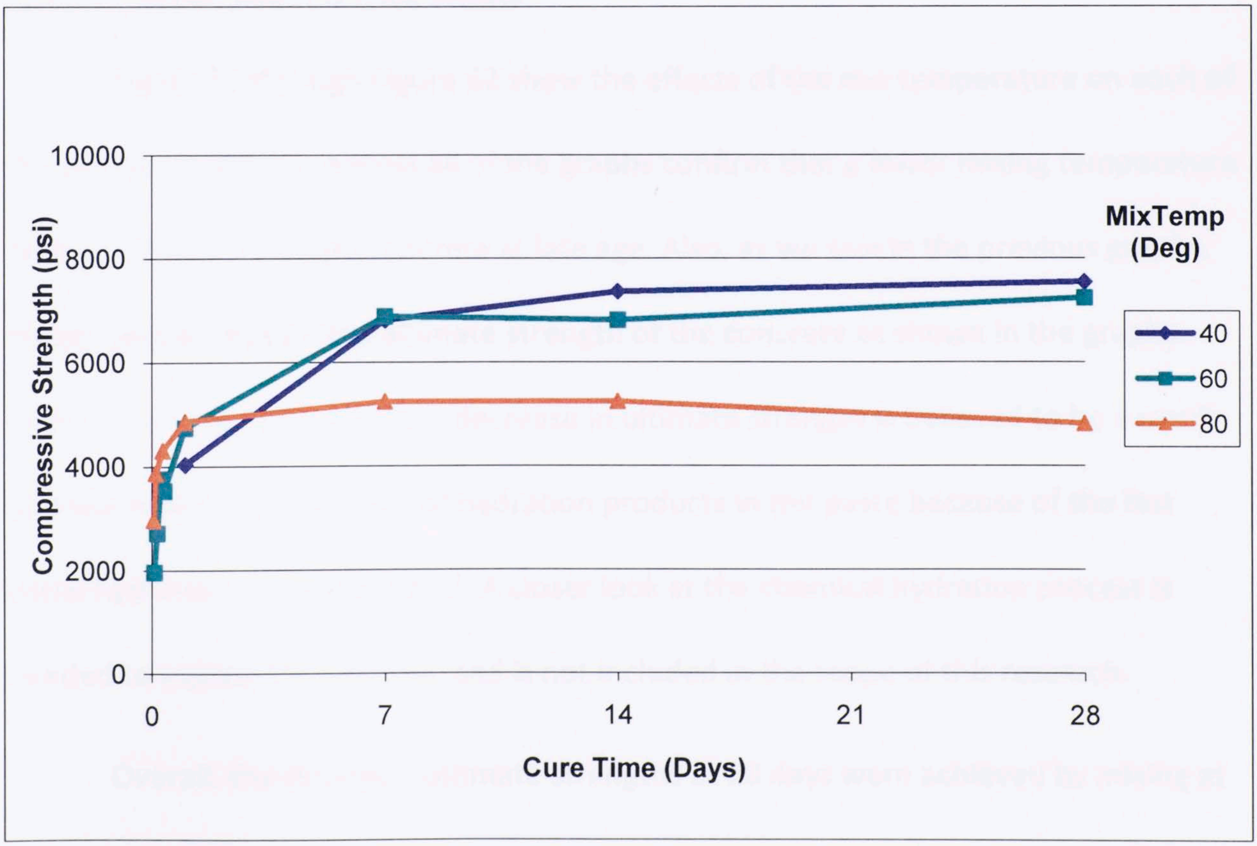

Figure 61 - Samples Cured at 40°F, High Strength

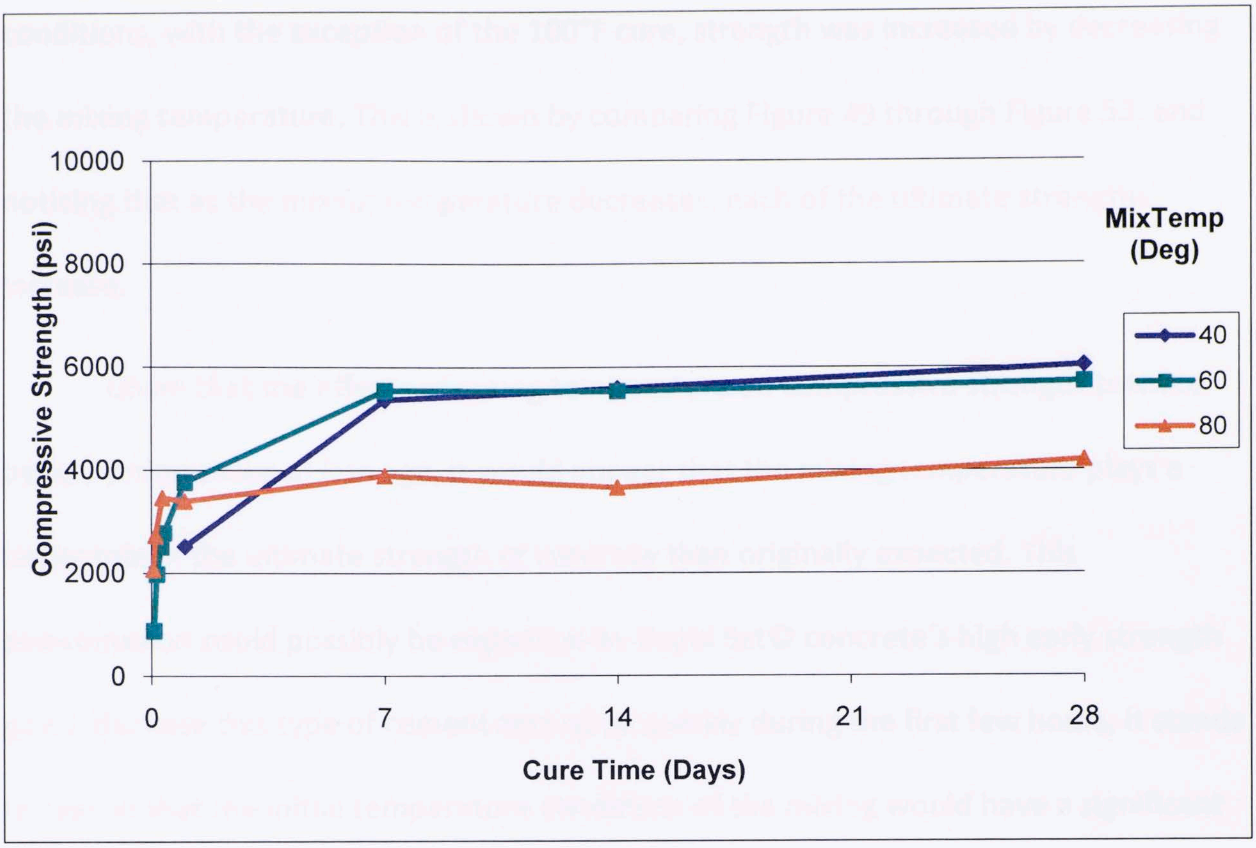

Figure 62 - Samples Cured at 40°F, Low Strength

Figure 55 through Figure 62 show the effects of the mix temperature on each of the curing conditions. Almost all of the graphs confirm that a lower mixing temperature returns a higher strength concrete at late age. Also, as we saw in the previous graphs, higher heat decreases the ultimate strength of the concrete as shown in the graphs above. One explanation for the decrease in ultimate strength is believed to be a result of a less uniform distribution of hydration products in the paste because of the fast initial hydration (Mindess, 1981). A closer look at the chemical hydration process is needed to explain this process, and is not included in the scope of this research.

Overall, the strongest ultimate strengths at 28 days were achieved by mixing at 40°F. This is shown in Figure 57 through Figure 61 with the samples mixed at 40°F being the strongest out of the group for a given curing condition. In each of the curing conditions, with the exception of the 100°F cure, strength was increased by decreasing the mixing temperature. This is shown by comparing Figure 49 through Figure 53, and noticing that as the mixing temperature decreases, each of the ultimate strengths increase.

Given that the effects of curing temperature on compressive strength seem to be less pronounced at late age, it would appear that the mixing temperature plays a larger role in the ultimate strength of concrete than originally expected. This phenomenon could possibly be explained by Rapid Set© concrete's high early strength gains. Because this type of cement sets up so quickly during the first few hours, it stands to reason that the initial temperature conditions of the mixing would have a significant effect on the overall strength of the mix.

6.3 Additional Results

Recalling from previous research discussed earlier about the effects of temperature on ordinary Portland cement (Eren, 2002), increasing the temperature increased the strength at early age, but higher temperatures over 68°F (20°C) decreased the late age strength. This study did not take mixing temperature as a variable, and instead held the mixing temperature constant with the specified cutting temperature. Recall Figure 1:

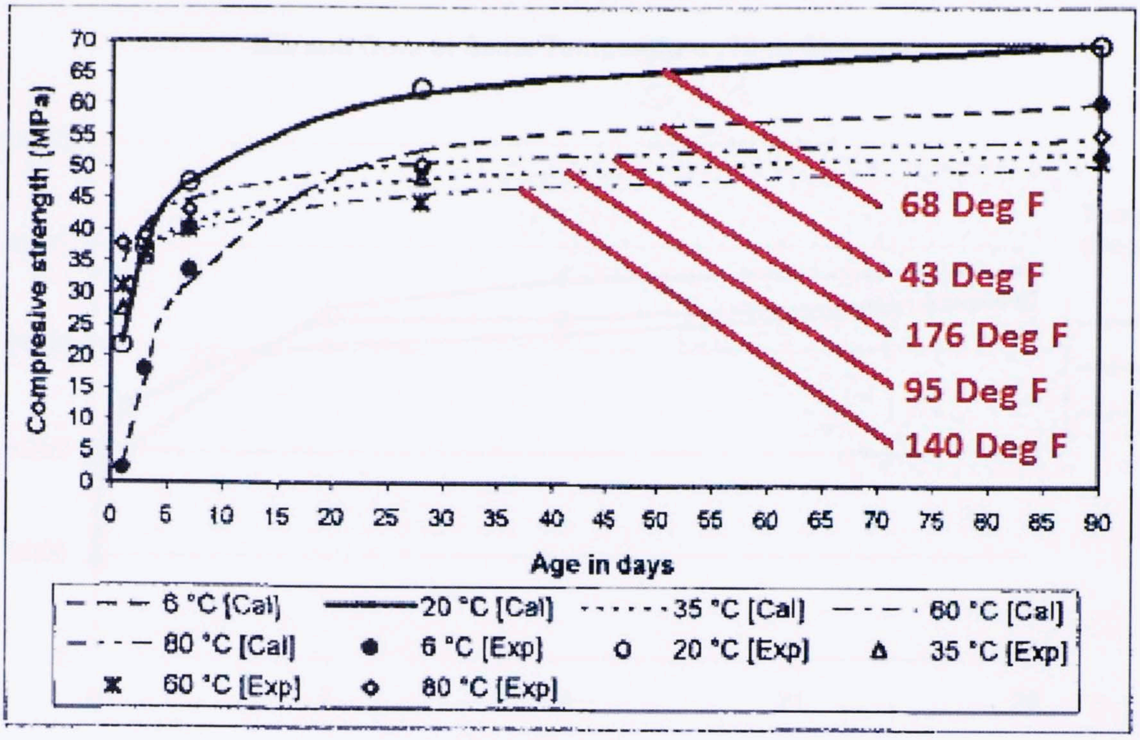

Figure 1- Portland Cement Strength at Various Mixing Temperatures (Eren 2002)

In order to make a comparison between the two tests and ordinary Portland cement and Rapid Set© cement, the test specimen results with the same mixing and curing temperature were plotted against each other for the high strength mix only and can be found in Figure 63.

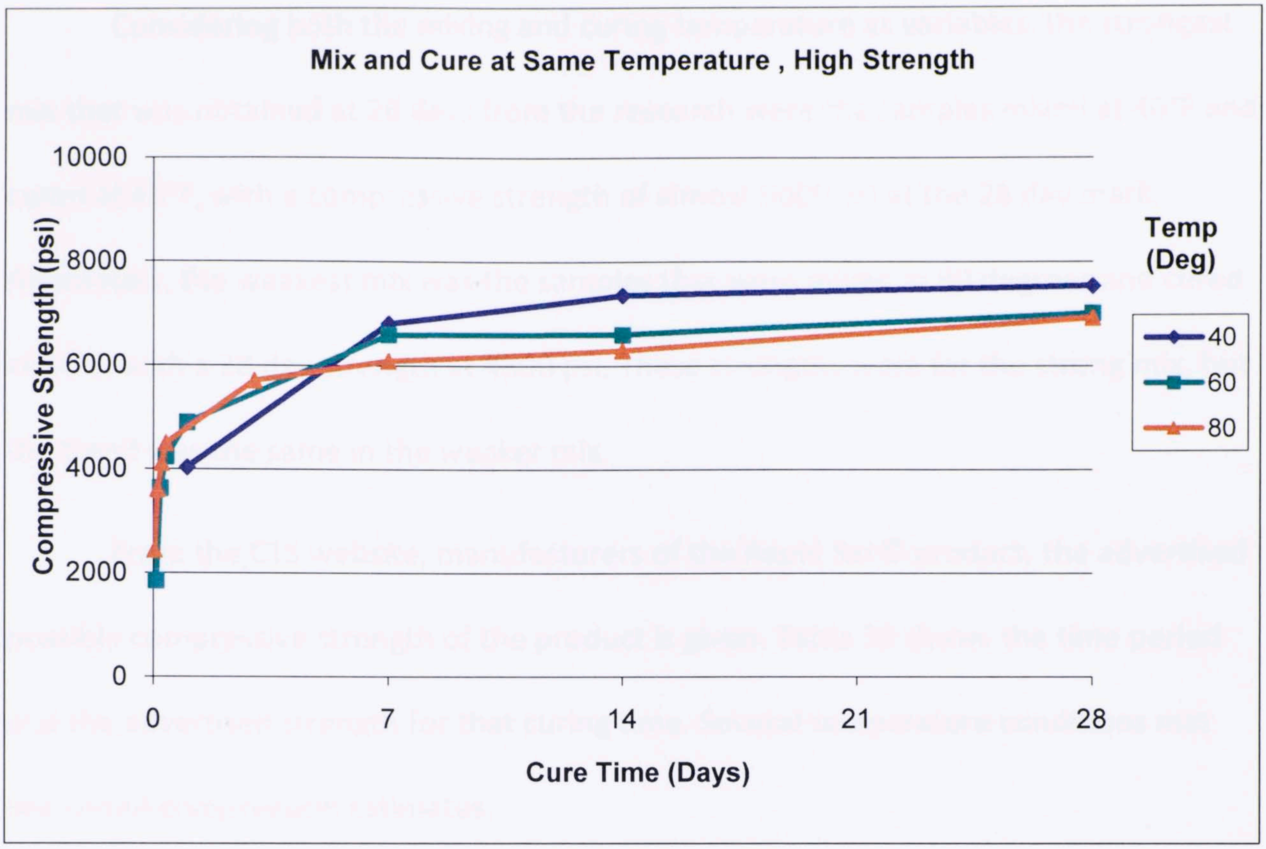

Figure 63 - Mixing and Curing at the Same Temperature

When comparing the results seen in Figure 63 with Eren's research on Portland cement, a few similarities can be seen. The lowest temperature, 42°F (6°C) in the case of Portland and 40°F in the case of Rapid Set©, resulted in the lowest early strength in both cements. In both cases, the coldest temperature surpasses the strengths of the warmer temperatures around the 7 to 14 day mark, and ends with a slightly higher strength at late age. However, the Portland cement mix had the highest strength achieved by the cure at 68°F (20°C), while the Rapid Set© cement's highest strength gain was at a mix and cure temperature of 40°F. A trend was less distinguishable on the low strength mixes.

Considering both the mixing and curing temperature as variables, the strongest mix that was obtained at 28 days from the research were the samples mixed at 40°F and cured at 60°F, with a compressive strength of almost 9000 psi at the 28 day mark. Alternately, the weakest mix was the samples that were mixed at 80 degrees and cured at 40°F, with a 28 day strength at 4800 psi. These strengths were for the strong mix, but the trend was the same in the weaker mix.

From the CTS website, manufacturers of the Rapid Set© product, the advertised possible compressive strength of the product is given. Table 39 shows the time period and the advertised strength for that curing time. Several temperature conditions met the stated compression estimates.

Table 39 – CTS Advertised Compression Results

Time	Req. Compression
1.5 hours	2500 psi
3 hours	5000 psi
24 hours	6500 psi
28 days	8000 psi

On a job site, it is especially important for rapid setting concrete to reach a certain compressive strength to allow for quick repairs or construction. In the field, highway repairs in particular, a compressive strength of around 3000 psi is generally needed before loads can be applied to the concrete (e.g. cars, equipment, pedestrians, etc.). A chart of the mixes and their temperatures and the time it took them to reach the 3000 psi benchmark can be seen in Table 40. The chart was sorted from the lowest to highest time (fastest to slowest setting). The results can be seen in Table 41.

Table 40 - Temperature and Time to Reach 3000 psi

	Strength		Mix Temperature (°F)			Cure Temperature (°F)				3000 PSI
Mix #	High	Low	40	60	80	40	60	80	100	Time (Hours)
7		X		X					X	5.0
8	X			X					X	1.7
9		X			X				X	2.6
10	X				X				X	1.1
11		X			X			X		2.6
12	X				X			X		2.0
13		X		X				X		3.9
14	X			X				X		2.1
15		X			X		X			8.8
16	X				X		X			4.6
17		X		X			X			11.6
18	X			X			X			3.9
19		X	X						X	2.3
20	X		X						X	1.4
21		X	X					X		3.0
22	X		X					X		2.4
23		X	X				X			6.2
24	X		X				X			3.6
25		X	X			X				48.6
26	X		X			X				17.9
27		X		X		X				12.4
28	X			X		X				4.8
29		X			X	X				4.9
30	X				X	X				1.6

Table 41 - Temperature and Time to Reach 3000 psi (Sorted)

	Strength		Mix Temperature (°F)			Cure Temperature (°F)				3000 PSI
Mix #	High	Low	40	60	80	40	60	80	100	Time (Hours)
10	X				X				X	1.1
20	X		X						X	1.4
30	X				X	X				1.6
8	X			X					X	1.7
12	X				X			X		2.0
14	X			X				X		2.1
19		X	X						X	2.3
22	X		X					X		2.4
9		X			X				X	2.6
11		X			X			X		2.6
21		X	X					X		3.0
24	X		X				X			3.6
13		X		X				X		3.9
18	X			X			X			3.9
16	X				X		X			4.6
28	X			X		X				4.8
29		X			X	X				4.9
7		X		X					X	5.0
23		X	X				X			6.2
15		X			X		X			8.8
17		X		X			X			11.6
27		X		X		X				12.4
26	X		X			X				17.9
25		X	X			X				48.6

Interesting trends can be seen from sorting the graph from quickest setting to slowest setting. Curing temperature seems to have an important role in the early strength gains. This trend is shown by the grouping of the curing temperatures from warmest to coldest, and the temperature groups overlap each other very clearly as the time increases. With the exception of a few outliers, it appears that the rate of early age strength gain increases as the curing temperature increases. The strength of the mixes shows an alternating pattern in Table 41. Instead of all of the high strength mixes achieving the 3000 psi first as one would expect, the high and low strengths achieve the 3000 psi in a varied pattern. This trend shows how temperature has a higher influence on the early age strength than the strength of the mix design.

As the chart shows, a warmer curing temperature is needed to gain early strength. In order to achieve 3000 psi in three hours the concrete must be cured at 80°F or warmer. This will provide a point of reference for contractors in the field looking to achieve the 3000 psi early strength benchmark.

The left half of the table shows the mixing temperatures. Mixing temperature appears to have little to no correlation with early strength gains. This is shown by the dispersion of the markers throughout the mixing temperature section of the table. This counters the original thought that the mixing temperature would play a larger role on early strength; however, mixing temperature should not be disregarded. As discussed, varying the mixing temperature influences the ultimate strength of the concrete. To confirm this, Table 42 shows the mixes ranked by their 28 day strengths.

Table 42 - Temperature and Ultimate Strength

	Strength		Mix Temperature (°F)			Cure Temperature (°F)				Ultimate Stgth
Mix #	High	Low	40	60	80	40	60	80	100	PSI
24	X		X				X			8915
22	X		X					X		8443
10	X				X				X	7967
26	X		X			X				7537
23		X	X				X			7448
14	X			X				X		7341
21		X	X					X		7288
28	X			X		X				7228
18	X			X			X			7011
12	X				X			X		6925
20	X		X						X	6809
9		X			X				X	6310
8	X			X					X	6104
11		X			X			X		6080
25		X	X			X				6025
13		X		X				X		5905
17		X		X			X			5856
27		X		X		X				5706
16	X				X		X			5627
19		X	X						X	5243
15		X			X		X			4840
30	X				X	X				4802
29		X			X	X				4190
7		X		X					X	4130

Table 42 above shows trends regarding ultimate strength and temperature. First, cure temperature now shows less of an influence, demonstrated by the dispersion of the cure temperature markers. Second, colder mixing temperatures appear to increase the ultimate strength of the concrete. In order from strongest to weakest, the mixing temperature of 40°F is grouped at the top of the chart, while the mix temperature of 60°F is grouped next, followed finally by the grouping of the 80°F mixing temperature mixes. Excluding the outliers in the chart, the trend shows that the lower mixing temperature leads to higher ultimate strength.

Shown in the graph, the stronger mix designs, achieved by lower water-to-cement ratio and higher cement content, achieved higher ultimate strength than the lower strength mix designs. The strength of the mix design plays a larger role in the ultimate strength of the mix than the curing temperature.

Slump versus Glenium 7500 amount was charted and can be seen in Figure 64. From this chart, it can be seen that raising and lowering the amount of Glenium 7500 in the mix raised and lowered the mixture's slump, respectively. Different amounts of Glenium 7500 were added to the initial mixes to find a ratio that would provide consistent slump, and that measurement was used for the rest of the mixes. The variance in Glenium 7500 used in the initial stages varies only slightly from the later mixes, and is not thought to adversely affect the results.

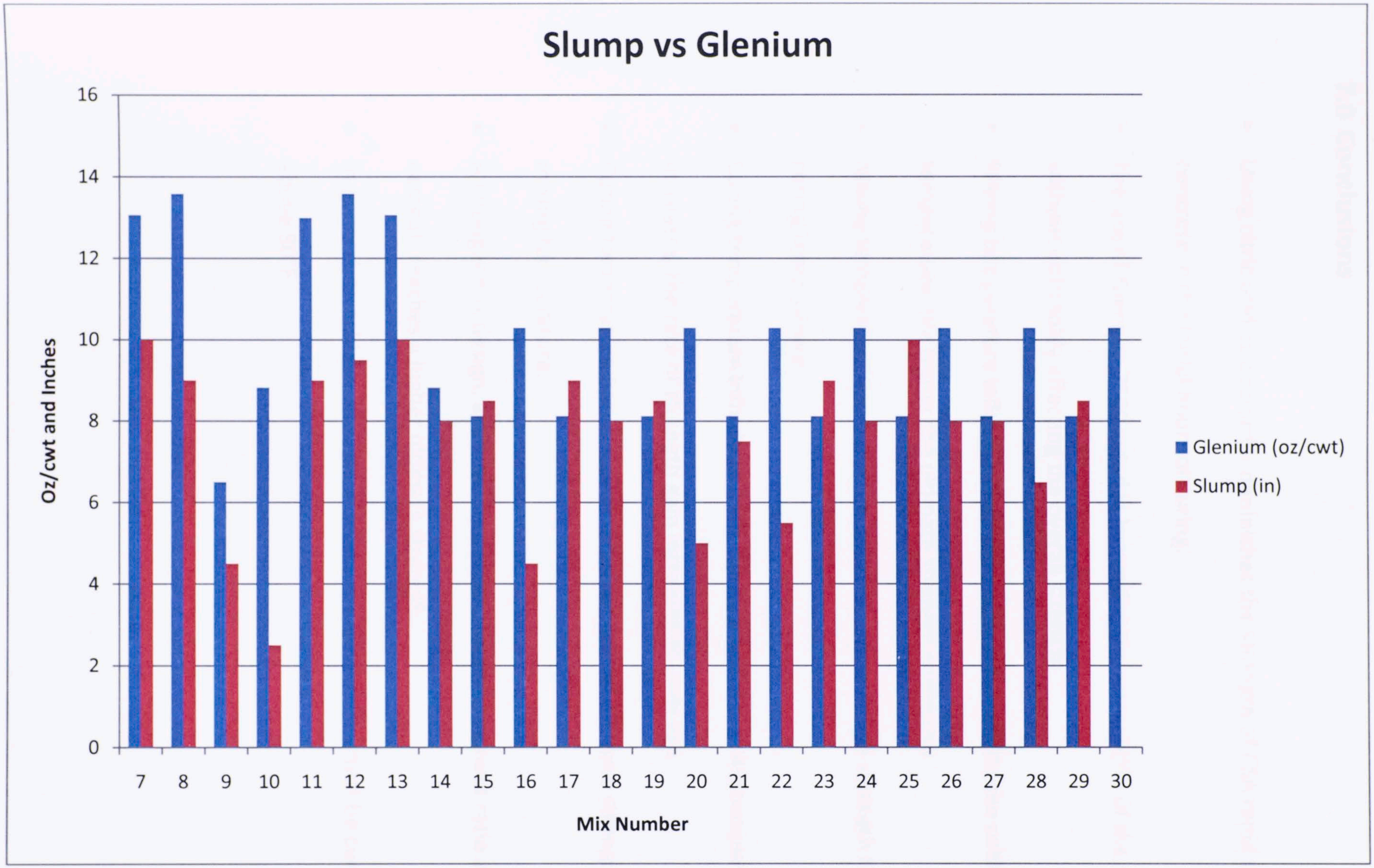

Figure 64 - Slump versus Glenium 7500 Amount

7.0 Conclusions

- Using citric acid as a retarder diminishes the strength of CSA rapid setting concrete in the initial hours of curing.
- The use of Glenium 7500 aided in increasing the workability of the concrete without noticeably affecting the overall strength.
- Mixing temperature influences late age, ultimate strength: the colder the mixing temperature, the higher the ultimate strength of the mix.
- Mixing temperature has less of an influence on early age strength than the curing temperature.
- Curing temperature influences early age strength: as curing temperature increases, the rate of strength gain increases at early age.
- Curing temperature has less of an influence on the ultimate strength than the mixing temperature.
- A stronger mix design, achieved by a lower water-to-cement ratio and more cement, reaches a higher ultimate strength.
- In general, to achieve 3000 psi in 3 hours, the concrete must be cured at or above 80°F

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Appendix A

Table 43 - Index of Batches

Date	Mix #	Mix Temp	Cure Temp	Strength	Additives
	1	80	100	NA	None
	2	80	100	NA	None
	3	80	100	L	Citric
	4	80	100	H	Citric
	5	60	Ambient	L	Citric
	6	60	Ambient	H	Citric
	6 B	60	Ambient		Citric
6/25	7	60	100	L	Glenium
6/25	8	60	100	H	Glenium
6/28	9	80	100	L	Glenium
6/28	10	80	100	H	Glenium
6/28	11	80	80	L	Glenium
6/28	12	80	80	H	Glenium
7/6	13	60	80	L	Glenium
7/6	14	60	80	H	Glenium
7/28	15	80	60	L	Glenium
7/28	16	80	60	H	Glenium
8/2	17	60	60	L	Glenium
8/2	18	60	60	H	Glenium
7/20	19	40	100	L	Glenium
7/21	20	40	100	H	Glenium
7/21	21	40	80	L	Glenium
7/20	22	40	80	H	Glenium
7/30	23	40	60	L	Glenium
7/30	24	40	60	H	Glenium
8/2	25	40	40	L	Glenium
8/2	26	40	40	H	Glenium
8/3	27	60	40	L	Glenium
8/3	28	60	40	H	Glenium
8/5	29	80	40	L	Glenium
8/5	30	80	40	H	Glenium

Batch # 1 Test: Rapid Set **6/14/2010**

w/c=	0.52	Sand % water =	3.42	start	10:00 AM
cement =	611	Rock % water =	0.26	batch	
Type =	Rapid Set			stop	10:14 AM
Air Entrain	0	Notes:	No Citric Acid, (80 mix, 100 cure)		

Sand SG=	2.63	SSD=	0.7	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101	
H2O SG=	1					
C SG=	3					
Latex SG=	1					

		1 yd	2.5	cu ft		
Cement	Rapid Set	611	56.57	lb		
Coarse Aggregate, #67		1777.1	164.55	lb		
Fine Aggregate, River Sand		1267.1	117.32	lb		
Water		293.9	27.22	lb		
Air Ent. Admixture	oz	0	0	ml		
Plasticizer Admix.	oz	0	0	ml		
(HRWR) ADVA Cast	oz	0	0	ml	oz/cwt =	0
DCI (Accel)	oz	0	0	ml	oz/cwt =	0
Latex (Acryl 60)	lbs	0	0	lbs		

Theoretica	Weight	Volume
Cement	611	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0	0.54
Latex (Acryl 60)	0	0
Air Entrained	0	0
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	37.08	148.32
Difference	%	-1.99

Concrete Temperature	NA
Air Temperature	73.4
Humidity	84%
Air Content	1.80%
Slump	1

Batch # 2

Test: Rapid Set

6/15/2010

w/c=	0.44	Sand % water =	3.42	start	
cement =	675	Rock % water =	0.26	batch	
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: Mix was too dry, did not use!

Sand SG=	2.63	SSD=	0.7	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101	
H2O SG=	1					
C SG=	3					
Latex SG=	1					

		1 yd	2.2	cu ft		
Cement Rapid Set		675	55	lb		
Coarse Aggregate, #67		1777.1	144.8	lb		
Fine Aggregate, River Sand		1265.4	103.11	lb		
Water		273.3	22.27	lb		
Air Ent. Admixture	oz	0	0	ml		
Plasticizer Admix.	oz	0	0	ml		
(HRWR) ADVA Cast	oz	0	0	ml	oz/cwt =	0
DCI (Accel)	oz	0	0	ml	oz/cwt =	0
Latex (Acryl 60)	lbs	0	0	lbs		

Theoretical	Weight	Volume
Cement	675	3.61
Water	297	4.76
Rock	1772.6	10.64
Air Entrapped 2%	0	0.54
Latex (Acryl 60)	0	0
Air Entrained	0	0
Sand	1223.5	7.46
Sum	3968.099	27

Expected Unit Wt		146.97
Measured	36.58	146.32
Difference	%	0.44

Concrete Temperature	
Air Temperature	86
Humidity	75%
Air Content	1.50%
Slump	0

Batch # 3	Test:	Rapid Set	6/17/2010

w/c=	0.52	Sand % water =	2.69	start	10:05 AM
cement =	611	Rock % water =	1.16	batch	
Type =	Rapid Set			stop	10:14 AM
Air Entrain	0	Notes:	Low strength, Citric Acid (m80, c100)		

Sand SG=	2.63	SSD=	0.7	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101	
H2O SG=	1					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611	52.05	lb		
Coarse Aggregate, #67		1793.1	152.75	lb		
Fine Aggregate, River Sand		1258.2	107.18	lb		
Water		287.3	24.47	lb		
Air Ent. Admixture	oz	0	0	ml		
Plasticizer Admix.	oz	0	0	ml		
(HRWR) ADVA Cast	oz	0	0	ml	oz/cwt =	0
DCI (Accel)	oz	0	0	ml	oz/cwt =	0
Latex (Acryl 60)	lbs	0	0	lbs		
Citric Acid	% wt/Cem	0.4	0.21	lbs		

Theoretica	Weight	Volume
Cement	611	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0	0.54
Latex (Acryl 60)	0	0
Air Entrained	0	0
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	NA	#VALUE!
Difference	%	#VALUE!

Concrete Temperature	87.6
Air Temperature	86
Humidity	60%
Air Content	NA
Slump	6.75

Batch # 4	Test: Rapid Set		6/17/2010

w/c=	0.45	Sand % water =	2.69	start	10:50 AM
cement =	675	Rock % water =	1.16	batch	
Type =	Rapid Set			stop	11:00 AM
Air Entrain	0	Notes:	High Strength, Citric Acid (m80, c100)		

Sand SG=	2.63	SSD=	0.7	b/bo =	0.65	Fineness Modulus = 2.5	
Rock SG=	2.67	SSD=	0.86	DRUW =	101		
H2O SG=	1						
C SG=	3						
Latex SG=	1						

		1 yd	2.3	cu ft		
Cement	Rapid Set	675	57.5	lb		
Coarse Aggregate, #67		1793.1	152.75	lb		
Fine Aggregate, River Sand		1238.3	105.48	lb		
Water		273.7	23.31	lb		
Air Ent. Admixture	oz	0	0	ml		
Plasticizer Admix.	oz	0	0	ml		
(HRWR) ADVA Cast	oz	0	0	ml	oz/cwt =	0
DCI (Accel)	oz	0	0	ml	oz/cwt =	0
Latex (Acryl 60)	lbs	0	0	lbs		
Citric Acid	% wt/Cem	0.4	0.23	lbs		

Theoretical	Weight	Volume
Cement	675	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0	0.54
Latex (Acryl 60)	0	0
Air Entrained	0	0
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.58	146.32
Difference	%	0.16

Concrete Temperature	86.5
Air Temperature	86
Humidity	60%
Air Content	2.30%
Slump	4.5

Batch # 5

Test: Rapid Set **6/22/2010**

w/c=	0.52	Sand % water =	1.87	start	8:46 AM
cement =	611	Rock % water =	0.71	batch	
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: Low strength, Citric Acid, (60 Mix, ambient cure)

Sand SG=	2.63	SSD=	0.7	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101	
H2O SG=	1					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611	52.05	lb		
Coarse Aggregate, #67		1785.1	152.07	lb		
Fine Aggregate, River Sand		1248	106.31	lb		
Water		305.9	26.05	lb		
Air Ent. Admixture	oz	0	0	ml		
Plasticizer Admix.	oz	0	0	ml		
(HRWR) ADVA Cast	oz	0	0	ml	oz/cwt =	0
DCI (Accel)	oz	0	0	ml	oz/cwt =	0
Latex (Acryl 60)	lbs	0	0	lbs		
Citric Acid	% wt/Cem	0.4	0.21	lbs		

Theoretical	Weight	Volume
Cement	611	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0	0.54
Latex (Acryl 60)	0	0
Air Entrained	0	0
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.78	147.12
Difference	%	-1.17

Concrete Temperature	75.6
Air Temperature	87
Humidity	58%
Air Content	1.00%
Slump	9
Material Temp	63.7
Mixer Temp	77.6

Batch # 6

Test: Rapid Set **6/22/2010**

w/c=	0.45	Sand % water =	1.87	start	9:13 AM
cement =	675	Rock % water =	0.71	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	High Strength, Citric Acid, (60 Mix, Ambient cure)		

Sand SG=	2.63	SSD=	0.7	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101	
H2O SG=	1					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675	57.5	lb		
Coarse Aggregate, #67		1785.1	152.07	lb		
Fine Aggregate, River Sand		1228.3	104.63	lb		
Water		292.1	24.88	lb		
Air Ent. Admixture	oz	0	0	ml		
Plasticizer Admix.	oz	0	0	ml		
(HRWR) ADVA Cast	oz	0	0	ml	oz/cwt =	0
DCI (Accel)	oz	0	0	ml	oz/cwt =	0
Latex (Acryl 60)	lbs	0	0	lbs		
Citric Acid	% wt/Cem	0.4	0.23	lbs		

Theoretical	Weight	Volume
Cement	675	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0	0.54
Latex (Acryl 60)	0	0
Air Entrained	0	0
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.91	147.64
Difference	%	-0.74

Concrete Temperature	72
Air Temperature	87
Humidity	58%
Air Content	2.10%
Slump	3.5
Material Temp	64.2
Mixer Temp	79.5

Batch # 6 B Test: Rapid Set **6/23/2010**

w/c=	0.45	Sand % water =	0.00	start	9:47 AM
cement =	675	Rock % water =	0.00	batch	Mixed 1:30 m total
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	High Strength, 0.2 Citric Acid, (60 Mix, Ambient cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml	oz/cwt =	0.00
Latex (Acryl 60)	lbs	0.0	0.00	lbs		
Citric Acid	% wt/Cem	0.2	0.12	lbs		

Theoretical	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.9	147.60
Difference	%	-0.71

Concrete Temperature	75.4
Air Temperature	86
Humidity	55%
Air Content	2.20%
Slump	3.5
Material Temp	60
Mixer Temp	

Batch # 7

Test: Rapid Set **6/25/2010**

w/c=	0.52	Sand % water =	0.00	start	6:00 AM
cement =	611	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Low strength, Glenium (60 Mix, 100 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	79.8	201.00	ml	oz/cwt =	13.06

Theoretical	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.08	144.32
Difference	%	0.76

Concrete Temperature	73.6
Air Temperature	81
Humidity	66%
Air Content	2.30%
Slump	9.75
Material Temp	63.3.
Mixer Temp	63

Batch # 8

Test: Rapid Set **6/25/2010**

w/c=	0.45	Sand % water =	0.00	start	11:31 AM
cement =	675	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	High strength, Glenium (60 Mix, 100 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	91.7	231	ml	oz/cwt =	13.58

Theoretical	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.2	144.80
Difference	%	1.20

Concrete Temperature	72.9
Air Temperature	81
Humidity	66%
Air Content	2.60%
Slump	9
Material Temp	64.2
Mixer Temp	56

Batch # 9		Test: Rapid Set			6/28/2010

w/c=	0.52	Sand % water =	0.00	start	9:38 AM
cement =	611	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Low strength, Glenium (80 Mix, 100 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	39.7	100.00	ml	oz/cwt =	6.50

Theoretical	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.52	146.08
Difference	%	-0.45

Concrete Temperature	84
Air Temperature	80
Humidity	77%
Air Content	2.60%
Slump	4.25"
Material Temp	80
Mixer Temp	75.6

Batch # 10

Test: Rapid Set **6/28/2010**

w/c=	0.45	Sand % water =	0.00	start	10:09 AM
cement =	675	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: High strength, Glenium (80 Mix, 100 cure)
erers

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5	
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0		
H2O SG=	1.0						
C SG=	3						
Latex SG=	1						

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	59.5	150	ml	oz/cwt =	8.82

Theoretical	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.54	146.16
Difference	%	0.27

Concrete Temperature	83
Air Temperature	80
Humidity	77%
Air Content	2.70%
Slump	2.5
Material Temp	
Mixer Temp	

Batch # 11

Test: Rapid Set **6/28/2010**

w/c=	0.52	Sand % water =	0.00	start	11:00 AM
cement =	611	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: Low strength, Glenium (80 Mix, 80 cure)

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	79.4	200.00	ml	oz/cwt =	12.99

Theoretica	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.35	145.40
Difference	%	0.02

Concrete Temperature	84.5
Air Temperature	80
Humidity	77%
Air Content	2.70%
Slump	9
Material Temp	80
Mixer Temp	83

Batch # 12

Test: Rapid Set

6/28/2010

w/c=	0.45	Sand % water =	0.00	start	11:38 AM
cement =	675	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: High strength, Glenium (80 Mix, 80 cure)
erers

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

			1 yd	2.3	cu ft		
Cement	Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67			1772.6	151.00	lb		
Fine Aggregate, River Sand			1205.8	102.72	lb		
Water			327.4	27.89	lb		
Air Ent. Admixture		oz	0.0	0.00	ml		
Plasticizer Admix.		oz	0.0	0.00	ml		
(HRWR) ADVA Cast		oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)		oz	0.0	0.00	ml		
Latex (Acryl 60)		lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500		Oz	91.7	231	ml	oz/cwt =	13.58

Theoretical	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.25	145.00
Difference	%	1.06

Concrete Temperature	83.5
Air Temperature	80
Humidity	77%
Air Content	
Slump	9.5
Material Temp	80
Mixer Temp	80

Batch # 13

Test: Rapid Set

7/6/2010

w/c=	0.52	Sand % water =	0.00	start	10:22 AM
cement =	611	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: Low strength, Glenium (60 Mix, 80 cure)

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0
H2O SG=	1.0				
C SG=	3				
Latex SG=	1				

Fineness Modulus = 2.5

		1 yd	2.3	cu ft		
Cement	Rapid Set	611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	79.8	201.00	ml	oz/cwt =	13.06

Theoretica	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.22	144.88
Difference	%	0.37

Concrete Temperature	71.4
Air Temperature	80.1
Humidity	65%
Air Content	2.60%
Slump	10"
Material Temp	62.4
Mixer Temp	60.0

Batch # 14

Test: Rapid Set **7/6/2010**

w/c=	0.45	Sand % water =	0.00	start	10:42 AM
cement =	675	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: High strength, Glenium (60 Mix, 80 cure)

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	59.5	150	ml	oz/cwt =	8.82

Theoretical	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.54	146.16
Difference	%	0.27

Concrete Temperature	71.2
Air Temperature	88.2
Humidity	65%
Air Content	2.60%
Slump	8"
Material Temp	63.7
Mixer Temp	52.0

Batch # 15+

Test: Rapid Set

7/28/2010

w/c=	0.52	Sand % water =	0.00	start	
cement =	611	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: Water Cured, Low strength, Glenium (80 Mix, 60 cure)

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	49.6	125.00	ml	oz/cwt =	8.12

	Theoretical Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.66	146.64
Difference	%	-0.84

Concrete Temperature	90
Air Temperature	81
Humidity	68%
Air Content	2.10%
Slump	8.5
Material Temp	87
Mixer Temp	80.0

Batch # 16+ Test: Rapid Set **7/28/2010**

w/c=	0.45	Sand % water =	0.00	start	
cement =	675	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Water Cured, High strength, Glenium (80 Mix, 60 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

			1 yd	2.3	cu ft		
Cement	Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67			1772.6	151.00	lb		
Fine Aggregate, River Sand			1205.8	102.72	lb		
Water			327.4	27.89	lb		
Air Ent. Admixture		oz	0.0	0.00	ml		
Plasticizer Admix.		oz	0.0	0.00	ml		
(HRWR) ADVA Cast		oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)		oz	0.0	0.00	ml		
Latex (Acryl 60)		lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500		Oz	69.5	175	ml	oz/cwt =	10.29

Theoretica	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured		0.00
Difference	%	100.00

Concrete Temperature	36.92
Air Temperature	82
Humidity	68%
Air Content	2.25%
Slump	4.5
Material Temp	85
Mixer Temp	80

Batch # 17+

Test: Rapid Set — **8/2/2010**

w/c=	0.52	Sand % water =	0.00	start	
cement =	611	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Water Cured, Low strength, Glenium (60 Mix, 60 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	49.6	125.00	ml	oz/cwt =	8.12

Theoretical	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.39	145.56
Difference	%	-0.09

Concrete Temperature	79
Air Temperature	90
Humidity	42%
Air Content	2.10%
Slump	9
Material Temp	70
Mixer Temp	51

Batch # 18+

Test: Rapid Set **8/2/2010**

w/c=	0.45	Sand % water =	0.00	start	
cement =	675	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Water Cured, High strength, Glenium (60 Mix, 60 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	69.5	175	ml	oz/cwt =	10.29

Theoretica	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.37	145.48
Difference	%	0.74

Concrete Temperature	82
Air Temperature	90
Humidity	42%
Air Content	2.70%
Slump	8
Material Temp	71
Mixer Temp	51

Batch # 19   Test: Rapid Set   7/20/2010

w/c=	0.52	Sand % water =	0.00	start	8:49 AM
cement =	611	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Low strength, Glenium (40 Mix, 100 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement	Rapid Set	611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	49.6	125.00	ml	oz/cwt =	8.12

Theoretical	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.4	145.60
Difference	%	-0.12

Concrete Temperature	59
Air Temperature	82
Humidity	62%
Air Content	2.80%
Slump	8.5
Material Temp	48
Mixer Temp	38.1

Batch # 20

Test: Rapid Set **7/21/2010**

w/c=	0.45	Sand % water =	0.00	start	
cement =	675	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	High strength, Glenium (40 Mix, 100 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	69.5	175	ml	oz/cwt =	10.29

Theoretical	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.72	146.88
Difference	%	-0.22

Concrete Temperature	56
Air Temperature	84
Humidity	61%
Air Content	2.60%
Slump	4.75
Material Temp	45
Mixer Temp	43

Batch # 21

Test: Rapid Set **7/21/2010**

w/c=	0.52	Sand % water =	0.00	start	
cement =	611	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Low strength, Glenium (40 Mix, 80 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	49.6	125.00	ml	oz/cwt =	8.12

Theoretical	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.55	146.20
Difference	%	-0.53

Concrete Temperature	57
Air Temperature	85
Humidity	61%
Air Content	2.80%
Slump	7.5
Material Temp	46
Mixer Temp	36

Batch # 22 Test: Rapid Set **7/20/2010**

w/c=	0.45	Sand % water =	0.00	start	9:07 AM
cement =	675	Rock % water =	0.00	batch	2 min
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	High strength, Glenium (40 Mix, 80 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	69.5	175	ml	oz/cwt =	10.29

Theoretica	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.6	146.40
Difference	%	0.11

Concrete Temperature	54
Air Temperature	83
Humidity	62%
Air Content	2.80%
Slump	5.5
Material Temp	45.1
Mixer Temp	38.5

Batch # 23+

Test: Rapid Set **7/29/2010**

w/c=	0.52	Sand % water =	0.00	start	
cement =	611	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Water Cured, Low strength, Glenium (40 Mix, 60 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	49.6	125.00	ml	oz/cwt =	8.12

	Theoretical Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.52	146.08
Difference	%	-0.45

Concrete Temperature	49
Air Temperature	82
Humidity	68%
Air Content	2.70%
Slump	9
Material Temp	38
Mixer Temp	40

Batch # 24+

Test: Rapid Set **7/29/2010**

w/c=	0.45	Sand % water =	0.00	start	
cement =	675	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Water Cured, High strength, Glenium (40 Mix, 60 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5	
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0		
H2O SG=	1.0						
C SG=	3						
Latex SG=	1						

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	69.5	175	ml	oz/cwt =	10.29

Theoretica	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.82	147.28
Difference	%	-0.49

Concrete Temperature	52
Air Temperature	82
Humidity	68%
Air Content	3.00%
Slump	8
Material Temp	39
Mixer Temp	43

Batch # 25

Test: Rapid Set **8/2/2010**

w/c=	0.52	Sand % water =	0.00	start	
cement =	611	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: Water Cured, Low strength, Glenium (40 Mix, 40 cure)

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement	Rapid Set	611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	49.6	125.00	ml	oz/cwt =	8.12

Theoretical	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.09	144.36
Difference	%	0.73

Concrete Temperature	57
Air Temperature	43
Humidity	42%
Air Content	2.50%
Slump	10
Material Temp	44
Mixer Temp	40

Batch # 26

Test: Rapid Set **8/2/2010**

w/c=	0.45	Sand % water =	0.00	start	
cement =	675	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Water Cured, High strength, Glenium (40 Mix, 40 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	69.5	175	ml	oz/cwt =	10.29

Theoretical	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.46	145.84
Difference	%	0.49

Concrete Temperature	60
Air Temperature	93
Humidity	42%
Air Content	3.00%
Slump	8
Material Temp	44
Mixer Temp	42

Batch # 27

Test: Rapid Set **8/3/2010**

w/c=	0.52	Sand % water =	0.00	start	
cement =	611	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: Water Cured, Low strength, Glenium (60 Mix, 40 cure)

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	49.6	125.00	ml	oz/cwt =	8.12

Theoretical	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.64	146.56
Difference	%	-0.78

Concrete Temperature	69
Air Temperature	80
Humidity	43%
Air Content	2.35%
Slump	8
Material Temp	61
Mixer Temp	60

Batch # 28	Test: Rapid Set		8/3/2010

w/c=	0.45	Sand % water =	0.00	start	
cement =	675	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Water Cured, High strength, Glenium (60 Mix, 40 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	69.5	175	ml	oz/cwt =	10.29

	Theoretical Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	34.67	138.68
Difference	%	5.38

Concrete Temperature	68.5
Air Temperature	81
Humidity	43%
Air Content	2.80%
Slump	6.5
Material Temp	60.5
Mixer Temp	55

Batch # 29

Test: Rapid Set **8/5/2010**

w/c=	0.52	Sand % water =	0.00	start	
cement =	611	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0	Notes:	Water Cured, Low strength, Glenium (80 Mix, 40 cure)		

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		611.0	52.05	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1225.2	104.37	lb		
Water		341.5	29.09	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	49.6	125.00	ml	oz/cwt =	8.12

Theoretical	Weight	Volume
Cement	611.0	3.26
Water	317.7	5.09
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1225.2	7.47
Sum	3926.432	27

Expected Unit Wt		145.42
Measured	36.24	144.96
Difference	%	0.32

Concrete Temperature	92
Air Temperature	82
Humidity	59%
Air Content	2.20%
Slump	8.5
Material Temp	87
Mixer Temp	82

Batch # 30

Test: Rapid Set **8/5/2010**

w/c=	0.45	Sand % water =	0.00	start	
cement =	675	Rock % water =	0.00	batch	
Type =	Rapid Set			stop	
Air Entrain	0				

Notes: Water Cured, High strength, Glenium (80 Mix, 40 cure)

Sand SG=	2.63	SSD=	0.70	b/bo =	0.65	Fineness Modulus = 2.5
Rock SG=	2.67	SSD=	0.86	DRUW =	101.0	
H2O SG=	1.0					
C SG=	3					
Latex SG=	1					

		1 yd	2.3	cu ft		
Cement Rapid Set		675.0	57.50	lb		
Coarse Aggregate, #67		1772.6	151.00	lb		
Fine Aggregate, River Sand		1205.8	102.72	lb		
Water		327.4	27.89	lb		
Air Ent. Admixture	oz	0.0	0.00	ml		
Plasticizer Admix.	oz	0.0	0.00	ml		
(HRWR) ADVA Cast	oz	0.0	0.00	ml	oz/cwt =	0.00
DCI (Accel)	oz	0.0	0.00	ml		
Latex (Acryl 60)	lbs	0.0	0.00	lbs	Goal:	13.6
Glenium 7500	Oz	69.5	175	ml	oz/cwt =	10.29

Theoretical	Weight	Volume
Cement	675.0	3.61
Water	303.8	4.87
Rock	1772.6	10.64
Air Entrapped 2%	0.0	0.54
Latex (Acryl 60)	0.0	0.00
Air Entrained	0.0	0.00
Sand	1205.8	7.35
Sum	3957.096	27

Expected Unit Wt		146.56
Measured	36.64	146.56
Difference	%	0.00

Concrete Temperature	
Air Temperature	82
Humidity	59%
Air Content	2.40%
Slump	
Material Temp	86
Mixer Temp	74.5

Appendix B

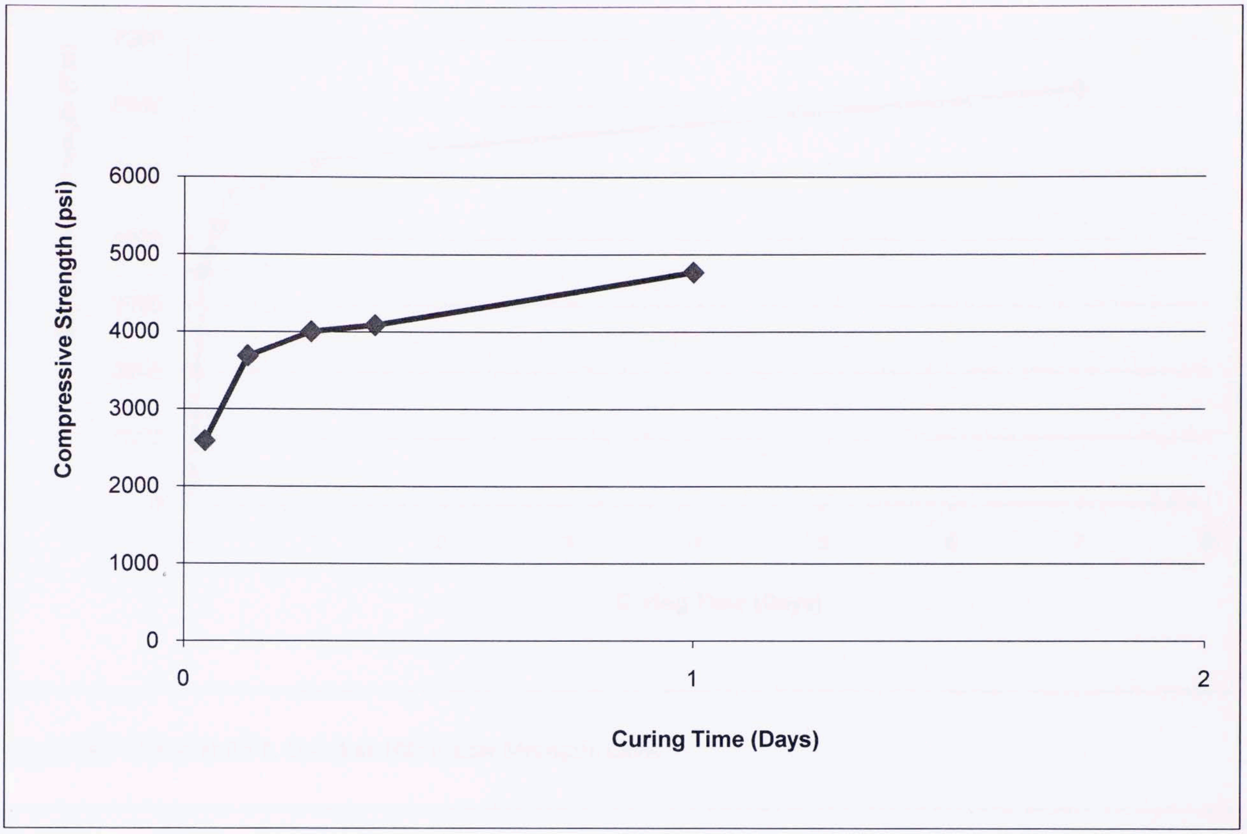

Figure 65 - Mixed at 80°F, Cured at 100°F, No Additives

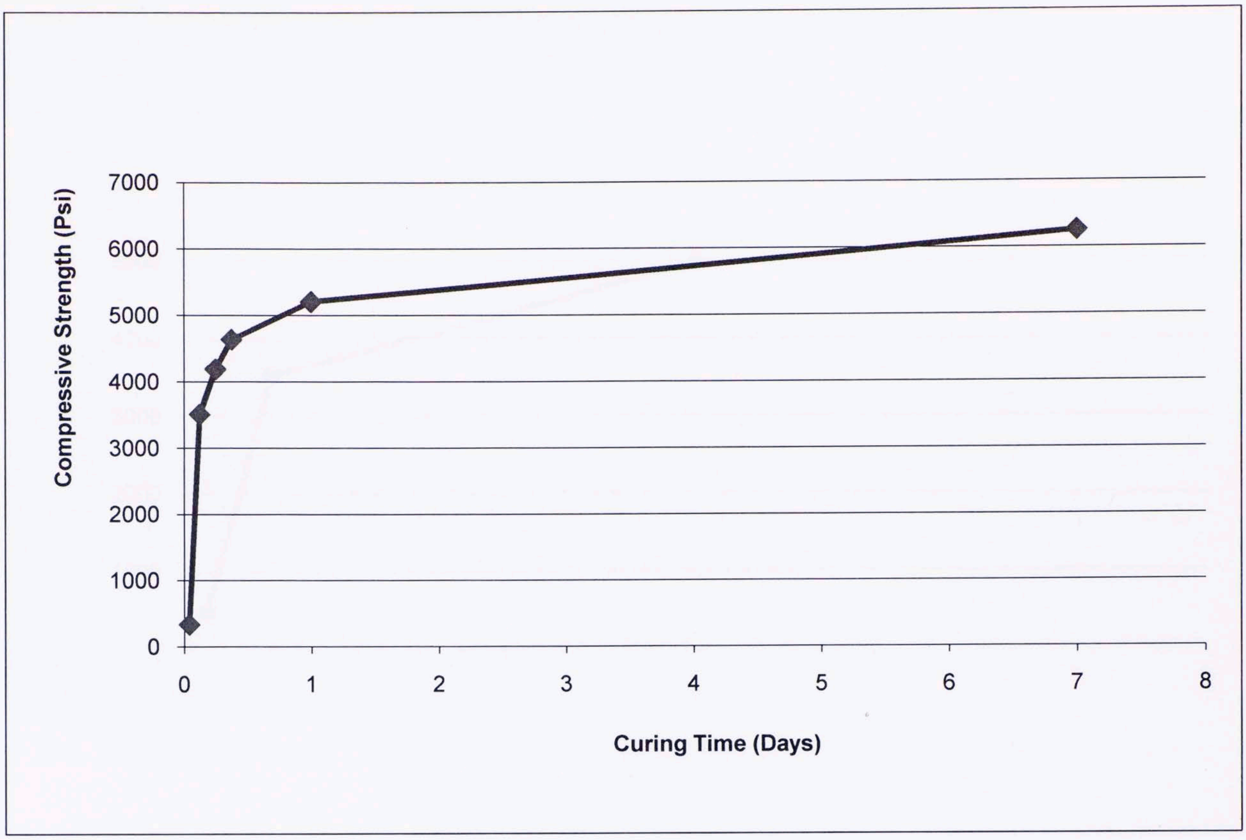

Figure 66 - Mixed at 80°F, Cured at 100°F, Low Strength, Citric

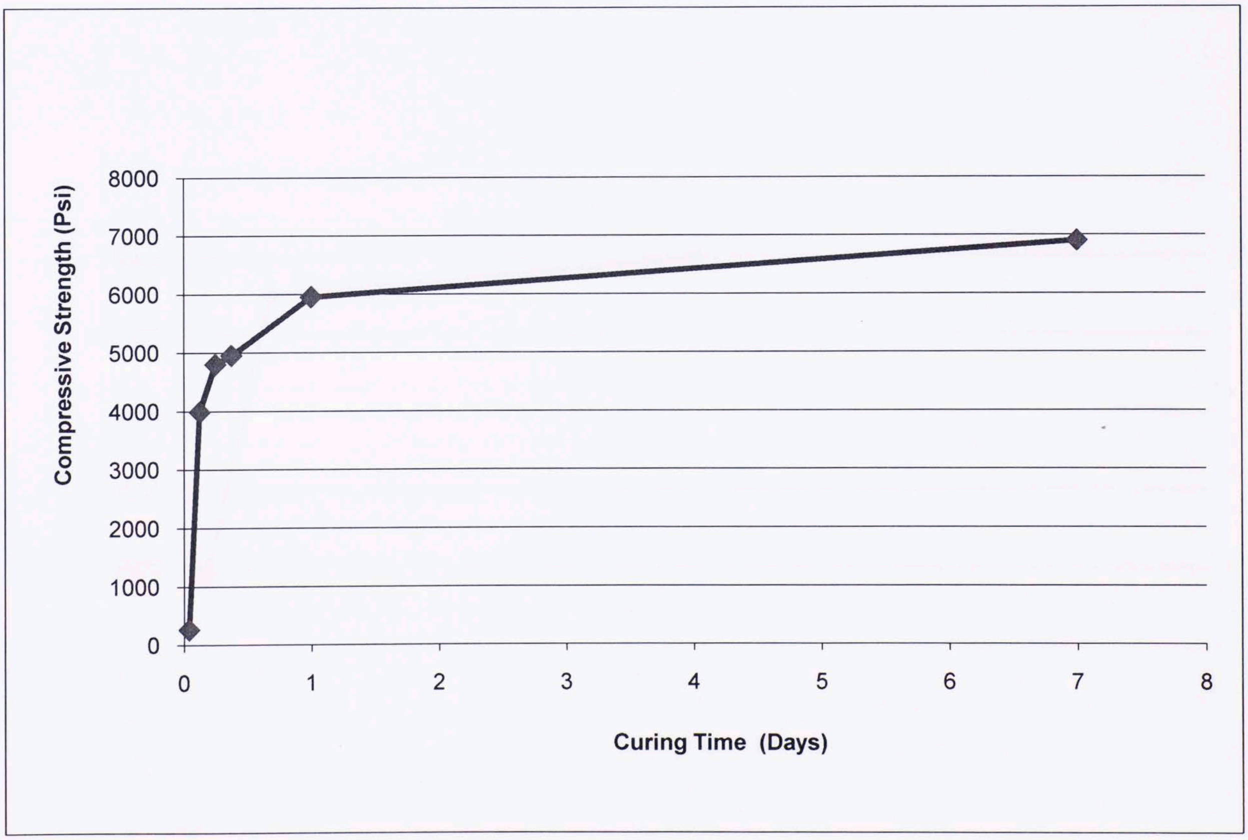

Figure 67 - Mixed at 80°F, Cured at 100°F, High Strength, Citric

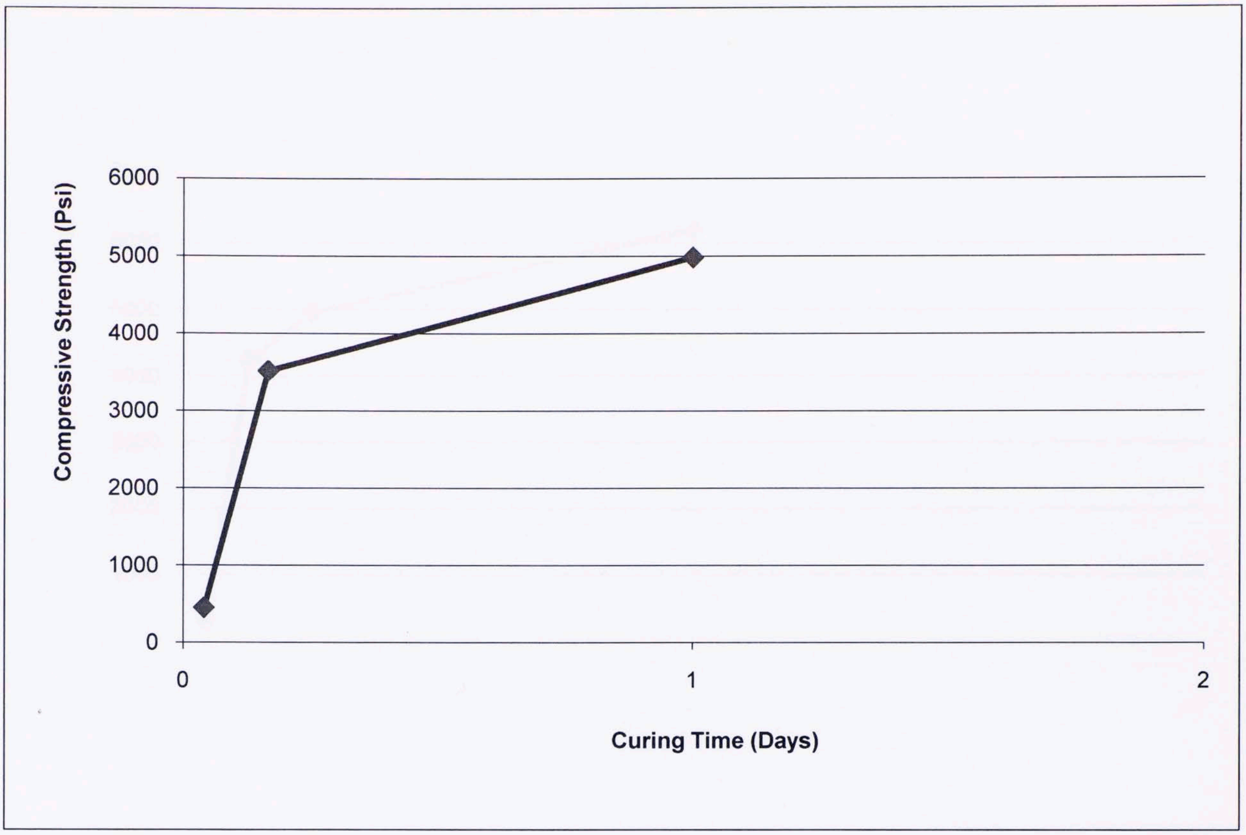

Figure 68 - Mixed at 60°F, Cured at Room Temperature, Low Strength, Citric

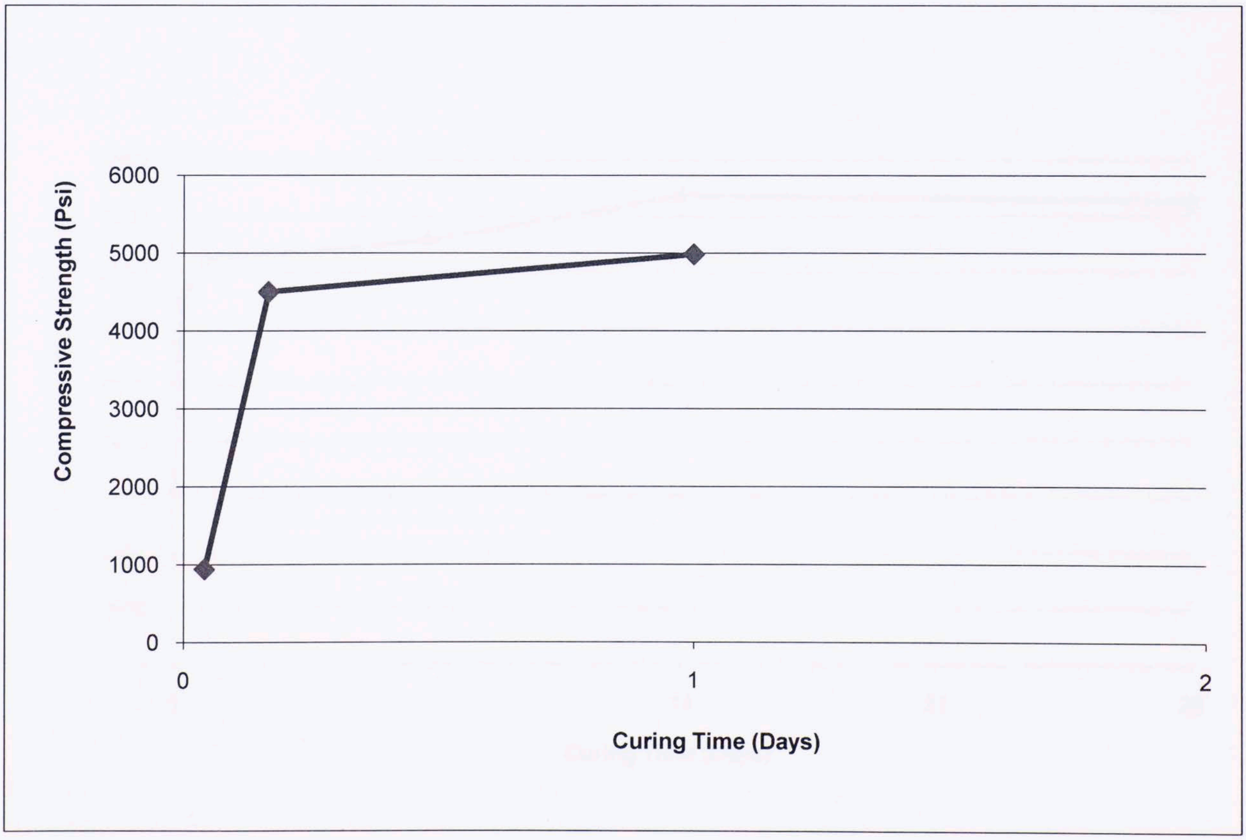

Figure 69 - Mixed at 60°F, Cured at Room Temperature, High Strength, Citric

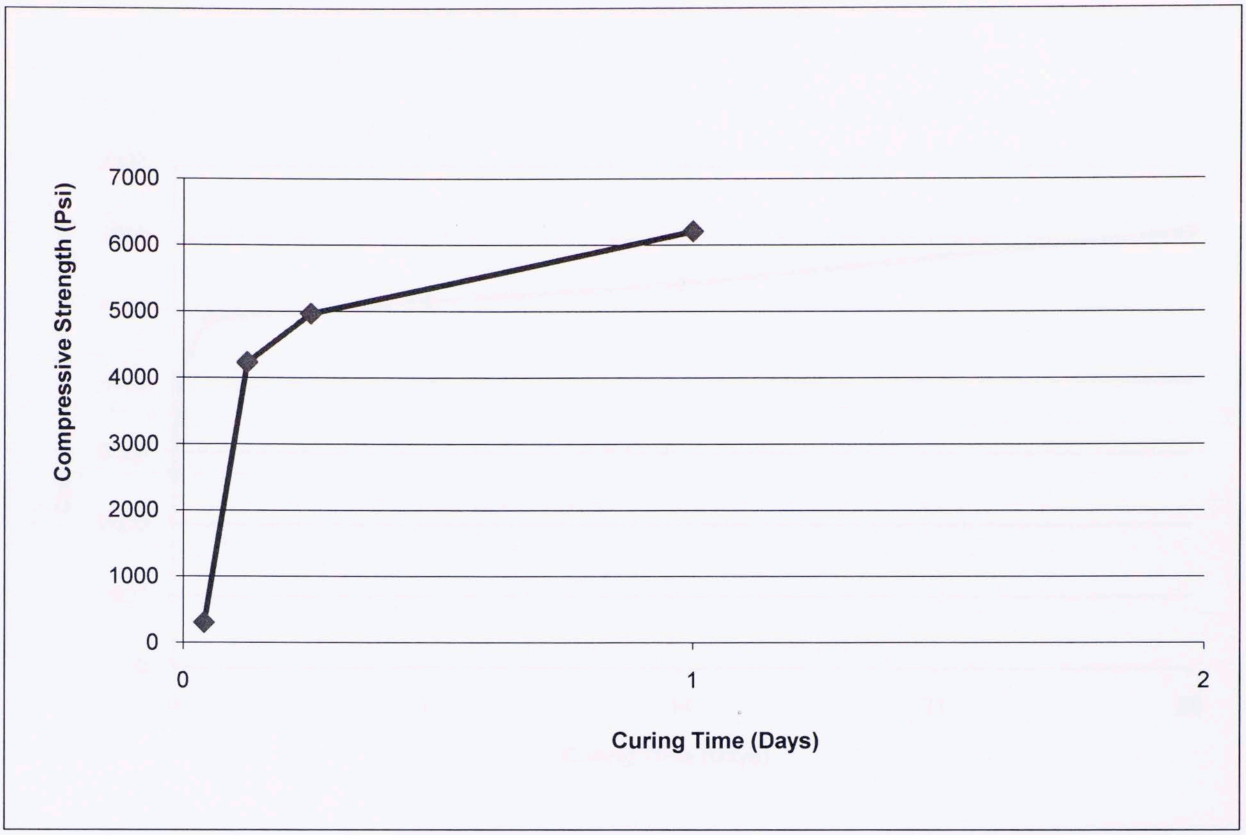

Figure 70 - Mixed at 60°F, Cured at Room Temperature, High Strength, Citric

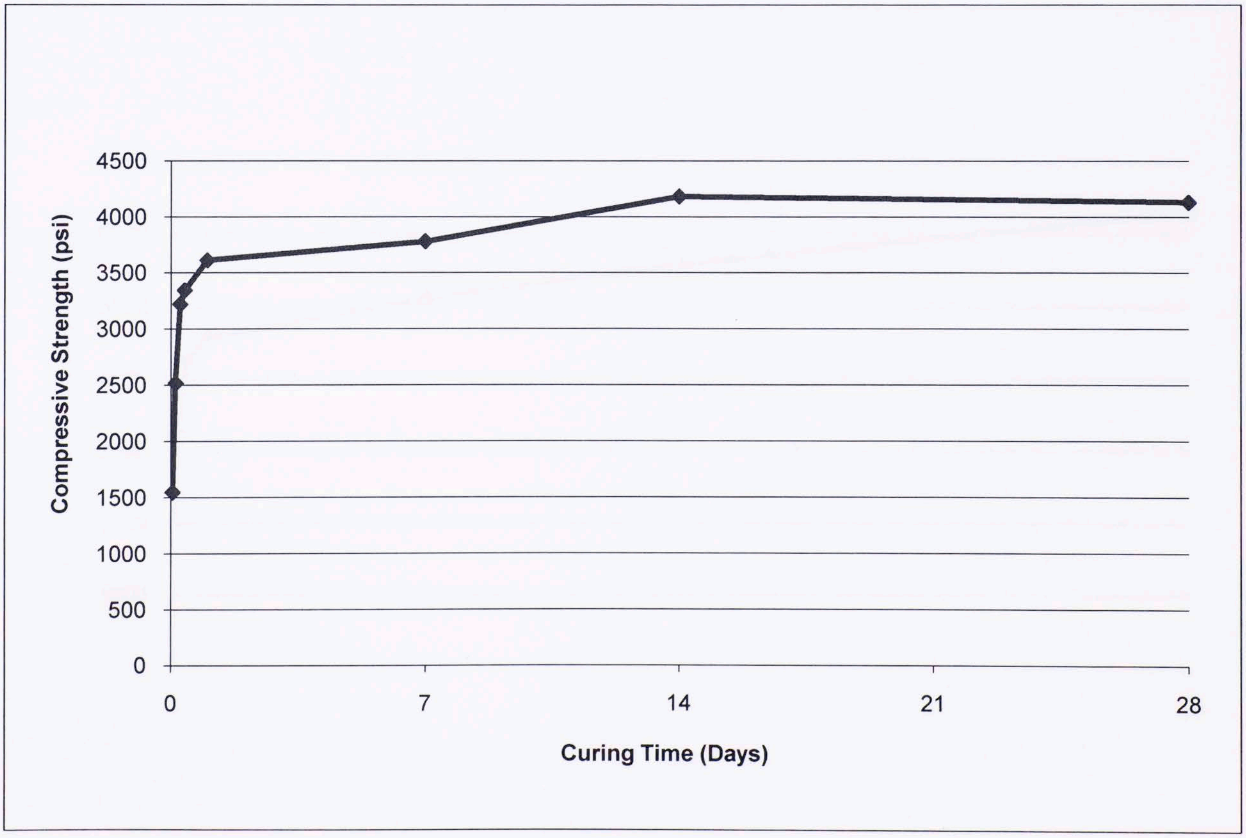

Figure 71 - Mixed at 60°F, Cured at 100°F, Low Strength, Glenium

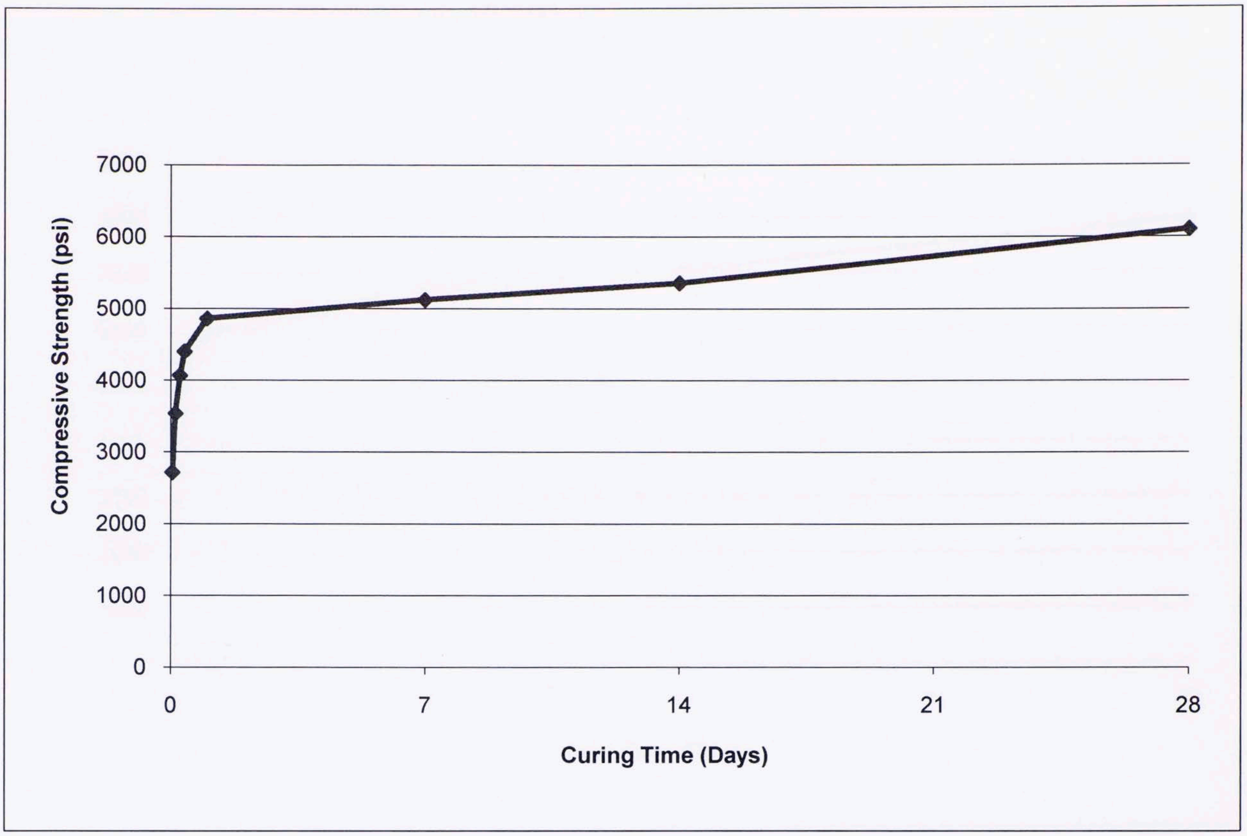

Figure 72 - Mixed at 60°F, Cured at 100°F, High Strength, Glenium

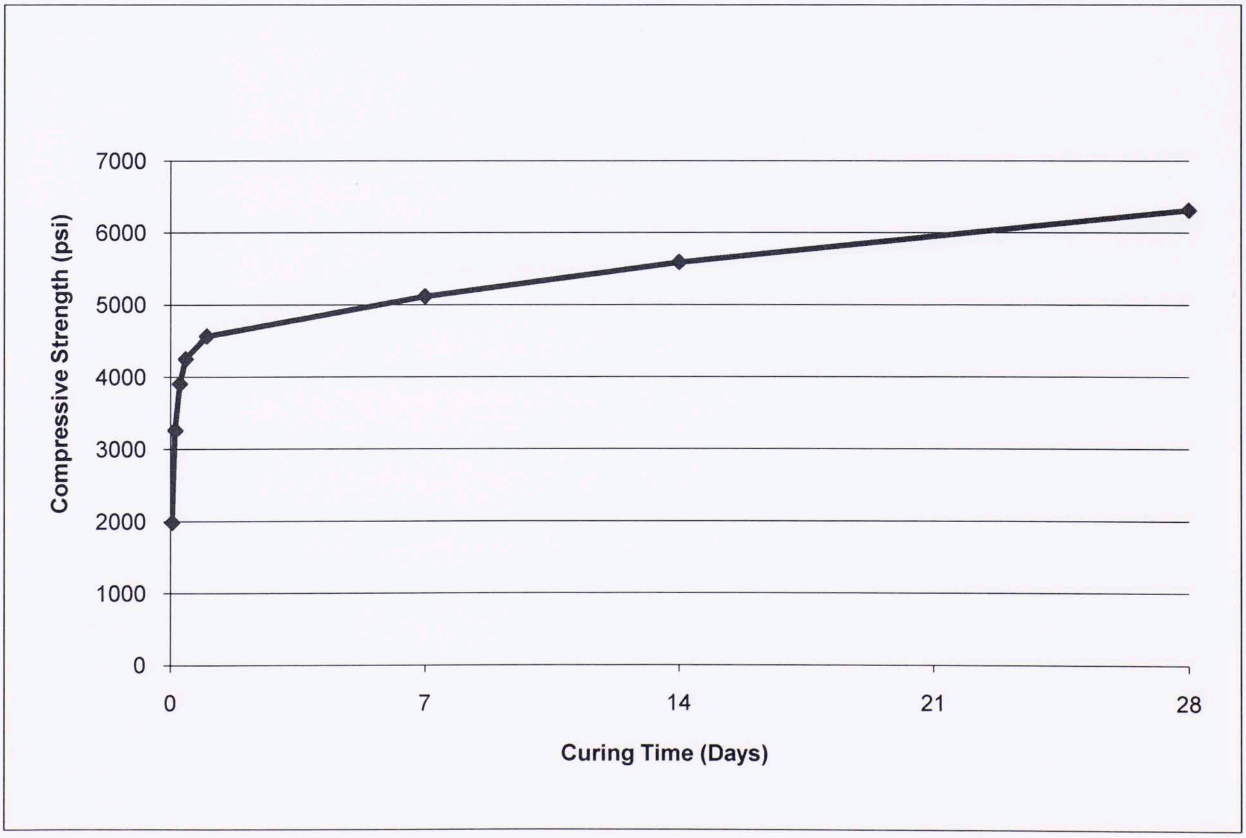

Figure 73 - Mixed at 80°F, Cured at 100°F, Low Strength, Glenium

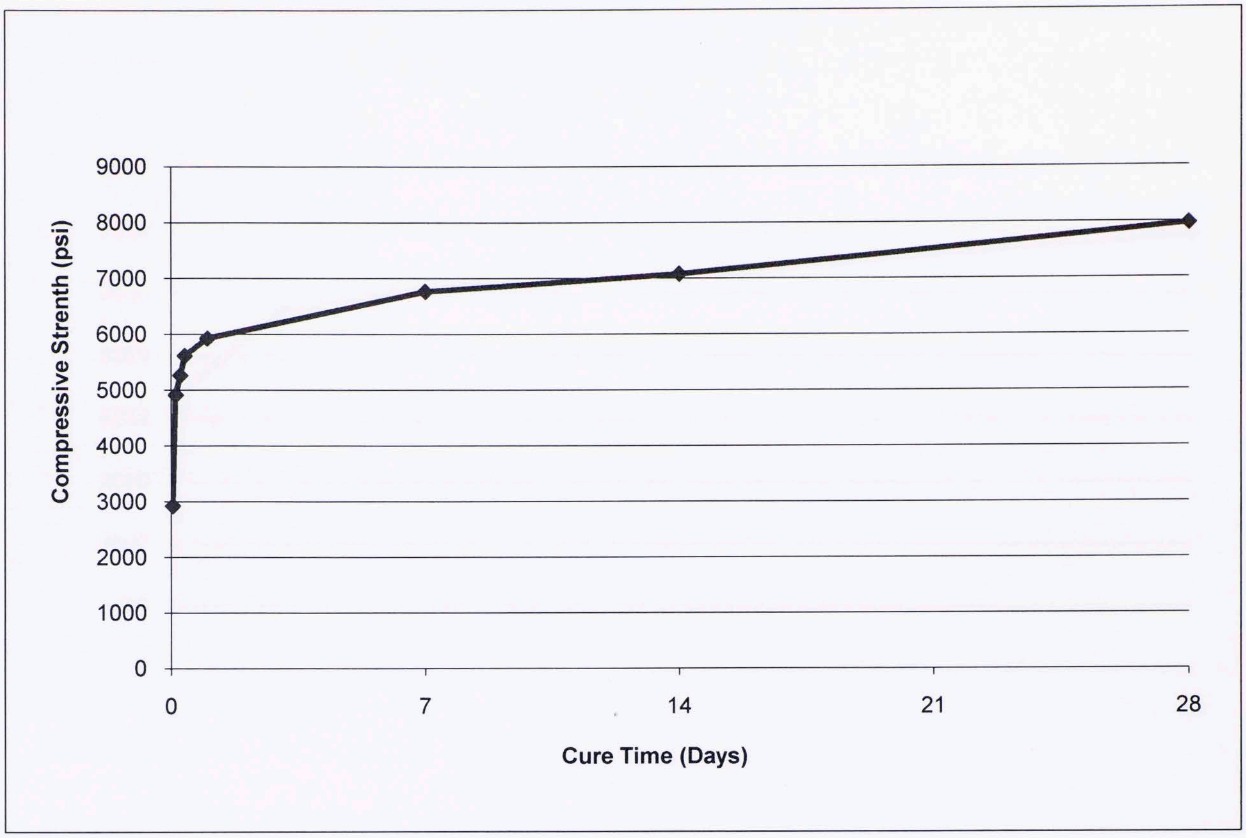

Figure 74 - Mixed at 80°F, Cured at 100°F, High Strength, Glenium

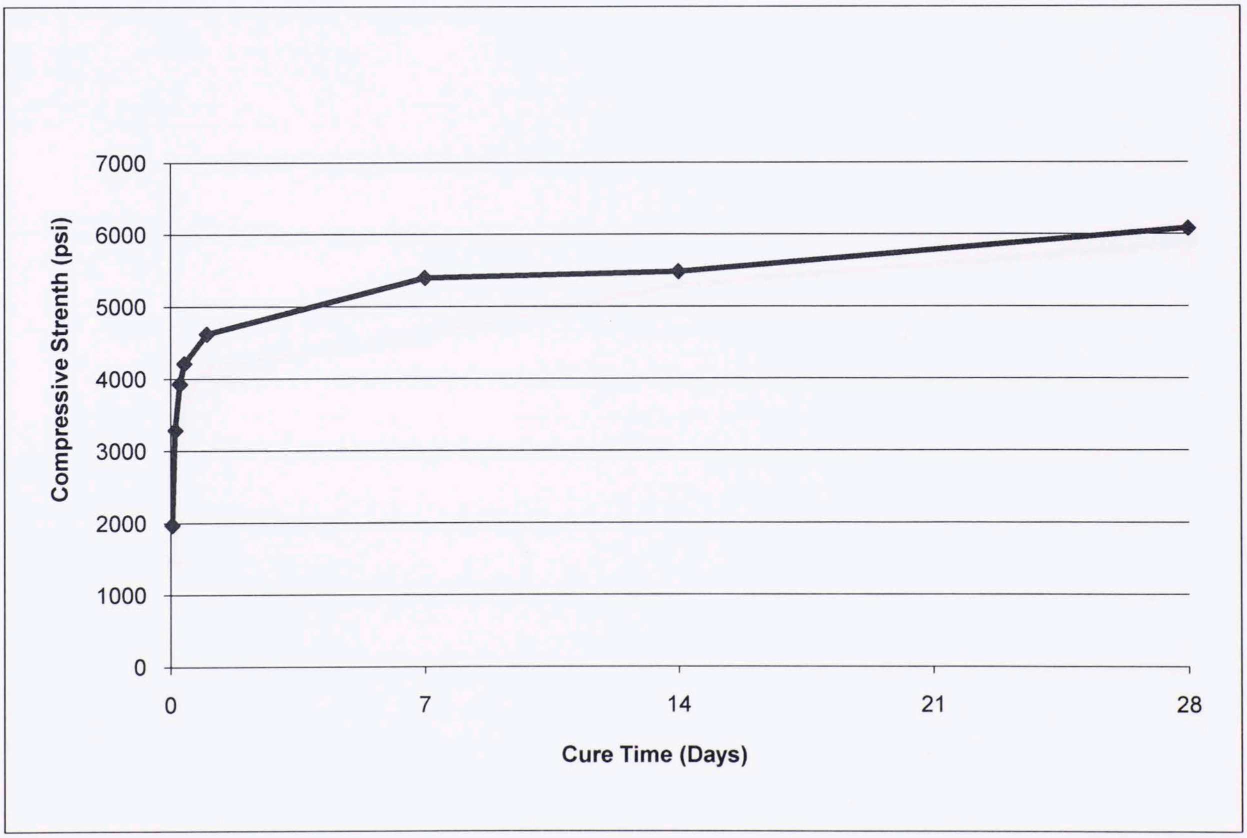

Figure 75 - Mixed at 80°F, Cured at 80°F, Low Strength, Glenium

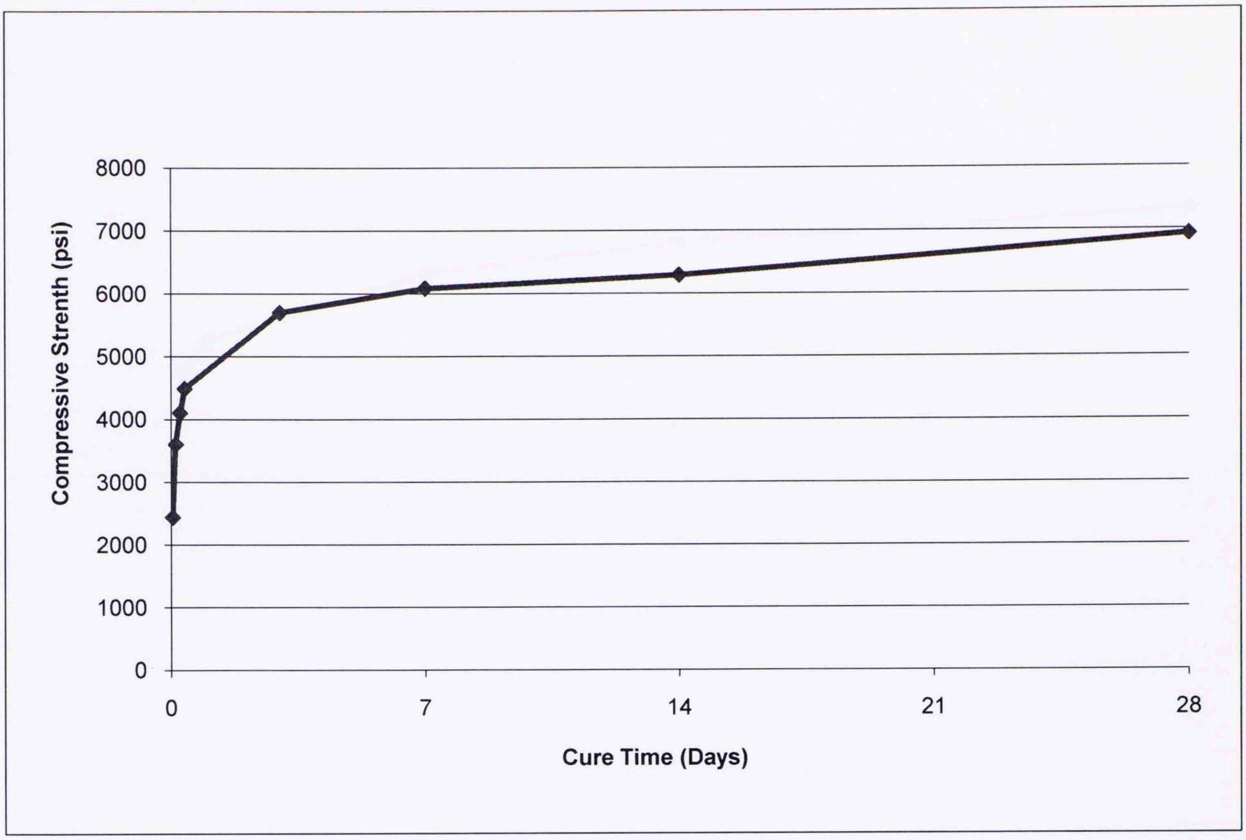

Figure 76 - Mixed at 80°F, Cured at 80°F, High Strength, Glenium

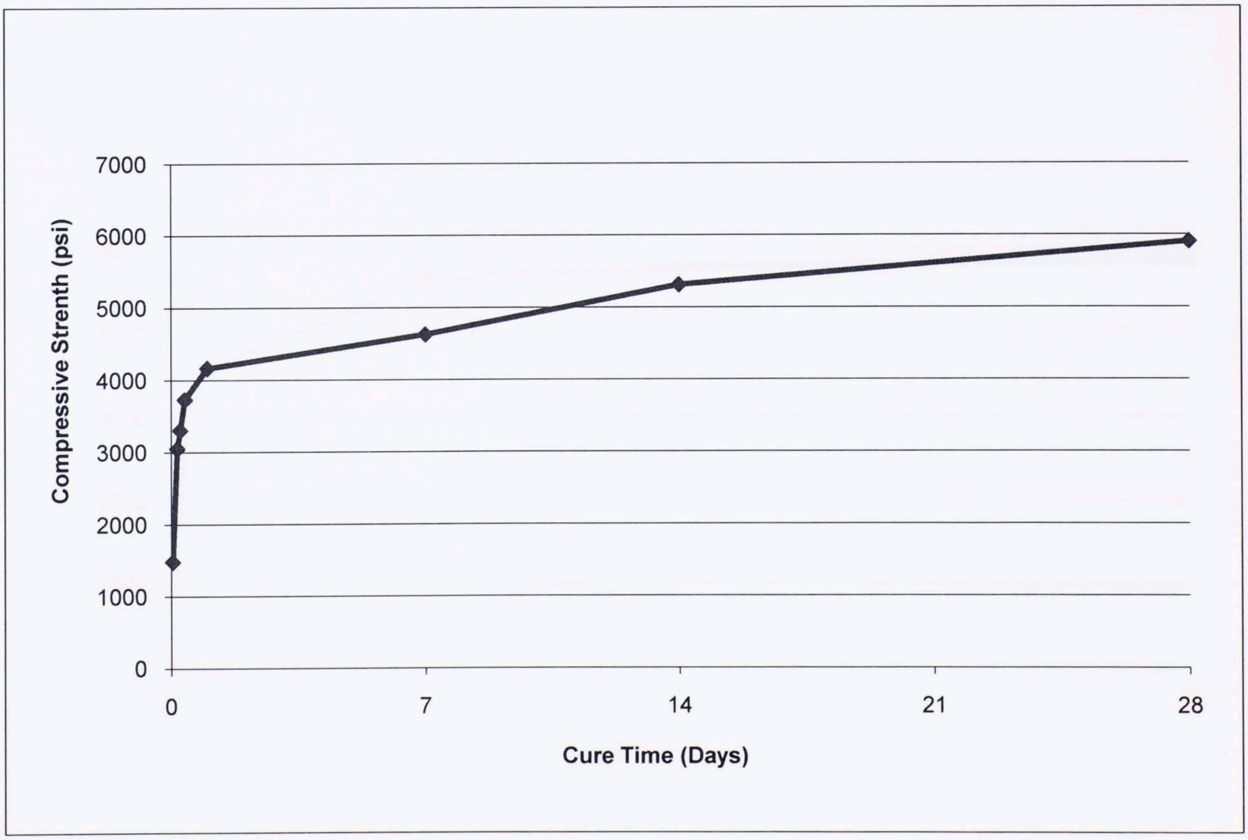

Figure 77 - Mixed at 60°F, Cured at 80°F, Low Strength, Glenium

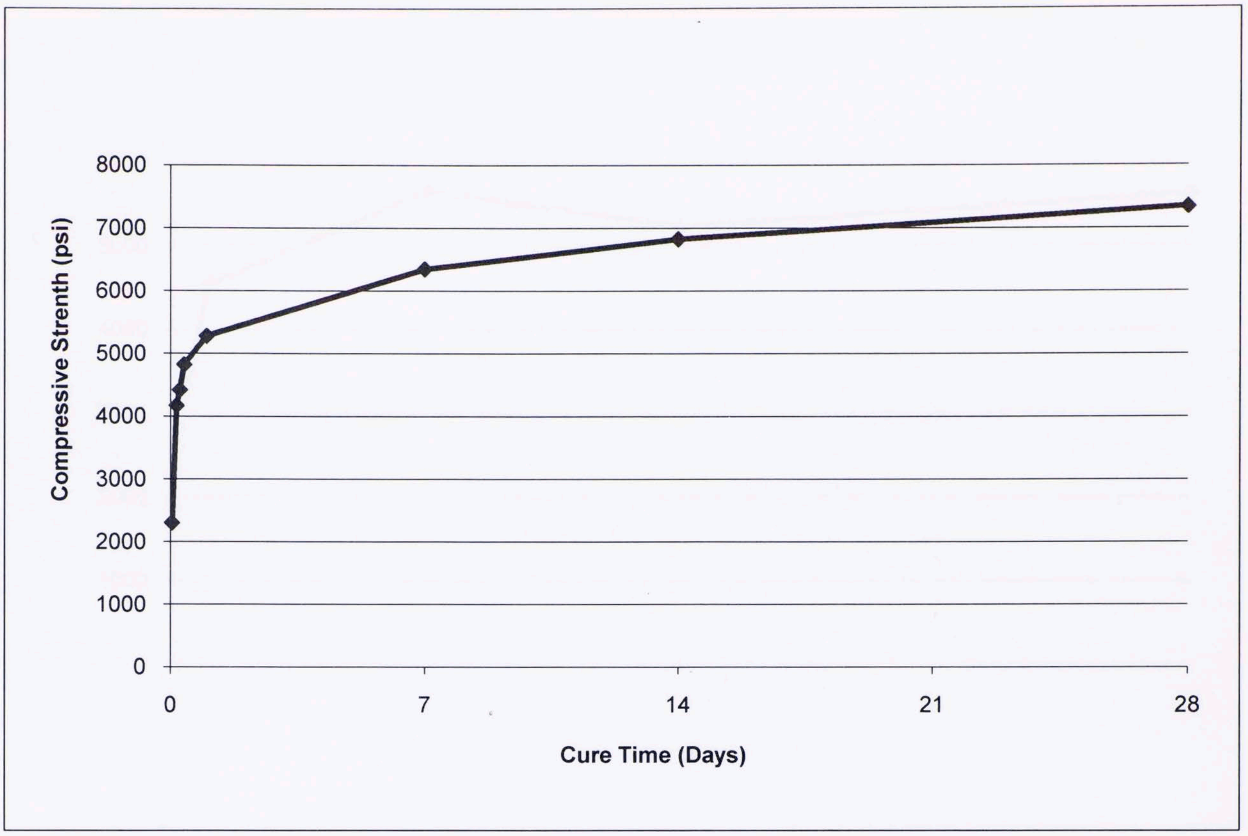

Figure 78 - Mixed at 60°F, Cured at 80°F, High Strength, Glenium

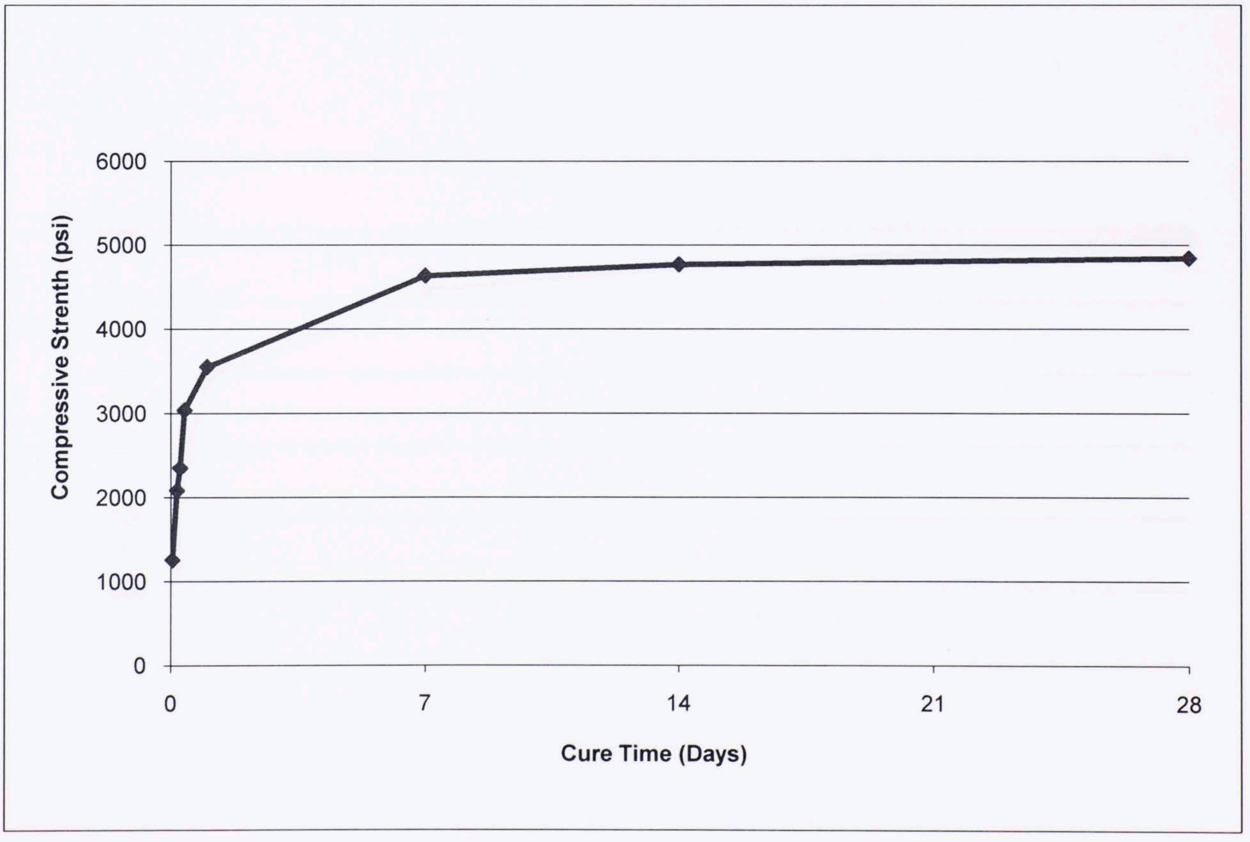

Figure 79 - Mixed at 80°F, Cured at 60°F, Low Strength, Glenium

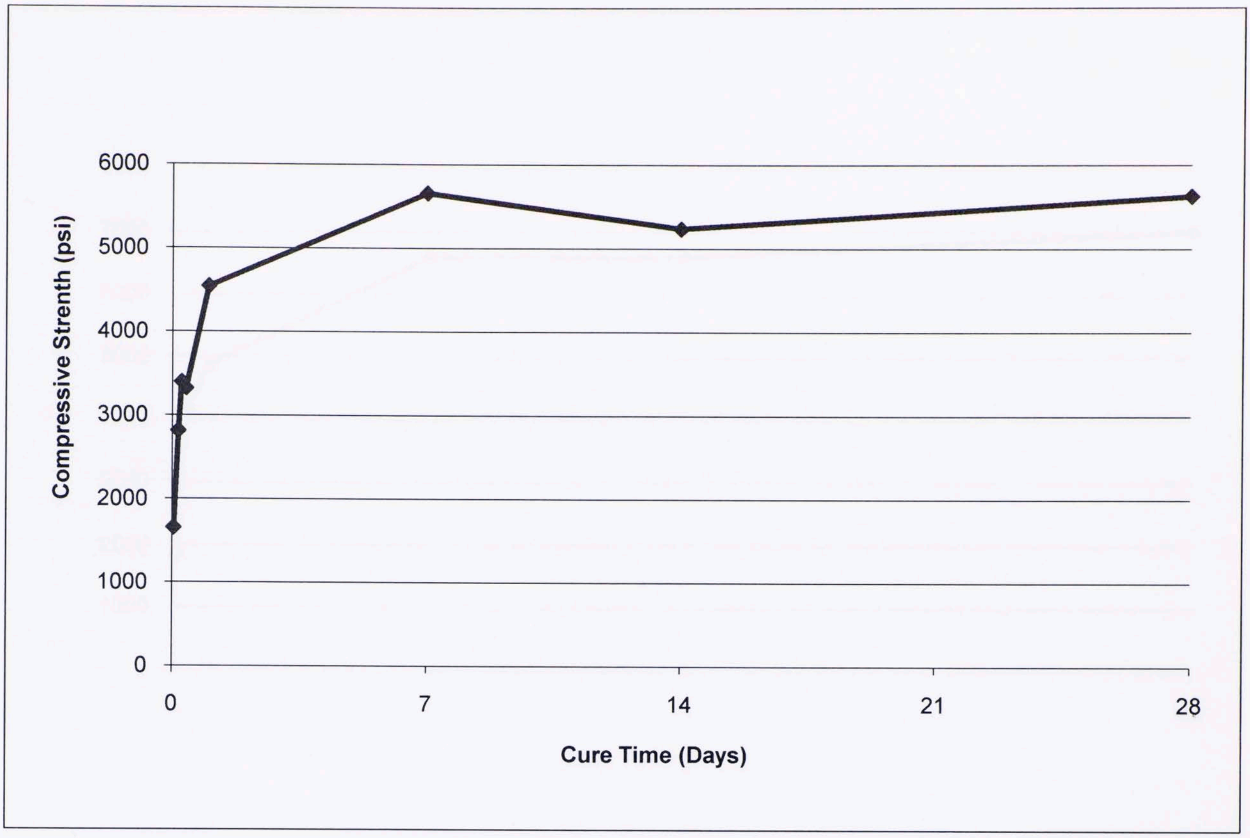

Figure 80 - Mixed at 80°F, Cured at 60°F, High Strength, Glenium

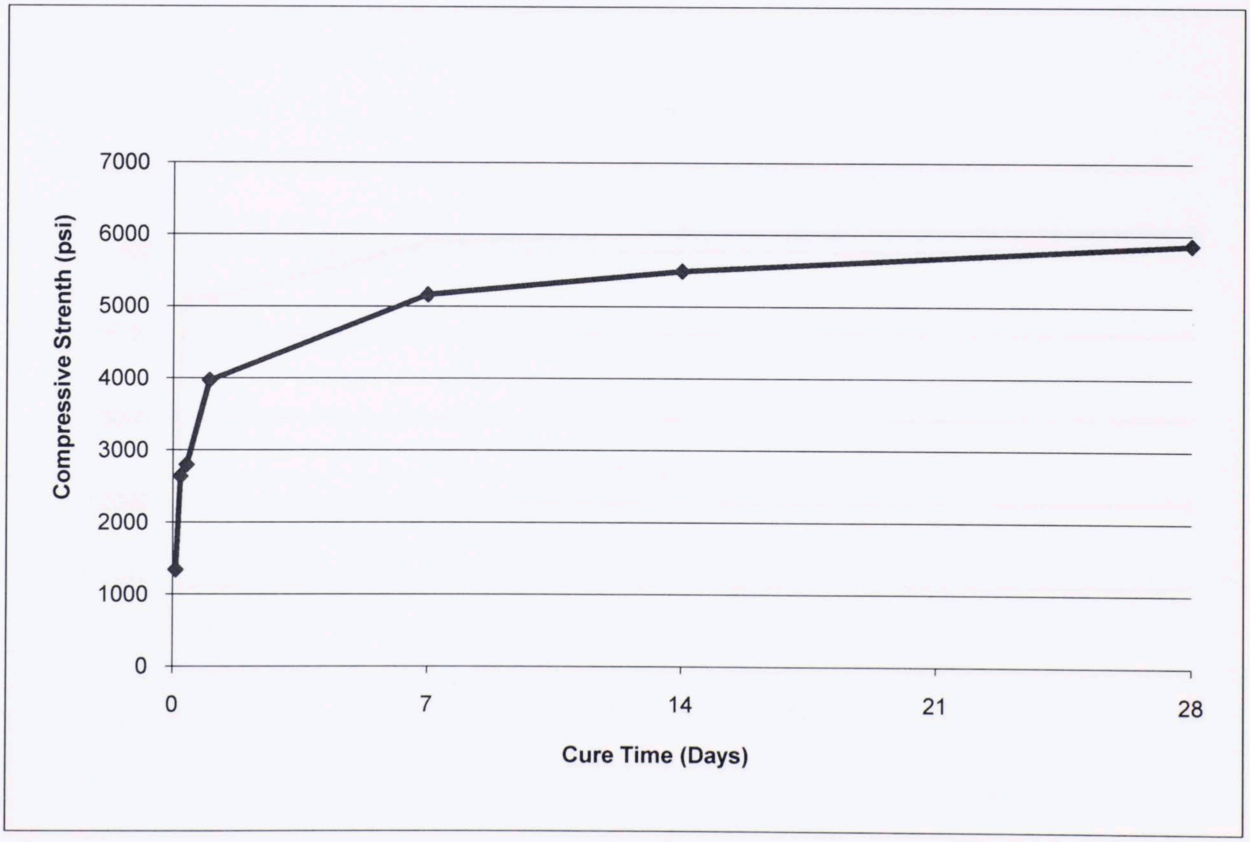

Figure 81 - Mixed at 60°F, Cured at 60°F, Low Strength, Glenium

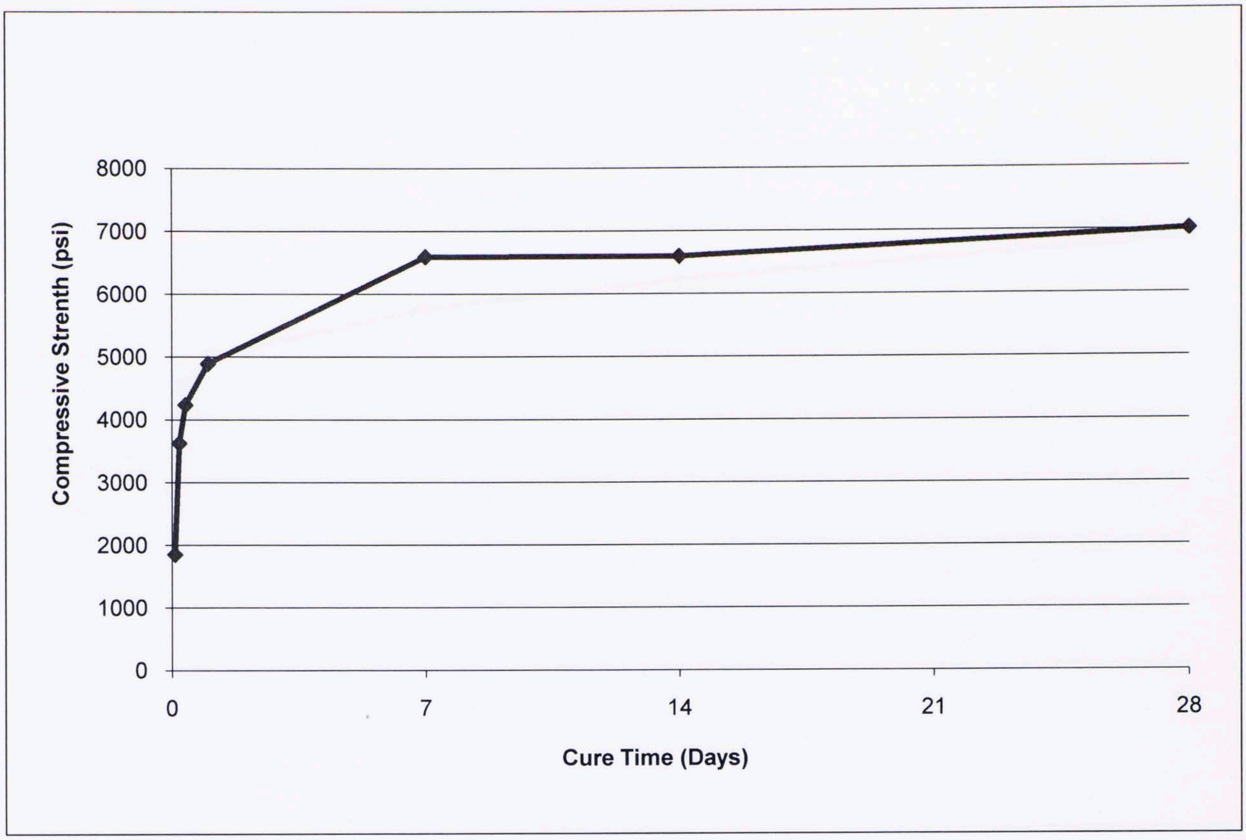

Figure 82 - Mixed at 60°F, Cured at 60°F, High Strength, Glenium

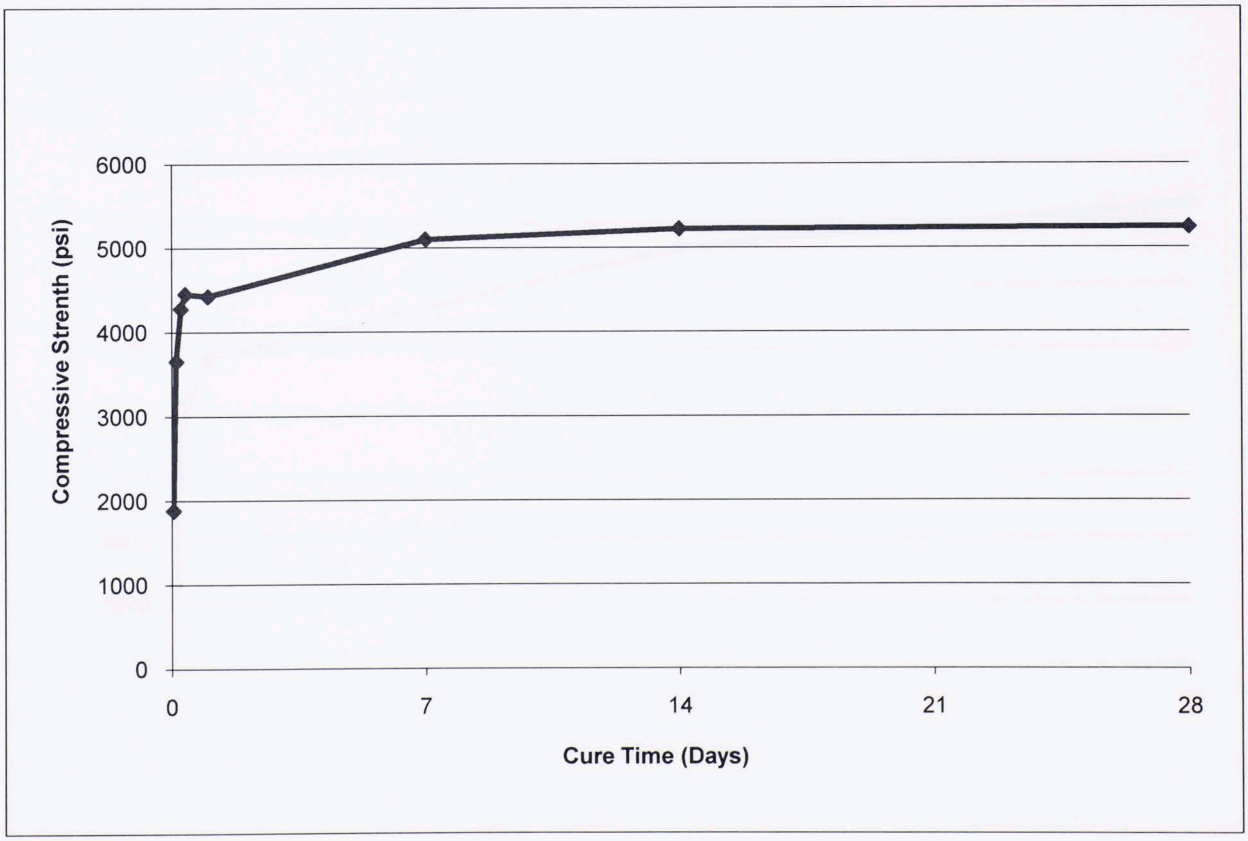

Figure 83 - Mixed at 40°F, Cured at 100°F, Low Strength, Glenium

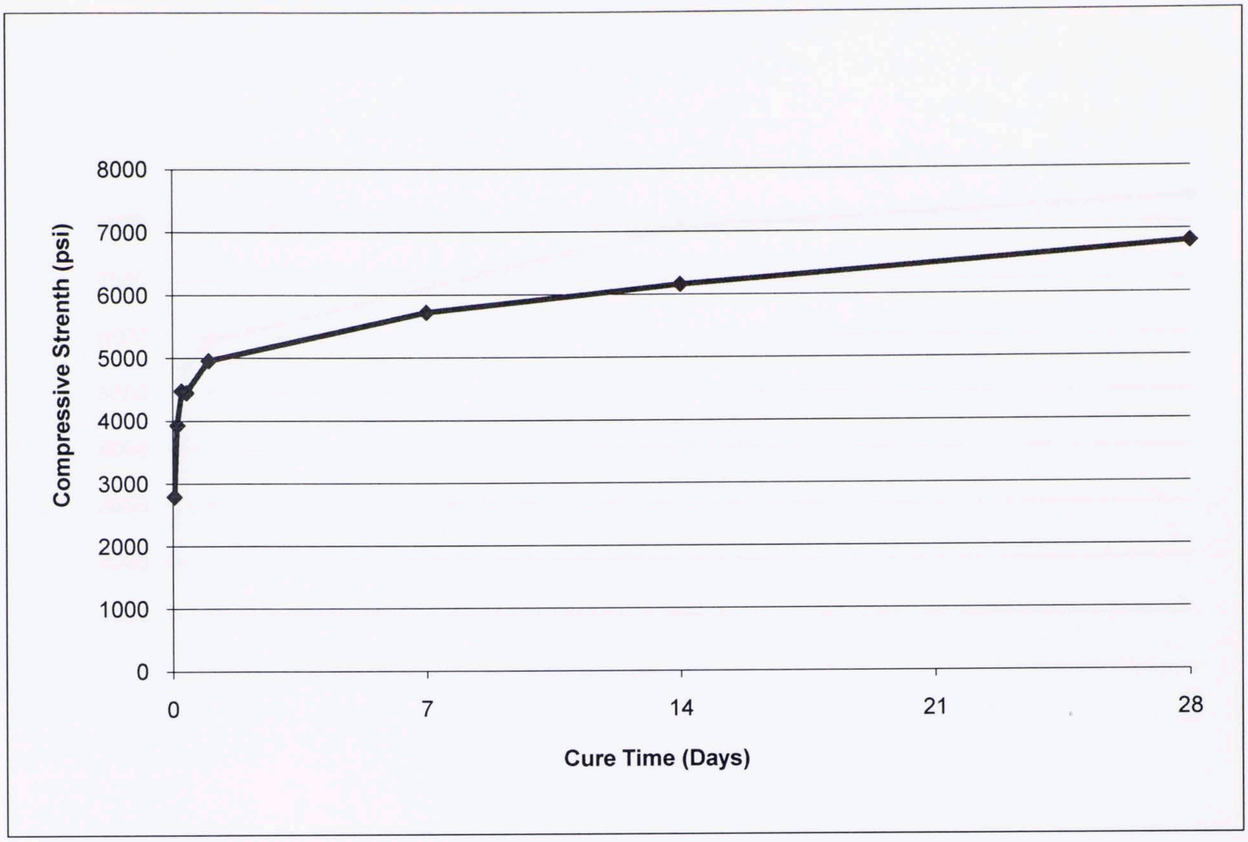

Figure 84 - Mixed at 40°F, Cured at 100°F, High Strength, Glenium

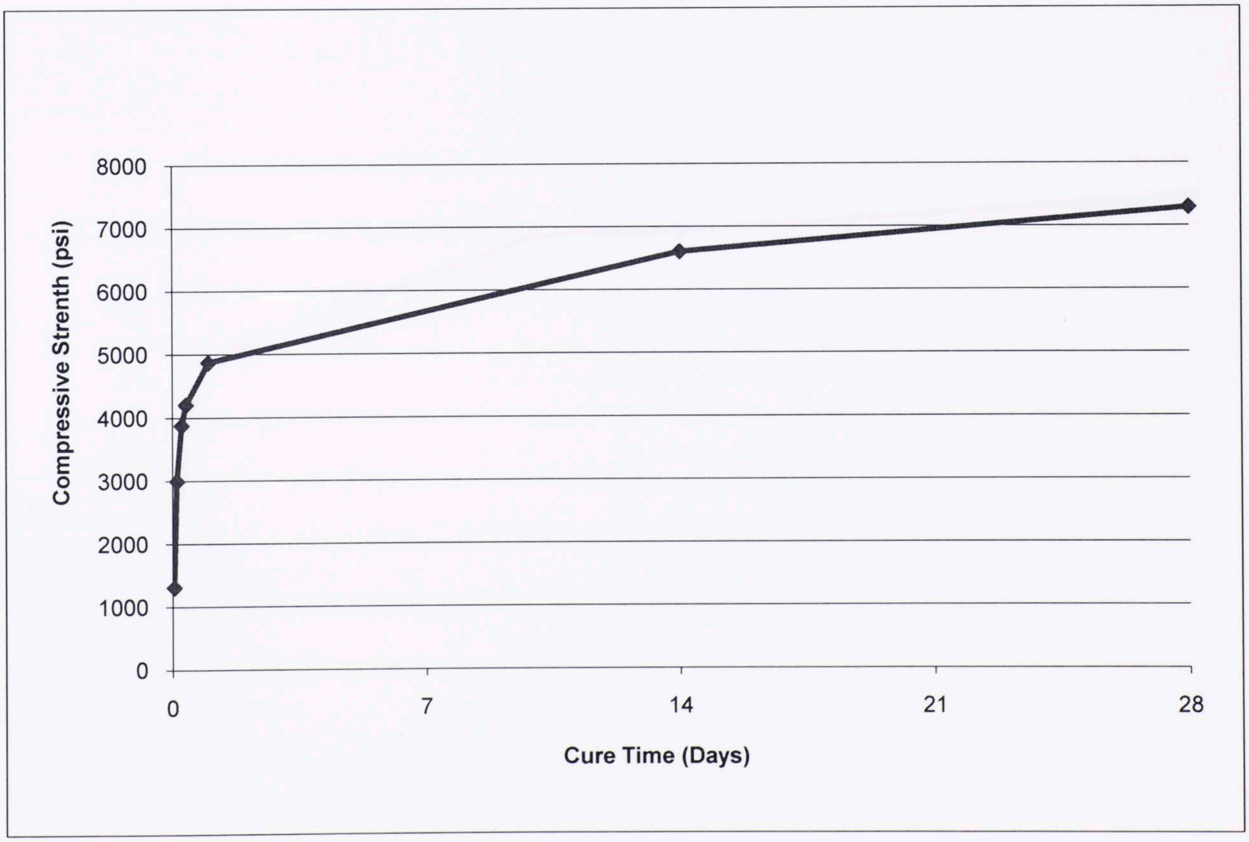

Figure 85 - Mixed at 40°F, Cured at 80°F, Low Strength, Glenium

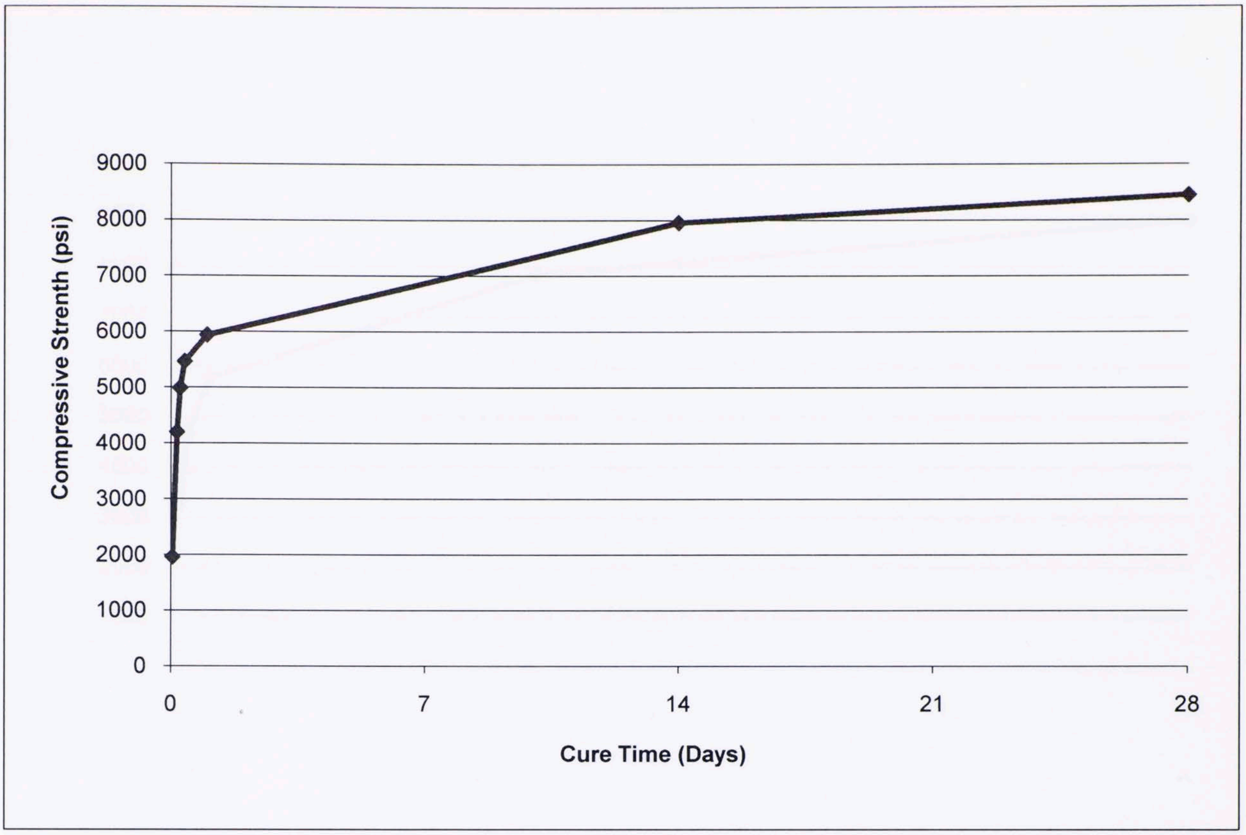

Figure 86 - Mixed at 40°F, Cured at 80°F, High Strength, Glenium

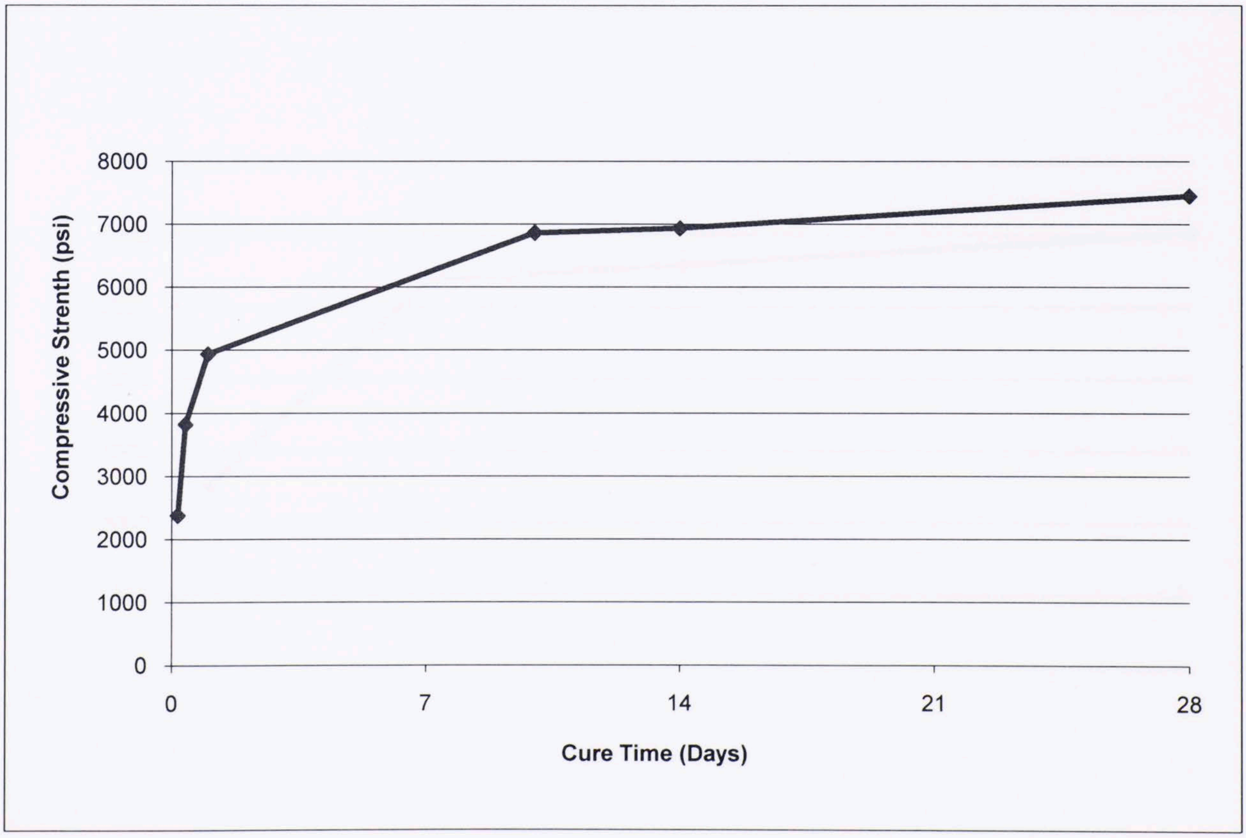

Figure 87 - Mixed at 40°F, Cured at 60°F, Low Strength, Glenium

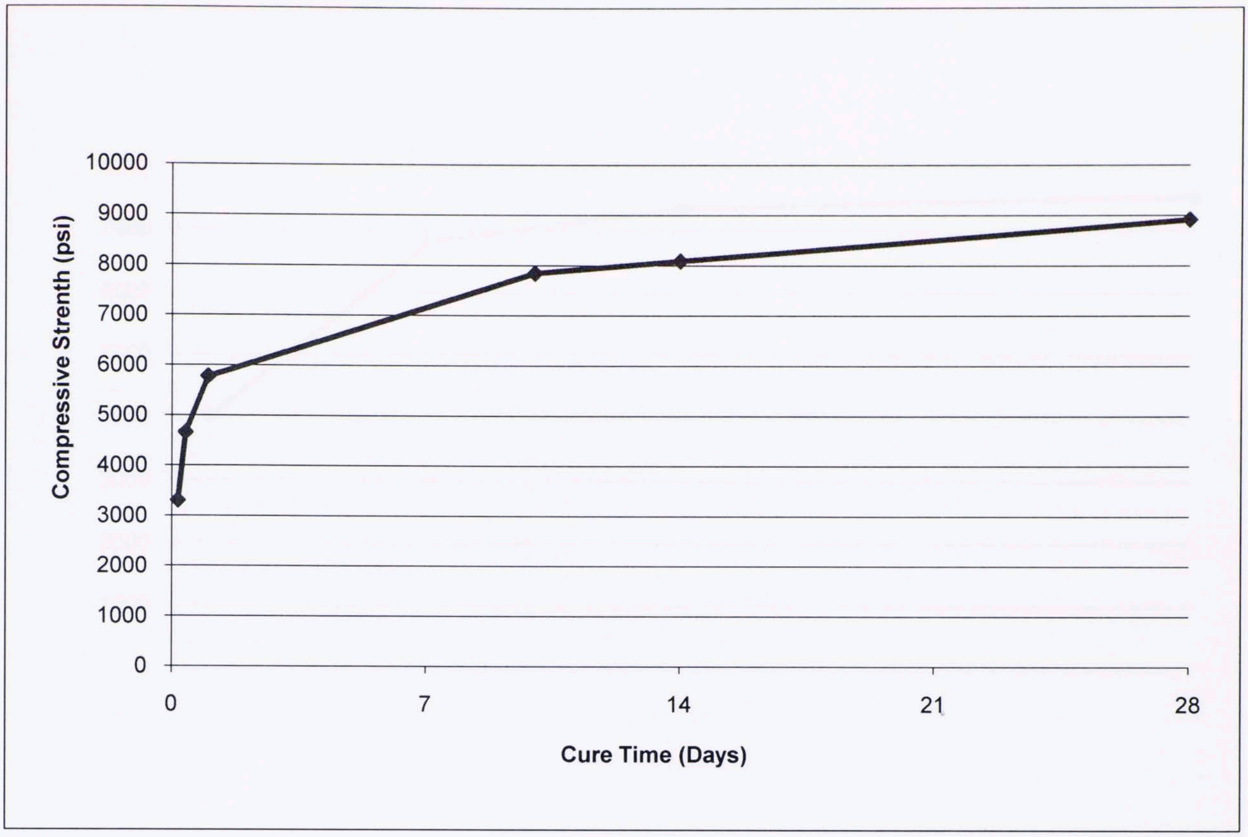

Figure 88 - Mixed at 40°F, Cured at 60°F, High Strength, Glenium

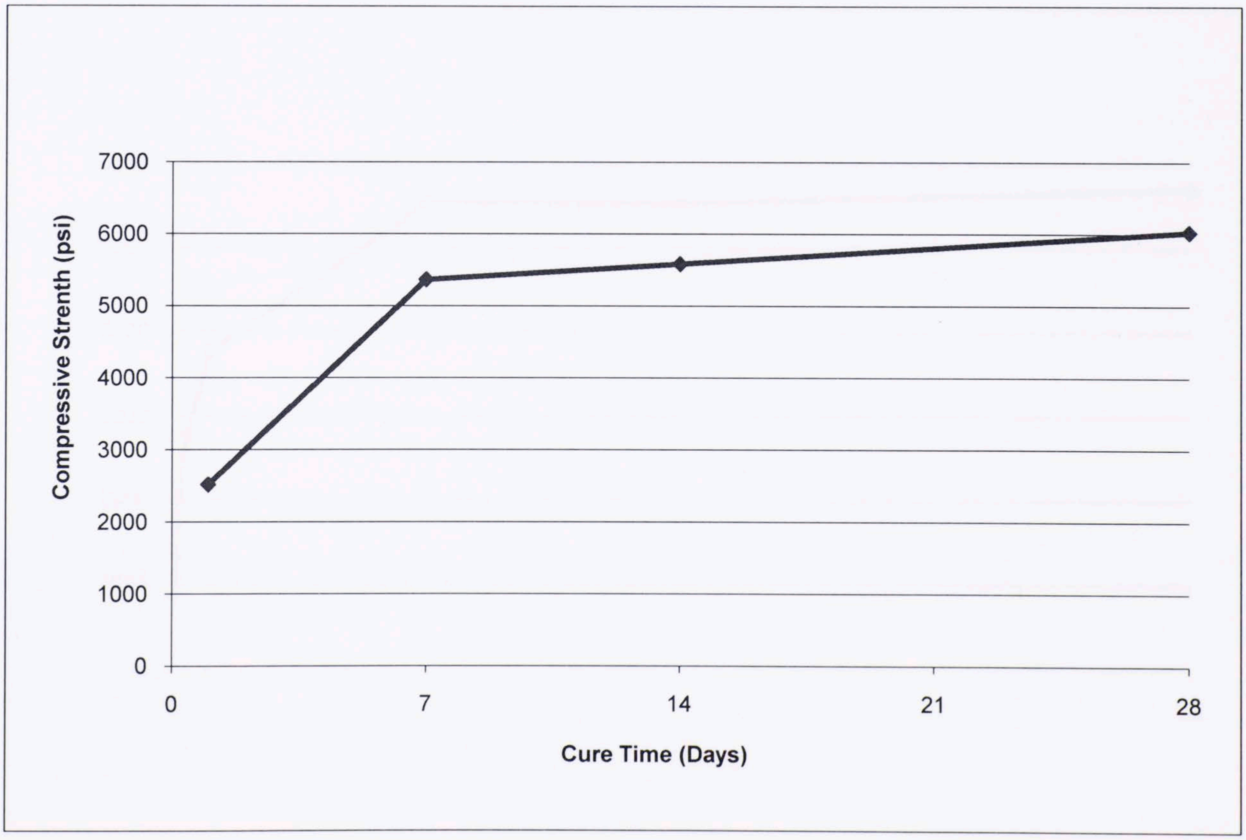

Figure 89 - Mixed at 40°F, Cured at 40°F, Low Strength, Glenium

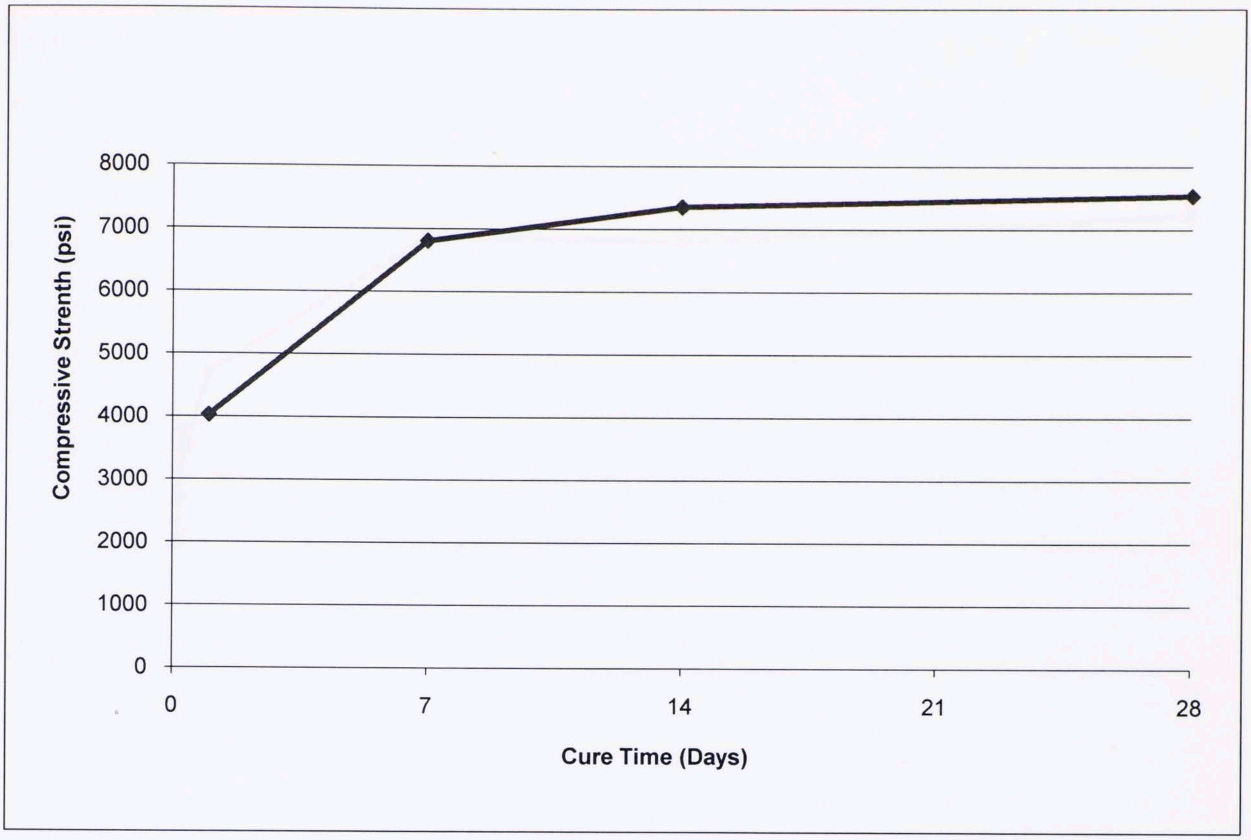

Figure 90 - Mixed at 40°F, Cured at 40°F, High Strength, Glenium

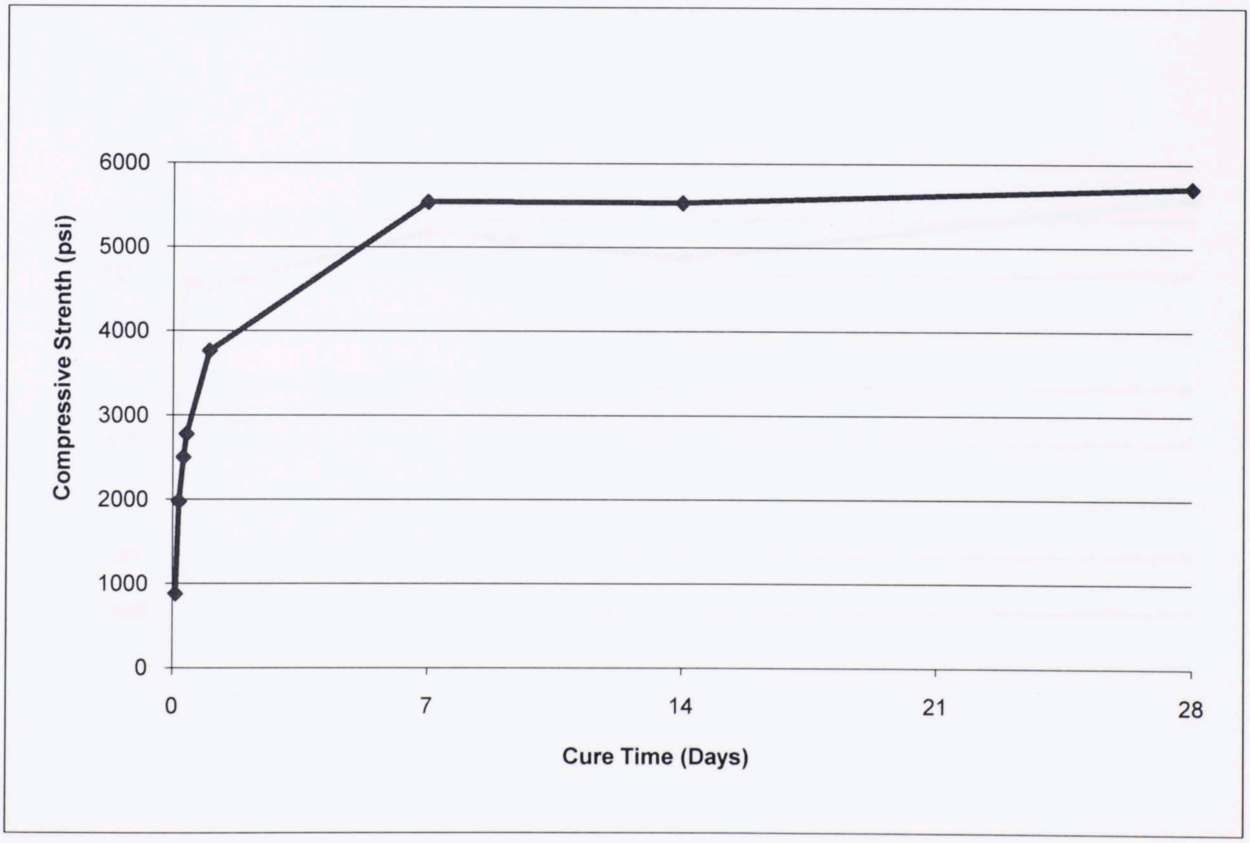

Figure 91 - Mixed at 60°F, Cured at 40°F, Low Strength, Glenium

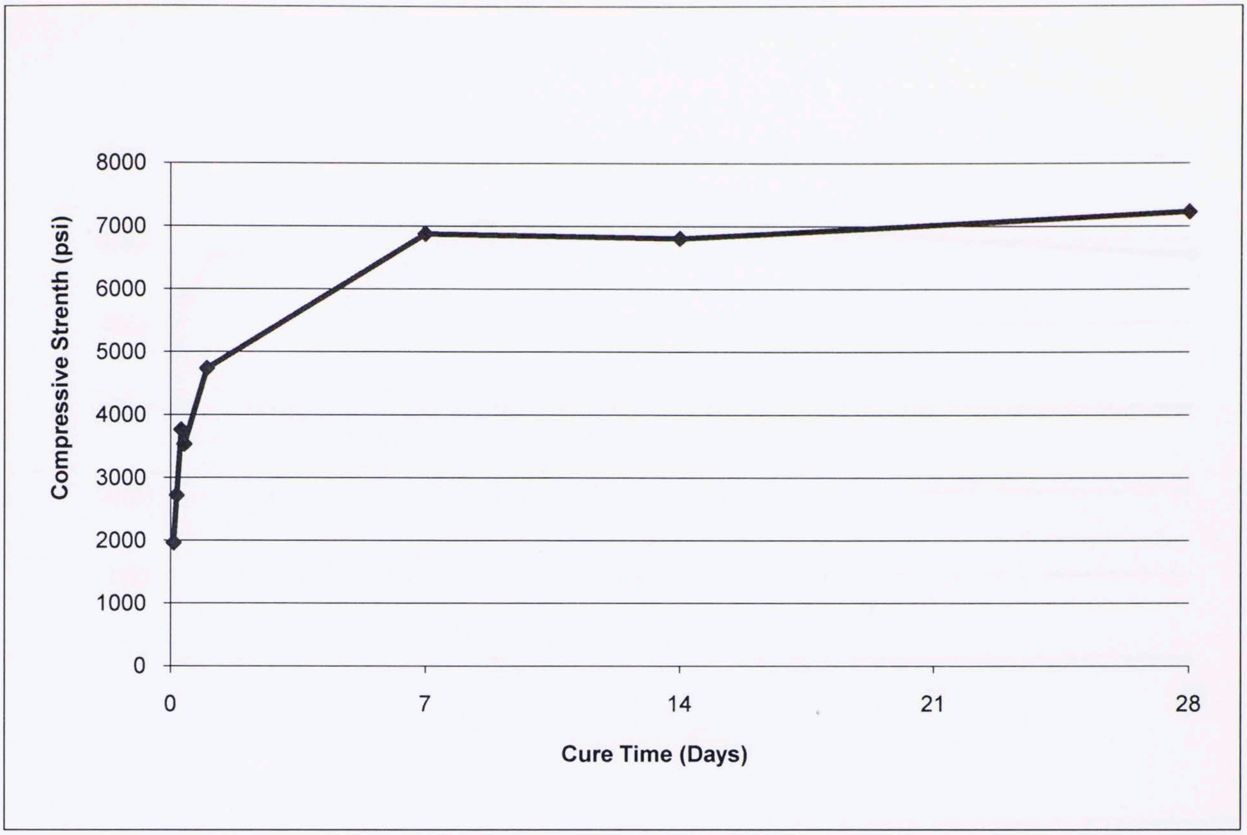

Figure 92 - Mixed at 60°F, Cured at 40°F, High Strength, Glenium

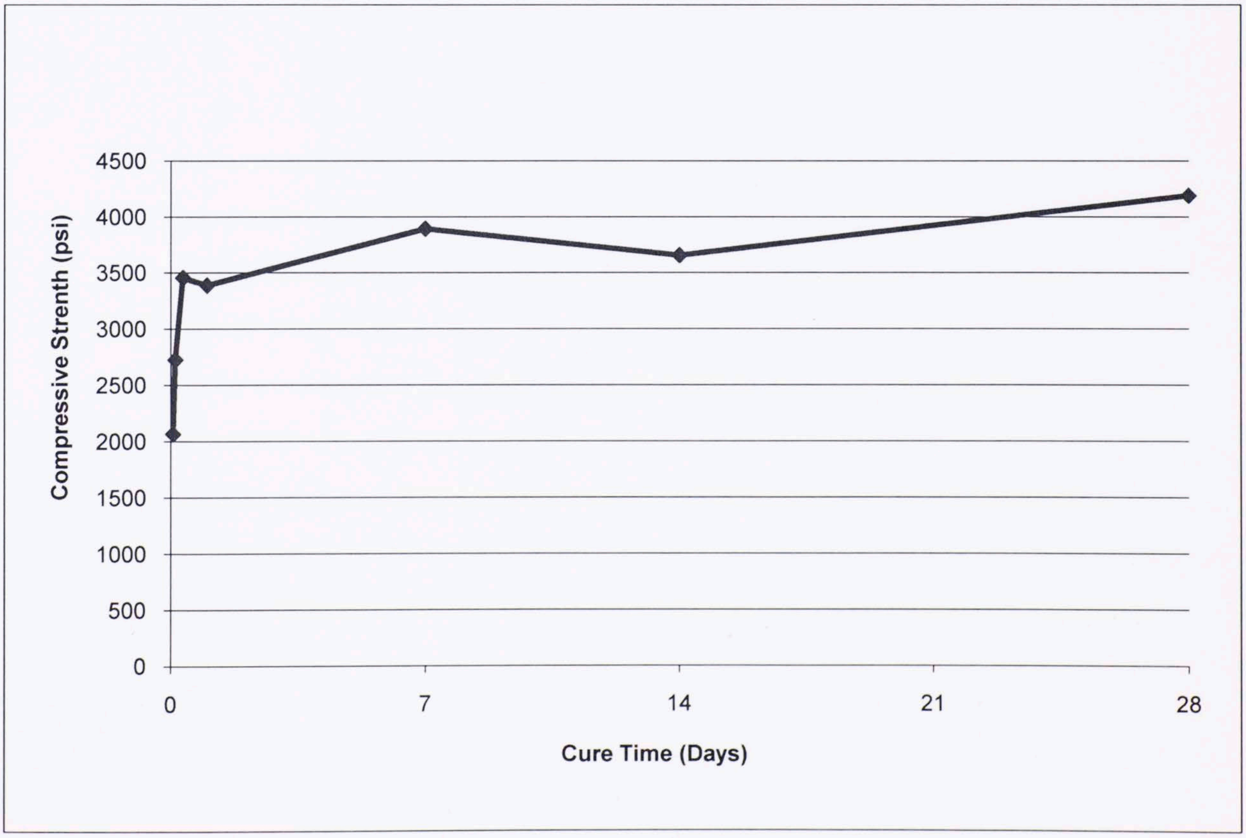

Figure 93 - Mixed at 80°F, Cured at 40°F, Low Strength, Glenium

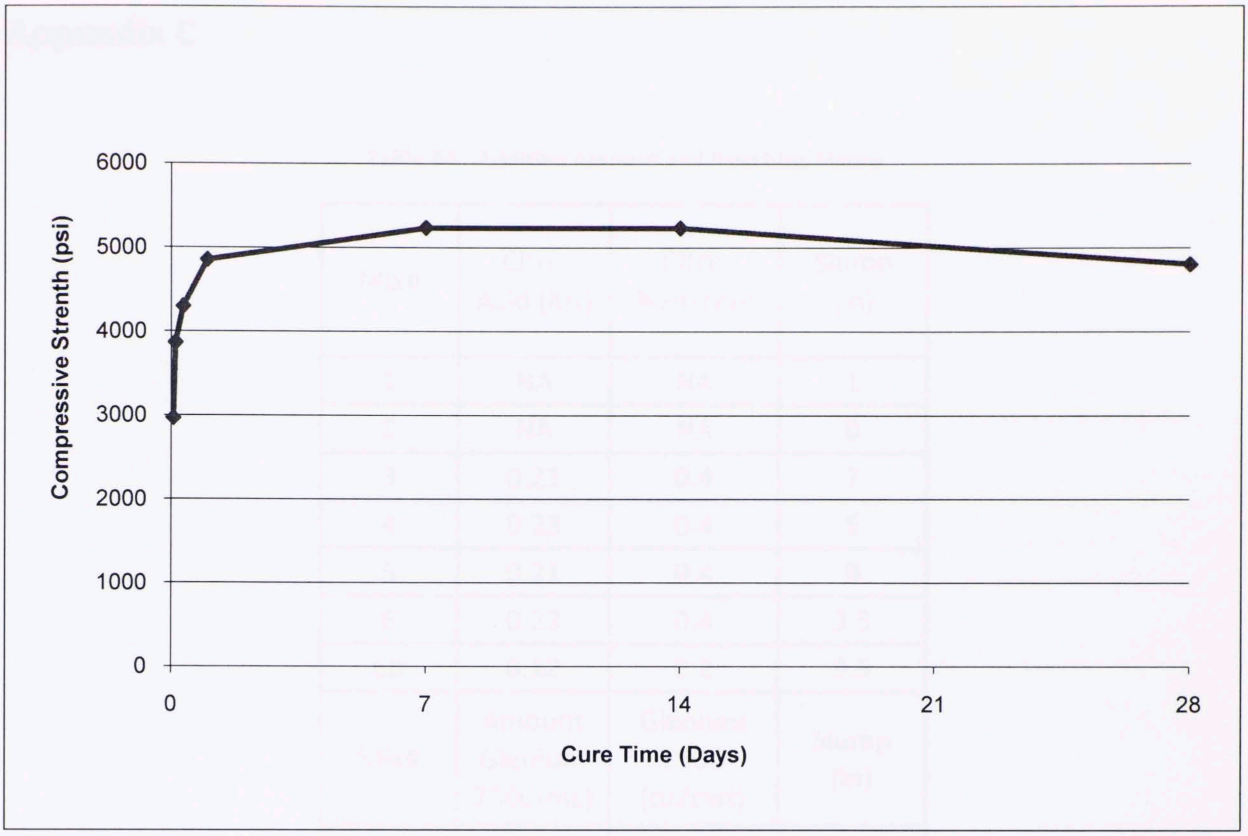

Figure 94 - Mixed at 80°F, Cured at 40°F, High Strength, Glenium

Appendix C

Table 44 - Additive Amount and Resulting Slump

Mix#	Citric Acid (lbs)	Citric %wt/cem	Slump (in)
1	NA	NA	1
2	NA	NA	0
3	0.21	0.4	7
4	0.23	0.4	5
5	0.21	0.4	9
6	0.23	0.4	3.5
6b	0.12	0.2	3.5
Mix#	Amount Glenium 7500(mL)	Glenium 7500 (oz/cwt)	Slump (in)
7	201	13.06	10
8	231	13.58	9
9	100	6.5	4.5
10	150	8.82	2.5
11	200	12.99	9
12	231	13.58	9.5
13	201	13.06	10
14	150	8.82	8
15	125	8.12	8.5
16	175	10.29	4.5
17	125	8.12	9
18	175	10.29	8
19	125	8.12	8.5
20	175	10.29	5
21	125	8.12	7.5
22	175	10.29	5.5
23	125	8.12	9
24	175	10.29	8
25	125	8.12	10
26	175	10.29	8
27	125	8.12	8

Mix#	Amount Glenium 7500(mL)	Glenium 7500 (oz/cwt)	Slump (in)
28	175	10.29	6.5
29	125	8.12	8.5
30	175	10.29	NA