BURNS COOLEY DENNIS, INC.

GEOTECHNICAL AND MATERIALS ENGINEERING CONSULTANTS

Influences of Cement Source and Sample of Cement Source on Compressive Strength Variability of Gravel Aggregate Concrete

State Study No 239

Project No. 106002 161000

Prepared for
Mississippi Department of Transportation

Prepared by
Robert L. Varner, P.E.

June, 2013

Technical Report Documentation Page

1. Report No. FHWA/MS-DOT-RD-13-239	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Influences of Cement Source and Sample of Cement Source on Compressive Strength Variability of Gravel Aggregate Concrete		5. Report Date June 2013 6. Performing Organization Code BCD No. 100448
7. Author Robert L. Varner, P.E.		8. Performing Organization Report No. MS-DOT-RD-13-239
9. Performing Organization Name and Address Burns Cooley Dennis, Inc. Post Office Box 12828 Jackson, Mississippi 39236		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project No. 106002 161000 Work Assignment No. BCD-MT 2010-03
12. Sponsoring Agency Name and Address Mississippi Department of Transportation P.O. Box 1850 Jackson, MS 39215-1850		13. Type Report and Period Covered **Final Report** (March 2011 to June 2013) 14. Sponsoring Agency Code
15. Supplementary Notes MDOT State Study 239		

16. Abstract: The strength of concrete is influenced by each constituent material used in the concrete mixture and the proportions of each ingredient. Water-cementitious ratio, cementitious materials, air content, chemical admixtures, and type of coarse aggregate are important factors that influence strength. Experience shows that variability of concrete strength is inevitable even when these factors are held constant. All constituent materials change with each sample of the material and these changes have influence on concrete strength. This study provides MDOT engineers with compressive strength data on gravel aggregate concrete using seven portland cements and three samples collected approximately one month apart from each source. Crushed limestone was used for control mixtures. Data was collected from eighty-four mixtures to show compressive strength variability of gravel aggregate concrete.

17. Key Words Cementitious Material, Chemical Properties, Coefficient of Variability, Compressive Strength, Cube Strength, Fly Ash, Mortar Cubes, Physical Properties, Portland Cement, Required Average Compressive Strength, Standard Deviation, Strength Variability, Variability, Water Cementitious Ratio		18. Distribution Statement Unclassified	
19. Security Classification. (of this report) Unclassified	20. Security Classification. (of this page) Unclassified	21. No. of Pages Including Cover 226	22. Price

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Mississippi Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government and the State of Mississippi assume no liability for its contents or use thereof.

The United States Government and the State of Mississippi do not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

Acknowledgements

This work was performed under the supervision of the MDOT TAC Committee:

Research Division: Bill Barstis, P.E.
Materials Division: James Williams, P.E.
Adam Browne, P.E

Special thanks to Holcim (USA), Inc. and Senior Technical Services Engineer, Tim Cost P.E., for their expertise and knowledge of cementitious materials along with testing services provided for this research.

This work was accomplished with the support of Burns Cooley Dennis' staff and management and the technical knowledge and experience of the following:

R.C. Ahlrich, Ph.D., P.E.
Howard Hornsby, E.I.
Scott Bivings

Abstract

Compressive strength of concrete is influenced by all aspects of the concrete mixture including each constituent material and proportions of each ingredient. Water-cementitious ratio, cementitious materials, air content, chemical admixtures, and coarse aggregate properties all influence compressive strength. Experience shows that variability of concrete strength is inevitable even when afore mentioned factors are held constant. Each constituent material has variability which influences concrete strength.

The primary cementing material in concrete is portland cement. When portland cement is combined with water, a chemical reaction called hydration occurs that causes concrete to set and gain strength. While strict quality control measures are in place at portland cement plants, the chemical composition of each sample of portland cement varies due to variations in raw materials and the manufacturing process. If the primary cementing material has variability in its chemical composition, the compressive strength of the concrete made with the portland cement may also have variability.

Mortar cubes are used as one quality control measure at portland cement plants. This strength testing is performed using strict control of the aggregates and water. Cement companies also test competitors' cements in their market areas to understand performance of similar cements in the area. However, little testing is performed on multiple samples from the same source and various sources of cement to determine the extent of variability in compressive strength of concrete.

If there is high variability in compressive strengths of concrete among portland cement concrete suppliers in a given region, the required average compressive strength (overdesign) of the concrete mixtures will need to reflect the magnitude of this variability. Required average compressive strength (f'_{cr}) is the overdesign used for concrete mixtures to provide additional strength to account for strength variability that occurs because of changes the concrete materials and testing.

The Mississippi Department of Transportation (MDOT) currently allows Contractors to change sources of cement, fly ash and slag cement without supporting compressive strength data on the concrete made from the new source of cement. This study provides MDOT engineers with compressive strength data on gravel aggregate concrete using seven typical Mississippi portland cement sources using three samples collected approximately one month apart from each source. Crushed limestone was used to develop control mixtures. Data was collected from eighty-four mixtures to show compressive strength variability of gravel aggregate concrete.

Table of Contents

List of Tables

List of Figures

Chapter 1 – Introduction

Background

While low concrete strength is rarely encountered on construction projects for the Mississippi Department of Transportation, there have been isolated incidences where low compressive strength has be reported. Mix design submittals and supporting data usually provide no indications of potential issues on such projects. These experiences can drive construction trends that have potentially negative implications for both project quality and costs. Variability and occasional experiences with lower-than-expected strength lead concrete suppliers to design mixes with increased overdesign margins, higher cementitious content, less beneficial re-use of byproduct pozzolans, selection of higher cost aggregates, and higher dosages of chemical admixtures. An unexpected trend observed in concrete projects since MDOT's implementation of QC/QA specifications is that Contractors and concrete suppliers are rarely taking advantage of opportunities to economize mix designs and reduce cementitious content in ongoing projects using project strength records and standard deviations. Since this becomes a missed profit opportunity, concrete suppliers must have concerns about the effects of possible strength variability that outweigh the potential for cost savings. All of these factors can drive the unit cost of concrete higher and related undesirable performance trends may include higher hydration heat, greater shrinkage and cracking, and more permeable, less durable concrete.

Concrete strength variability influences MDOT mix submittal requirements and criteria for screening proposed concrete mixtures and preventing low concrete strength, to the extent possible. A better understanding of strength variability in common concrete mixtures and the key influences of specific materials and proportions was needed to facilitate evaluation of these criteria.

Antidotal evidence suggests that problematic concrete strength variability may be linked to uncrushed gravel coarse aggregates and the use of fly ash replacement of cement near practical or specification limits. In some cases it has been evident that the cement source may be part of the influences, and strength performance has improved dramatically with the same mix design after a change of cement. In such cases, though, there has rarely been any indication of significantly different cement strength potential (comparing the two sources) as evidenced by

routine cement mortar cube strength testing. Concrete producers and Contractors have also learned that such problematic strengths can often be quickly remedied by discontinuing the use of fly ash to replace portland cement. Yet the same combination of materials used with a different cement source may produce strengths in excess of a similar mixture proportioned with 100% portland cement indicating that cement variation may have considerable influence on compressive strength variability of concrete made with local materials.

MDOT currently allows the Contractor to change the cement source of an approved mixture upon written request and subsequent approval by representatives of MDOT's Materials Division (MDOT Concrete Field Manual, Section 5.7) (1). This source change is typically allowed without compressive strength data documenting the impact of the change in cement. Changing cement sources on a project when proposed by the Contractor is common and the potential influence of cement variation has been documented as having little impact to compressive strength variability contributing only 260 psi to standard deviation of compressive strength of concrete (2).

Variability of concrete compressive strength is influenced by all aspects of the concrete mixture including each constituent material and proportions of each ingredient. Each constituent concrete material should meet the criteria established by the American Association of State Highway and Transportation Officials (AASHTO) or the American Society for Testing and Materials (ASTM). These components must be proportioned to produce concrete that meets the required performance characteristics specified for the applicable concrete item being constructed. The performance characteristic that is required for all of MDOT's road or bridge construction is compressive strength. For this reason, both MDOT Engineers and concrete mixture designers need to understand factors that influence concrete strength variability and if characteristics exist within local materials that increase strength variability.

Factors that Influence Compressive Strength Variability

Concrete has a coefficient of variation of 20 percent which is relatively high compared to other construction materials such as steel bars having a coefficient of variation ranging from 6 to 10 percent (2). This high coefficient of variation should be expected due to all of the factors that

influence concrete compressive strength. Cement, water, fine and coarse aggregates, temperature, mixture properties, batching, water measurement, mixing, handling and sampling, compaction, size and shape of test specimens, curing, and testing all contribute to variability of concrete compressive strength (2). A brief discussion is provided below of generally accepted factors that have influence on concrete compressive strength including: 1) water-cementitious materials ratio (w/cm); 2) paste-aggregate interface; 3) supplemental cementitious materials; 4) air content; 5) aggregate shape; 6) water reducing admixtures; and 7) quality control testing.

Water Cementitious Ratio

The primary factor that influences the strength of concrete is water cement (w/c) or water-cementitious (w/cm) ratio. The relationship between concrete strength and w/cm ratio has been accepted for nearly 100 years following the studies of Duff A. Abrams in 1918 and is frequently referred to as the Abrams' water-cement ratio law (3). Based on extensive research and experience on this topic, as long as the aggregates and air content remain constant, the lower the w/cm ratio of the mixture, the higher the concrete's compressive strength will be.

Paste-Aggregate Interface

The paste-aggregate interface is considered the weakest region of concrete and could be the controlling factor of concrete compressive strength (4). Most of the known concrete failure mechanisms can be attributed to the performance of the paste-aggregate bond and its performance in the concrete matrix. Since this is the weakest part of the matrix, and is the part of the matrix that precedes failure in almost every case, it is critical that the variation in compressive strength that can be attributed to other factors be controlled to as high of a degree as possible. In general, bond failure occurs before failure of either the paste or the aggregate. This region is weak because cracks exist in this part of the concrete matrix prior to the application of any applied stresses due to bleeding, segregation, and volume changes of the paste during hydration (4).

There are no standard test methods for measuring the bond strength of aggregates in concrete, but the bond strength depends on many factors common to concrete failure. Bond strength, as does concrete strength, increases as w/cm ratio decreases. The bond strength also

depends on the cement source as does the compressive strength of the concrete. Air entrainment can reduce the bond strength, since air voids can reduce the contact area between the paste and the aggregates (4). The absorption of the aggregates can affect the bonding of the paste to the aggregate (process of absorption can improve contact between the paste and the aggregate) (4). Paste-aggregate bond failures do not typically occur between the paste and the fine aggregates, and seems to increase in likelihood as the maximum aggregate particle size increases (4). Finally, the smoother the texture of the coarse aggregate the lower the bond strength tends to be. Aggregates with relatively rough texture, like crushed aggregates, typically have a higher surface area available for bonding. (4).

Supplemental Cementitious Materials (Class C and Class F Fly Ash)

Economics and sulfate conditions influence the use of supplementary cementitious materials (SCM's) in MDOT concrete projects. Fly ash is the most common SCM used in MDOT concrete. The two classes of fly ash commonly used are Class C and Class F. The amount of cement replacement with SCM's is generally limited by specifications and is dependent on the sulfate conditions for MDOT concrete. MDOT specifications allow portland cement to be replaced with up to 25 percent fly ash for all classes of concrete. Fly ash replacement can increase the setting time of concrete and reduce early age strength. Mixtures proportioned with fly ash generally develop strength over a longer period of time and frequently result in higher strength mixes than mixtures with portland cement alone (5). Some Class C fly ashes combined with certain cements can result in little to no change in setting time and early age strength and can even cause flash setting in certain conditions (6).

Air Content

Entrapped air is present in all concrete. This air is created during mixing, handling, and placing the concrete. Entrapped air voids are relatively large when compared to intentionally entrained air voids. Entrained air voids are purposefully put in the cement-paste portion of the concrete to provide a system of voids to accommodate water when freezing and expansion occurs. Intentionally entrained air voids are extremely small ranging in size from 10 to 1000 μm in diameter (3). Entrained air is necessary in most concrete exposed to freezing and thawing cycles to protect the concrete from surface scaling. Both entrapped air and entrained air cause

voids in the cement-paste which decrease the strength of the cement-paste and the paste-aggregate bond which reduces concrete strength. It has been noted that for every percentage of entrained air, flexural strengths can be expected to decrease 2 to 3 percent, while compressive strengths can be expected to reduce 3 to 4 percent (7).

Aggregate Shape

Aggregate shape can influence the strength of concrete mixtures due to the effect aggregate shape has on water demand. Well-graded cubical and spherical particles tend to pack better decreasing the amount of water necessary to maintain workability, thereby reducing w/c ratio and increasing strength. Conversely, flat and elongated aggregates can increase the water necessary to maintain workability, thereby increasing w/c ratio and decreasing strength (8). According to Shilstone, rounded gravels or cubical crushed stones are desirable because they lead to mixtures that have improved workability, better pumpability and finishability, produce consistent high strengths, and lower shrinkage (9).

Water-Reducing Admixtures

Water reducing admixtures are used to improve the quality of concrete and to obtain specified strength at lower cement contents. The basic role of water reducing admixtures is to deflocculate the cement particles agglomerated together and release the water tied up in these agglomerations, producing more fluid paste at lower water contents. Normal water reducers typically reduce the required water content for a concrete mixture by 5 to 10 percent, whereas high-range water reducers can reduce water content by 12 to 40 percent (3). Based on the decrease in water needed to reach the desired slump, concrete strengths can be increased by the addition of water reducers because a lower w/cm can be used while maintaining a consistent slump.

Quality Control Testing

It has long been accepted that proper quality control testing is needed to produce consistent, acceptable construction materials test results. This is especially important in concrete construction. Numerous variables can affect the outcome of compressive strength test results including; sampling, testing, handling, initial curing, final curing, and compressive strength

testing. AASHTO T 22 / ASTM C 39 "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" provides an acceptable range for companion cylinders of 10.6 percent when three 4 in. X 8 in.-cylinders are tested in laboratory conditions. This acceptable range is only applicable for compressive strengths ranging from 2,500 psi to 4,700 psi and when specimens are sampled, tested, handled, and cured in accordance with all AASHTO /ASTM test methods associated with testing concrete cylinders for compressive strength. When any part of the testing and handling of the specimens breaks down, the measured compressive strength of the concrete will be influenced. None of the breakdowns that can occur during testing and handling (aside from possibly initial curing temperatures and loading rate of cylinders during the compressive strength test) influence the compressive strength in a positive way. Instead, the effects of improper handling and testing of concrete generally decrease the expected compressive strength of concrete. The standard deviation obtainable when testing identical specimens under laboratory conditions is 150 psi (2).

Required Average Compressive Strength

Some overdesign or safety factor is included in mixture proportioning to compensate for variability in concrete strength as described in the previous paragraphs. This overdesign is addressed with the use Required Average Compressive Strength (f'_{cr}). MDOT specifications require concrete mixtures to be designed based on either previous field experience or laboratory trial mixtures. If results from field experience or laboratory test show that the average compressive strength determined from either field experience of laboratory trial mixtures equals or exceeds the required average strength (f'_{cr}), the mixture proportion can then be submitted to MDOT engineers for approval.

Field Experience

When using field experience, MDOT specifications require that at least 10 consecutive sets of 28-day compressive strength tests be used to calculate the standard deviation of the concrete strengths. Provided that the average compressive strength of the field tests is greater than the specified compressive strength for the given class of concrete plus 1.43 times the standard deviation, the concrete proportions may be accepted by MDOT engineers.

Based on Burns Cooley Dennis' (BCD) experience on MDOT projects, the standard deviation for 10 consecutive sets of 28-day compressive strengths used on MDOT projects can range from as low as 147 psi to 713 psi, with an average of approximately 307 psi. Based on these standard deviations, the overdesign could range from as little as 210 psi to 1,020 psi over the specified compressive strength for the given class of concrete.

Laboratory Trial Mixture

When the laboratory trial mixture option is selected for proportioning concrete mixtures, the required average compressive strength must be 1,200 psi over the specified compressive strength for classes of concrete requiring less than 5,000 psi and 1,400 psi over the specified strength for classes of concrete requiring 5,000 psi or more. The average of three compressive strength specimens tested at 28-days must meet or exceed the required average compressive strength for the particular class of concrete.

Objective

The objective of this research was to investigate concrete strength variability of gravel aggregate concrete as influenced by cementitious materials. This research documents concrete strength variability using different cement sources and different samples of each cement source.

Approach

Eighty-four concrete mixtures were used in this research to investigate the influence of cement source, sample, and type on compressive strength of concrete. Seven different cements from six sources were used in this research. One plant produced two types of cement. Each of the seven cements is noted herein as a unique cement using letters A through G. Samples of the seven cements were collected on three separate occasions (Sample No. 1, Sample No. 2, and Sample No. 3) that were at least one month apart. Each of the seven cements was used to produce twelve mixtures. These mixtures were proportioned with gravel aggregates using 100% cement, 75% cement with 25% Class C fly ash, and 75% cement with 25% Class F fly ash. Each of these mixtures was repeated two additional times with additional samples providing a total of sixty-four mixtures for this research. Crushed limestone coarse aggregate was used in combinations with these same cementitious materials to provide control mixtures for cement

sample No. 1 providing twenty-one control mixtures. Table 1 presents a description of experimental mixtures. Compressive strengths were determined for each concrete mixture and compressive strengths of mortar cubes were determined for each cement sample. In addition, Holcim (US), Inc. conducted chemical and physical analysis of each sample of cement. Blind samples were sent to Holcim (US), Inc. by BCD in sample containers with the same identification used in this research so the source was not revealed.

Table 1 – Experimental Mixtures

Mix Number	Cement Source	Cement Type	Sample No.	Aggregate Type	Percent Cement	Percent Class C Fly Ash	Percent Class F Fly Ash
1 - 9	A	II	1,2,3	Gravel	100		
					75	25	
					75		25
10 - 12			1	Stone	100		
					75	25	
					75		25
13 - 21	B	II	1,2,3	Gravel	100		
					75	25	
					75		25
22 - 24			1	Stone	100		
					75	25	
					75		25
25 - 33	C	I	1,2,3	Gravel	100		
					75	25	
					75		25
34 - 36			1	Stone	100		
					75	25	
					75		25
37 – 45	D	II	1,2,3	Gravel	100		
					75	25	
					75		25
46 - 48			1	Stone	100		
					75	25	
					75		25
49 - 57	F	II	1,2,3	Gravel	100		
					75	25	
					75		25
58 - 60			1	Stone	100		
					75	25	
					75		25
61 - 69	G	II	1,2,3	Gravel	100		
					75	25	
					75		25
70 -72			1	Stone	100		
					75	25	
					75		25
73 - 81	E	1L	1,2,3	Gravel	100		
					75	25	
					75		25
82 - 84			1	Stone	100		
					75	25	
					75		25

Chapter 2 - Materials

Hydraulic Cement

Both ordinary portland cement (OPC) and blended cement were used in this study. These are hydraulic cements and provide the primary cementing material in the mixtures. Type I and Type II portland cements meeting requirements of AASHTO M 85 / ASTM C 150 "Standard Specification for Portland Cement" and a Type IL cement meeting requirements of AASHTO 240 / ASTM C 595 "Standard Specification for Blended Hydraulic Cements" were used. Hydraulic cements react with water and produce calcium silicate hydrate and other cementing compounds that cause concrete to set and gain strength. A byproduct of this reaction is calcium hydroxide which remains suspended in the concrete matrix and may be available to react with pozzolans such as Class C or Class F fly ash to create more cementing compounds. Chemical and physical properties of each cement sample used in this research were tested by Holcim (US), Inc. and results are presented in Tables 2 through 8.

Type I and Type II

Type I or Type II portland cement meeting requirements of ASTM C 150 / AASHTO M 85 are hydraulic cements made to conform to specific chemical and physical property limits according to these specifications. One source of Type I cement and five sources of Type II cement were used in this research.

Type IL

Type IL cement meeting requirements of AASHTO M240 / ASTM C595 was also used in this study. This blended cement specification now provides for limestone as one of the permitted blended or interground materials in this cement that was formerly limited to pozzolans, or slag, or some combinations of these materials. The addition of limestone and Type IL to AASHTO M240 / ASTM C595 occurred in 2012. Type IL cement can contain from 5 to 15 percent limestone (10). This type of cement is also hydraulic cement and usually performs similarly to Type I or Type II portland cement. Type IL used in this research is ordinary portland cement except that the interground limestone content was approximately 10 percent. While MDOT does not currently included Type IL cement in their specifications for portland

cement used in concrete, this cement was included in this research so MDOT engineers can evaluate it for future use. Only one source of Type IL cement was used in this study.

Table 2 - Chemical and Physical Properties of Cement A

Chemical Properties	Sample 1	Sample 2	Sample 3
Silicon Dioxide (SiO_2), %	19.93	20.32	20.12
Aluminum Oxide (Al_2O_3), %	4.36	4.4	4.44
Ferric Oxide (Fe_2O_3), %	2.87	2.9	2.89
Calcium Oxide (CaO), %	64.25	64.18	64
Magnesium Oxide (MgO), %	2.19	2.19	2.2
Sulfur Trioxide (SO_3), %	2.84	2.84	2.81
Loss of Ignition (LOI), %	2.1	2.3	2.01
Insoluble Residue, %	0.39	0.26	0.43
Free Lime, %	0.73	0.14	0.15
Sodium Oxide (Na_2O), %	0.16	0.15	0.16
Na_2O Equivalent, %	0.54	0.54	0.53
Potassium Oxide (K_2O), %	0.59	0.58	0.57
Tricalcium Silicate (C_3S), %	68.58	60.69	65.66
Dicalcium Silicate (C_2S), %	5.42	11.23	8.15
Tricalcium Aluminate (C_3A), %	6.69	6.74	6.87
Tetracalcium Aluminoferrite (C_4AF), %	8.74	8.81	8.8
Physical Properties			
Blaine Fineness, m^2/kg	388	404	411
325 Mesh (% passing)	94.3	93.4	93.56
Time of setting (Vicat) Initial Set, minutes	155	165	130
Time of setting (Vicat) Final Set, minutes	250	315	230
Air Content, %	9.17	8.4	8.94
False Set, %	28.6	50	60
Normal Consistency, %	25.5	25.5	25.2
Autoclave Expansion, %	-0.02	-0.03	-0.02
Flow, %	94	104	104
Compressive Strength, 1 day (psi)	2370	2120	2330
Compressive Strength, 3 day (psi)	4340	4310	4070
Compressive Strength, 7 day (psi)	5140	5570	5050
Compressive Strength, 28 day (psi)	6600	6530	7400

Table 3 - Chemical and Physical Properties of Cement B

Chemical Properties	Sample 1	Sample 2	Sample 3
Silicon Dioxide (SiO_2), %	19.69	19.72	19.66
Aluminum Oxide (Al_2O_3), %	4.36	4.46	4.4
Ferric Oxide (Fe_2O_3), %	3.35	3.29	3.28
Calcium Oxide (CaO), %	63.8	63.79	63.73
Magnesium Oxide (MgO), %	2.86	2.98	2.96
Sulfur Trioxide (SO_3), %	2.62	2.68	2.68
Loss of Ignition (LOI), %	2.73	2.25	2.95
Insoluble Residue, %	0.4	0.22	0.04
Free Lime, %	0.27	0.18	0.2
Sodium Oxide (Na_2O), %	0.15	0.15	0.15
Na_2O Equivalent, %	0.53	0.52	0.53
Potassium Oxide (K_2O), %	0.58	0.56	0.57
Tricalcium Silicate (C_3S), %	68.55	64.72	68.15
Dicalcium Silicate (C_2S), %	4.73	6.9	4.94
Tricalcium Aluminate (C_3A), %	5.89	6.24	6.11
Tetracalcium Aluminoferrite (C_4AF), %	10.19	9.99	9.99
Physical Properties			
Blaine Fineness, m^2/kg	430	382	423
325 Mesh (% passing)	97.1	95.39	95.59
Time of setting (Vicat) Initial Set, minutes	175	137	150
Time of setting (Vicat) Final Set, minutes	260	252	250
Air Content, %	10.4	8.95	9.06
False Set, %	72.2	83.87	71.43
Normal Consistency, %	26.5	25.2	25.2
Autoclave Expansion, %	0.02	0.01	0.01
Flow, %	105	110	116
Compressive Strength, 1 day (psi)	2320	2470	2190
Compressive Strength, 3 day (psi)	3990	4020	3920
Compressive Strength, 7 day (psi)	5010	5090	4910
Compressive Strength, 28 day (psi)	5990	6300	6400

Table 4 - Chemical and Physical Properties of Cement C

Chemical Properties	Sample 1	Sample 2	Sample 3
Silicon Dioxide (SiO_2), %	18.79	18.85	18.88
Aluminum Oxide (Al_2O_3), %	5.56	5.49	5.46
Ferric Oxide (Fe_2O_3), %	3.55	3.41	3.33
Calcium Oxide (CaO), %	64.2	64.45	64.62
Magnesium Oxide (MgO), %	0.84	0.86	0.82
Sulfur Trioxide (SO_3), %	3.6	3.68	3.49
Loss of Ignition (LOI), %	1.86	2.26	2.22
Insoluble Residue, %	0.44	0.08	0.3
Free Lime, %	0.93	0.58	0.93
Sodium Oxide (Na_2O), %	0.14	0.13	0.12
Na_2O Equivalent, %	0.57	0.54	0.55
Potassium Oxide (K_2O), %	0.66	0.62	0.65
Tricalcium Silicate (C_3S), %	65.83	64.03	68.15
Dicalcium Silicate (C_2S), %	4.22	4.94	2.73
Tricalcium Aluminate (C_3A), %	8.73	8.76	8.83
Tetracalcium Aluminoferrite (C_4AF), %	10.81	10.37	10.14
Physical Properties			
Blaine Fineness, m^2/kg	408	413	427
325 Mesh (% passing)	94.7	91.9	91.65
Time of setting (Vicat) Initial Set, minutes	110	80	105
Time of setting (Vicat) Final Set, minutes	200	165	200
Air Content, %	9.07	7.39	8.06
False Set, %	86.11	57.58	71.43
Normal Consistency, %	25.5	25.2	25.7
Autoclave Expansion, %	0	0.25	0.06
Flow, %	98	94	92
Compressive Strength, 1 day (psi)	2790	2790	2800
Compressive Strength, 3 day (psi)	4500	4440	4670
Compressive Strength, 7 day (psi)	5670	5110	5520
Compressive Strength, 28 day (psi)	6070	6430	6090

Table 5 - Chemical and Physical Properties of Cement D

Chemical Properties	Sample 1	Sample 2	Sample 3
Silicon Dioxide (SiO_2), %	19.17	20.1	20.03
Aluminum Oxide (Al_2O_3), %	4.9	4.61	4.92
Ferric Oxide (Fe_2O_3), %	3.6	3.32	3.46
Calcium Oxide (CaO), %	64.27	64.2	63.83
Magnesium Oxide (MgO), %	1.17	1.55	1.35
Sulfur Trioxide (SO_3), %	3.73	3.64	3.63
Loss of Ignition (LOI), %	1.68	1.26	1.28
Insoluble Residue, %	0.35	0.11	0.02
Free Lime, %	0.51	1.02	0.73
Sodium Oxide (Na_2O), %	0.25	0.23	0.21
Na_2O Equivalent, %	0.51	0.48	0.49
Potassium Oxide (K_2O), %	0.39	0.38	0.43
Tricalcium Silicate (C_3S), %	67.21	62.04	59.29
Dicalcium Silicate (C_2S), %	4.26	10.68	12.68
Tricalcium Aluminate (C_3A), %	6.89	6.6	7.18
Tetracalcium Aluminoferrite (C_4AF), %	10.97	10.11	10.53
Physical Properties			
Blaine Fineness, m^2/kg	390	423	429
325 Mesh (% passing)	96.1	97.31	96.45
Time of setting (Vicat) Initial Set, minutes	130	90	100
Time of setting (Vicat) Final Set, minutes	200	165	190
Air Content, %	8.96	6.61	6.5
False Set, %	72.41	67.86	87.5
Normal Consistency, %	26.5	26.8	26.5
Autoclave Expansion, %	0.03	0.03	0
Flow, %	103	112	100
Compressive Strength, 1 day (psi)	2550	2440	2530
Compressive Strength, 3 day (psi)	4480	4400	4080
Compressive Strength, 7 day (psi)	5480	4890	4560
Compressive Strength, 28 day (psi)	6400	6440	6400

Table 6 - Chemical and Physical Properties of Cement E

Chemical Properties	Sample 1	Sample 2	Sample 3
Silicon Dioxide (SiO_2), %	18.59	18.72	18.68
Aluminum Oxide (Al_2O_3), %	4.34	4.03	4.25
Ferric Oxide (Fe_2O_3), %	3.19	3.17	3.15
Calcium Oxide (CaO), %	64.63	64.55	64.17
Magnesium Oxide (MgO), %	1.33	1.54	1.5
Sulfur Trioxide (SO_3), %	3.06	3.54	3.64
Loss of Ignition (LOI), %	4.72	4.71	4.55
Insoluble Residue, %	1.13	0.37	0.41
Free Lime, %	0.45	0.55	0.44
Sodium Oxide (Na_2O), %	0.21	0.21	0.21
Na_2O Equivalent, %	0.47	0.45	0.44
Potassium Oxide (K_2O), %	0.39	0.36	0.35
Tricalcium Silicate (C_3S), %	66.92	68.29	61.44
Dicalcium Silicate (C_2S), %	0.31	0	5.07
Tricalcium Aluminate (C_3A), %	6.06	5.27	5.93
Tetracalcium Aluminoferrite (C_4AF), %	9.65	9.59	9.59
Physical Properties			
Blaine Fineness, m^2/kg	491	518	560
325 Mesh (% passing)	97.6	98.51	98.42
Time of setting (Vicat) Initial Set, minutes	130	125	115
Time of setting (Vicat) Final Set, minutes	215	200	180
Air Content, %	7.44	5.76	5.59
False Set, %	70	81.82	80.65
Normal Consistency, %	27.4	26.8	26.8
Autoclave Expansion, %	-0.01	-0.03	NR
Flow, %	100	110	100
Compressive Strength, 1 day (psi)	2250	2670	2850
Compressive Strength, 3 day (psi)	4350	4590	4710
Compressive Strength, 7 day (psi)	5000	5270	5390
Compressive Strength, 28 day (psi)	6740	7160	7120

Table 7 - Chemical and Physical Properties of Cement F

Chemical Properties	Sample 1	Sample 2	Sample 3
Silicon Dioxide (SiO_2), %	19.05	19.24	19.57
Aluminum Oxide (Al_2O_3), %	4.83	4.67	4.45
Ferric Oxide (Fe_2O_3), %	3.25	3.18	3.42
Calcium Oxide (CaO), %	62.88	63.26	64.03
Magnesium Oxide (MgO), %	3.45	3.35	2.38
Sulfur Trioxide (SO_3), %	3.35	3.28	3.16
Loss of Ignition (LOI), %	2.54	2.55	2.52
Insoluble Residue, %	0.35	0.02	0.46
Free Lime, %	0.83	0.53	0.12
Sodium Oxide (Na_2O), %	0.1	0.1	0.07
Na_2O Equivalent, %	0.41	0.41	0.52
Potassium Oxide (K_2O), %	0.48	0.47	0.68
Tricalcium Silicate (C_3S), %	64.55	61.52	68.15
Dicalcium Silicate (C_2S), %	5.92	7.46	4.7
Tricalcium Aluminate (C_3A), %	7.3	6.98	6
Tetracalcium Aluminoferrite (C_4AF), %	9.89	9.66	10.4
Physical Properties			
Blaine Fineness, m^2/kg	413	388	409
325 Mesh (% passing)	96.7	96.79	96.25
Time of setting (Vicat) Initial Set, minutes	110	110	100
Time of setting (Vicat) Final Set, minutes	210	180	170
Air Content, %	7.5	6.96	8.39
False Set, %	90.32	91.43	84.38
Normal Consistency, %	26.5	26.5	25.8
Autoclave Expansion, %	0.07	0.06	0.05
Flow, %	101	104	112
Compressive Strength, 1 day (psi)	2280	2370	2300
Compressive Strength, 3 day (psi)	3720	3890	3750
Compressive Strength, 7 day (psi)	5390	4820	4700
Compressive Strength, 28 day (psi)	6430	5940	6460

Table 8 - Chemical and Physical Properties of Cement G

Chemical Properties	Sample 1	Sample 2	Sample 3
Silicon Dioxide (SiO_2), %	19.57	20.05	19.33
Aluminum Oxide (Al_2O_3), %	4.33	4.24	4.63
Ferric Oxide (Fe_2O_3), %	3.81	3.6	3.13
Calcium Oxide (CaO), %	63.56	63.69	63.1
Magnesium Oxide (MgO), %	2.59	2.8	3.31
Sulfur Trioxide (SO_3), %	3.05	3.1	3.29
Loss of Ignition (LOI), %	1.84	1.59	2.05
Insoluble Residue, %	0.29	0.09	0.39
Free Lime, %	0.14	0.17	0.57
Sodium Oxide (Na_2O), %	0.07	0.08	0.07
Na_2O Equivalent, %	0.52	0.56	0.38
Potassium Oxide (K_2O), %	0.68	0.73	0.47
Tricalcium Silicate (C_3S), %	66.78	62.22	65.01
Dicalcium Silicate (C_2S), %	5.72	9.91	6.37
Tricalcium Aluminate (C_3A), %	5.03	5.14	6.97
Tetracalcium Aluminoferrite (C_4AF), %	11.59	10.95	9.53
Physical Properties			
Blaine Fineness, m^2/kg	406	394	441
325 Mesh (% passing)	96.8	95.24	97.32
Time of setting (Vicat) Initial Set, minutes	190	155	115
Time of setting (Vicat) Final Set, minutes	250	245	190
Air Content, %	8.28	7.51	7.39
False Set, %	86.21	95.24	86.11
Normal Consistency, %	26.6	25.8	25.8
Autoclave Expansion, %	0.03	0.03	0.02
Flow, %	111	113	120
Compressive Strength, 1 day (psi)	2030	2050	2450
Compressive Strength, 3 day (psi)	3840	4000	4300
Compressive Strength, 7 day (psi)	4630	4610	4920
Compressive Strength, 28 day (psi)	5730	5550	6020

Supplementary Cementitious Materials (SCMs)

Supplementary Cementitious Materials (SCMs) are included in concrete mixtures as part of the overall cementitious system. Most concrete produced in Mississippi incorporates SCMs in the mixture, particularly Class C and Class F fly ash. SCMs are often added to concrete in order to improve some plastic or hardened properties of the concrete. SCMs included in this research are from a single sample of Class C fly ash and Class F fly ash. SCMs have both hydraulic and pozzolanic value in concrete. Pozzolans are materials that have little cementing value by themselves, but will react with calcium hydroxide to provide more cementing compounds.

Fly Ash

Fly ash is finely divided residue of burned ground coal, captured from the flue gases of a coal combustion device, usually at a coal-burning electric power plant. The combustion byproduct is usually harvested with electrostatic precipitators, conveyed to storage and shipping, and is commonly used as a cementitious component of concrete without further processing. However, some fly ash is enhanced by separation of particle sizes and chemical treatment of carbon residue in the ash. Class C and Class F fly ash conform to the provisions of AASHTO M 295 / ASTM C 618 "Standard Specification for Coal Fly Ash and Calcined Natural Pozzolan for Use in Concrete." The distinction between the two classes is usually related to the type of coal burned in production of the ash. Class C fly ash can contain a total calcium content (expressed as CaO) higher than 10 percent, but MDOT specifications require a CaO content of Class C fly ash greater than or equal to 8.0 percent. MDOT specifications require a CaO content of less than or equal to 8.0 percent for Class F fly ash. Both classes of fly ash are predominately pozzolanic. Functionally, a Class F fly ash is typically more nearly pure pozzolan than a Class C fly ash. A Class C fly ash may have slight hydraulic cementitious reactivity and other reactive chemical components. It is possible for a fly ash source to conform to both Class C and Class F fly ash designations; however, MDOT requires that fly ash be classified as either Class C or Class F. MDOT concrete specifications allow Class C and Class F fly ash to be used to replace up to 25 percent of the portland cement for all classes of concrete. Chemical and physical properties of the Class C and Class F fly ash used in this research were provided by the supplier and are presented in Table 9 and 10, respectively.

Table 9: Class C Fly Ash - Chemical and Physical Properties

Chemical Properties	Results
Silicon Dioxide (SiO_2), %	35.76
Aluminum Oxide (Al_2O_3), %	19.18
Iron Oxide (Fe_2O_3), %	6.39
Sum of Constituents, %	61.33
Sulfur Trioxide (SO_3), %	2.09
Calcium Oxide (CaO), %	24.35
Moisture Content, %	0.07
Loss on Ignition, %	0.40
Available Alkalies, as Na_2O, %	1.4
Physical Properties	**Results**
Fineness, % retained on No. 325	18.87
Strength Activity Index 7 day, % of control	100.0
Strength Activity Index 28 day, % of control	97.0
Water Requirement, % control	95.0
Autoclave Soundness, %	0.05
True Particle Density	2.60

Table 10: Class F Fly Ash - Chemical and Physical Properties

Chemical Properties	Results
Total Silica, Aluminum, Iron, %	89.2
Silicon Dioxide (SiO_2), %	54.1
Aluminum Oxide (Al_2O_3), %	27.7
Iron Oxide (Fe_2O_3), %	7.6
Sulfur Trioxide (SO_3), %	0.1
Calcium Oxide (CaO), %	1.4
Moisture Content, %	0.1
Loss on Ignition, %	2.9
Available Alkalies, as Na_2O, %	0.7
Sodium Oxide, %	0.15
Potassium Oxide, %	0.80
Physical Properties	**Results**
Fineness, % retained on No. 325	18.0
Strength Activity Index 7 day, % of control	76.6
Strength Activity Index 28 day, % of control	86.6
Water Requirement, % control	96.3
Autoclave Soundness	-0.05
Drying Shrinkage, Increase at 28 day, %	0.00
Density Mg/m^3	2.20

Aggregates

The aggregates used in this research were produced at three different sources. The No. 67 gravel from one source, the No. 67 crushed limestone from one source, and the concrete sand from another source. All of these sources are approved by MDOT for use in concrete. The No. 67 gravel has an absorption of 4.67 percent which is a higher absorption than average values for Mississippi gravel. The percent passing the No. 30 sieve on the sand exceeded MDOT's limits by 5 percent and this is not uncommon for Mississippi aggregates. However, the same sand source and sample was used for all mixtures so any impact of this excessive amount of material passing the No. 30 sieve is uniform for all mixtures. The properties for the aggregates used in this research are presented in Table 11.

Table 11 - Average Aggregate Properties

Sieve Size	No. 67 Gravel		No. 67 Stone		Sand	
	Individual % Retained	Total % Passing	Individual % Retained	Total % Passing	Individual % Retained	Total % Passing
1"	0.0	100.0	0.0	100.0	0.0	100.0
¾"	2.9	97.0	2.7	97.0	0.0	100.0
½"	29.8	67.0	41.3	56.0	0.0	100.0
3/8"	25.3	42.0	18.0	38.0	0.0	100.0
No. 4	35.8	6.0	31.7	6.0	1.0	99.0
No. 8	5.2	1.0	2.9	3.0	5.6	93.0
No. 16	0.3	1.0	0.6	3.0	6.3	87.0
No. 30	0.1	1.0	0.2	3.0	12.5	75.0
No. 50	0.0	1.0	0.2	2.0	51.0	24.0
No. 100	0.1	0.0	0.1	2.0	22.6	1.0
No. 200	0.1	0.4	0.1	2.2	0.4	0.7
FM	6.51		6.45		2.21	
Bulk Gravity (DRY)	2.316		2.666		2.621	
Bulk Gravity (SSD)	2.424		2.690		2.630	
Absorption %	4.67		0.88		0.34	

Water Reducer

A type A water-reducing admixture meeting requirements of AASHTO M 194 / ASTM C 494 "Standard Specifications for Chemical Admixtures for Concrete" was used in each of the concrete mixtures in this research. Water reducers can be used to provide a higher slump without increasing the water-cementitious ratio or lower water-cementitious ratio without reducing slump. In addition, higher strengths can be achieved due to increased dispersion of the cementitious particles leading to increased hydration. The dosage rate for all mixtures is 3.05 ounces per 100 pounds of cementitious materials in the mixture, i.e., 16.1 ounces per cubic yard of concrete. No other chemical admixture was used in this research.

Chapter 3 – Concrete Mixtures

Mixture Development

The influence of cement source, supplemental cementitious materials, and aggregate type on concrete compressive strength variability is described herein based on laboratory test results and experience gained during production of eighty-four laboratory mixtures. The mixture proportions used in this research were based on initial trial batches. These trial batches, using 100% cement and one cement source, established the required total cementitious materials, water, and admixture dosage required to produce a 3 in. slump using oven dry aggregates. Trial and error batches were conducted until the water and cement content were determined to meet this criteria. The weight of cement determined from the trail batches was 526.40 pounds per cubic yard (pcy) with a corresponding weight of water of 236.88 pcy, i.e., 28.4 gallons pcy. This cement and water content provided a w/cm ratio of 0.450 that was used for all of the mixes in this research. The dosage rate selected for the Type A water reducer was 3.05 ounces per 100 pounds of cementitious material. This total cement, water content, and admixture dosage was then used for all mixtures of this research with no subsequent requirement for slump, temperature, air content, or unit weight.

Coarse Aggregate Content

The weight of coarse aggregate was calculated based on MDOT's requirement for minimum coarse aggregate content for concrete paving. Section 501 "Portland Cement Concrete Pavement" of the MDOT's Specifications for Road and Bridge Construction requires a minimum coarse aggregate content of 72 percent of the volume of a cubic yard of concrete. The minimum dry weight of coarse aggregate per cubic yard (pcy) of concrete is then calculated using Equation 1.

$$W_{CA} = 0.72 \; x 27 \; x \; DRUW \qquad (1)$$

Where:

W_{CA} = Weight of Coarse Aggregate

DRUW = Dry Rodded Unit Weight

Typical Mixtures

The average dry rodded unit weight of the No. 67 gravel used in this study was 92 pounds per cubic foot (pcf). Using this weight in Equation 1 gives a dry coarse aggregate weight of 1790 pounds. This coarse aggregate weight was used for all gravel aggregate mixtures. The absolute volume of cement, water, coarse aggregate, and entrapped air was then calculated and subtracted from a total of 27 cubic feet to determine the volume of sand needed for proper yield. See Table 12 for typical mixture proportions using 100% cement (100) along with gravel aggregates.

This typical mixture was then adjusted to incorporate Class C or Class F fly ash. The 526.4 pounds of cement was replaced pound for pound with Class C or Class F fly ash at a replacement rate of 25 percent. This provided additional typical mixtures with 394.80 pcy of cement and 131.60 pcy of either Class C or Class F fly ash. See Tables 13 and 14 for typical mixture proportions using gravel aggregate along with 75% cement and 25% Class C fly ash (75/25C) and 75% cement and 25% Class F fly ash (75/25F), respectively.

Typical mixtures described in the previous paragraphs were adjusted for use with crushed limestone coarse aggregate. In order to make these adjustments, the same absolute volume of coarse aggregate that was used in the typically gravel aggregate mixtures was maintained for the crushed limestone mixtures. This absolute volume was 12.39 cubic feet. The weight of crushed limestone needed for 12.39 cubic feet was 2061 pounds. See Tables 15 through 17 for typically mixtures proportions using crushed limestone coarse aggregate.

These typical mixture proportions were then used in combination with all seven cements. The only exception was Cement E. Cement E was Type IL cement and its specific gravity was 3.10 in lieu of 3.15 that was used in volume calculations for all other cements. Therefore, adjustments were made to the sand weight for mixes 73 through 84 to compensate for the additional volume provided by the Type IL cement.

Table 12 – Typical Mixture Proportions: Gravel Aggregates – (100)

Material	Dry Weights (pcy)	Absolute Volume (ft^3)
Cement	526.40	2.68
Total Cementitious	526.40	2.68
Coarse Aggregate	1790	12.39
Fine Aggregate	1265	7.73
Water	236.88	3.80
Entrapped Air	0	0.41
w/cm	0.45	

Table 13 – Typical Mixture Proportions: Gravel Aggregates – (75/25C)

Material	Dry Weights (pcy)	Absolute Volume (ft^3)
Cement	394.80	2.01
Class C Fly Ash	131.60	0.81
Total Cementitious	526.40	2.82
Coarse Aggregate	1790	12.39
Fine Aggregate	1242	7.59
Water	236.88	3.80
Entrapped Air	0	0.41
w/cm	0.45	

Table 14 – Typical Mixture Proportions: Gravel Aggregates – (75/25F)

Material	Dry Weights (pcy)	Absolute Volume (ft^3)
Cement	394.80	2.01
Class F Fly Ash	131.60	0.96
Total Cementitious	526.40	2.97
Coarse Aggregate	1790	12.39
Fine Aggregate	1218	7.45
Water	236.88	3.80
Entrapped Air	0	0.41
w/cm	0.45	

Table 15 – Typical Mixture Proportions: Crushed Limestone Aggregates – (100)

Material	Dry Weights Per Cubic Yard (lbs.)	Absolute Volume (ft^3)
Cement	526.40	2.68
Total Cementitious	526.40	2.68
Coarse Aggregate	2061	12.39
Fine Aggregate	1265	7.73
Water	236.88	3.80
Entrapped Air	0	0.41
w/cm	0.45	

Table 16 – Typical Mixture Proportions: Crushed Limestone Aggregates – (75/25C)

Material	Dry Weights (pcy)	Absolute Volume (ft^3)
Cement	394.80	2.01
Class C Fly Ash	131.60	0.81
Total Cementitious	526.40	2.82
Coarse Aggregate	2061	12.39
Fine Aggregate	1242	7.59
Water	236.88	3.80
Entrapped Air	0	0.41
w/cm	0.45	

Table 17 – Typical Mixture Proportions: Crushed Limestone Aggregates – (75/25F)

Material	Dry Weights (pcy)	Absolute Volume (ft^3)
Cement	394.80	2.01
Class F Fly Ash	131.60	0.96
Total Cementitious	526.40	2.97
Coarse Aggregate	2061	12.39
Fine Aggregate	1217	7.44
Water	236.88	3.80
Entrapped Air	0	0.41
w/cm	0.45	

Mix Designations

Two designations were assigned to each mixture include; 1) mixture number and 2) mixture name. Mixes were numbered in sequential order 1 through 84 and this number was used for laboratory documentation and to identify cylinders for specific mixes. A mixture name was also given to each mix to easily identify important information that was specific for each mixture. For example, Mix 2 has a mix name of Gravel A1 75/25C. The first word identifies the type of coarse aggregate used in the mixture, either gravel or crushed limestone. The next letter identifies the cement and in this example the cement is Cement A. The number following the cement number represents the sample number of the cement. The next number is the percent cement followed by the percent fly ash. The last letter is the type of fly ash used in the mixture. In addition, all cement samples were given a unique number to identify the cement. For example, CS-A-1 represents Cement A and sample 1. See Table 18 for a detailed description of each mixture.

Table 18 - Mix Descriptions

Mix Number	Cement	Cement Type	Aggregate Type	Cement Sample No.	Percent Cement	Percent Class C Fly Ash	Percent Class F Fly Ash	Mix Identification		
								Code	No.	Name
1-9	A	Type II	Gravel	CS-A-1	100			Mix 1	1	Gravel A1 100
				CS-A-1	75	25		Mix 2	2	Gravel A1 75/25C
				CS-A-1	75		25	Mix 3	3	Gravel A1 75/25F
				CS-A-2	100			Mix 4	4	Gravel A2 100
				CS-A-2	75	25		Mix 5	5	Gravel A2 75/25C
				CS-A-2	75		25	Mix 6	6	Gravel A2 75/25F
				CS-A-3	100			Mix 7	7	Gravel A3 100
				CS-A-3	75	25		Mix 8	8	Gravel A3 75/25C
				CS-A-3	75		25	Mix 9	9	Gravel A3 75/25F
10-12			Stone	CS-A-1	100			Mix 10	10	Stone A1 100
				CS-A-1	75	25		Mix 11	11	Stone A1 75/25C
				CS-A-1	75		25	Mix 12	12	Stone A1 75/25F
13-21	B	Type II	Gravel	CS-B-1	100			Mix 13	13	Gravel B1 100
				CS-B-1	75	25		Mix 14	14	Gravel B1 75/25C
				CS-B-1	75		25	Mix 15	15	Gravel B1 75/25F
				CS-B-2	100			Mix 16	16	Gravel B2 100
				CS-B-2	75	25		Mix 17	17	Gravel B2 75/25C
				CS-B-2	75		25	Mix 18	18	Gravel B2 75/25F
				CS-B-3	100			Mix 19	19	Gravel B3 100
				CS-B-3	75	25		Mix 20	20	Gravel B3 75/25C
				CS-B-3	75		25	Mix 21	21	Gravel B3 75/25F
22-24			Stone	CS-B-1	100			Mix 22	22	Stone B1 100
				CS-B-1	75	25		Mix 23	23	Stone B1 75/25C
				CS-B-1	75		25	Mix 24	24	Stone B1 75/25F
25-33	C	Type I	Gravel	CS-C-1	100			Mix 25	25	Gravel C1 100
				CS-C-1	75	25		Mix 26	26	Gravel C1 75/25C
				CS-C-1	75		25	Mix 27	27	Gravel C1 75/25F
				CS-C-2	100			Mix 28	28	Gravel C2 100
				CS-C-2	75	25		Mix 29	29	Gravel C2 75/25C
				CS-C-2	75		25	Mix 30	30	Gravel C2 75/25F
				CS-C-3	100			Mix 31	31	Gravel C3 100
				CS-C-3	75	25		Mix 32	32	Gravel C3 75/25C
				CS-C-3	75		25	Mix 33	33	Gravel C3 75/25F
34-36			Stone	CS-C-1	100			Mix 34	34	Stone C1 100
				CS-C-1	75	25		Mix 35	35	Stone C1 75/25C
				CS-C-1	75		25	Mix 36	36	Stone C1 75/25F
37-45	D	Type II	Gravel	CS-D-1	100			Mix 37	37	Gravel D1 100
				CS-D-1	75	25		Mix 38	38	Gravel D1 75/25C
				CS-D-1	75		25	Mix 39	39	Gravel D1 75/25F
				CS-D-2	100			Mix 40	40	Gravel D2 100
				CS-D-2	75	25		Mix 41	41	Gravel D2 75/25C
				CS-D-2	75		25	Mix 42	42	Gravel D2 75/25F
				CS-D-3	100			Mix 43	43	Gravel D3 100
				CS-D-3	75	25		Mix 44	44	Gravel D3 75/25C
				CS-D-3	75		25	Mix 45	45	Gravel D3 75/25F
46-48			Stone	CS-D-1	100			Mix 46	46	Stone D1 100
				CS-D-1	75	25		Mix 47	47	Stone D1 75/25C
				CS-D-1	75		25	Mix 48	48	Stone D1 75/25F

Table 18 - Mix Description (Continued)

Mix Number	Cement	Cement Type	Aggregate Type	Cement Sample No.	Percent Cement	Percent Class C Fly Ash	Percent Class F Fly Ash	Mix Identification		
								Code	No.	Name
49-57	F	Type II	Gravel	CS-F-1	100			Mix 49	49	Gravel F1 100
				CS-F-1	75	25		Mix 50	50	Gravel F1 75/25C
				CS-F-1	75		25	Mix 51	51	Gravel F1 75/25F
				CS-F-2	100			Mix 52	52	Gravel F2 100
				CS-F-2	75	25		Mix 53	53	Gravel F2 75/25C
				CS-F-2	75		25	Mix 54	54	Gravel F2 75/25F
				CS-F-3	100			Mix 55	55	Gravel F3 100
				CS-F-3	75	25		Mix 56	56	Gravel F3 75/25C
				CS-F-3	75		25	Mix 57	57	Gravel F3 75/25F
58-60			Stone	CS-F-1	100			Mix 58	58	Stone F1 100
				CS-F-1	75	25		Mix 59	59	Stone F1 75/25C
				CS-F-1	75		25	Mix 60	60	Stone F1 75/25F
61-69	G	Type II	Gravel	CS-G-1	100			Mix 61	61	Gravel G1 100
				CS-G-1	75	25		Mix 62	62	Gravel G1 75/25C
				CS-G-1	75		25	Mix 63	63	Gravel G1 75/25F
				CS-G-2	100			Mix 64	64	Gravel G2 100
				CS-G-2	75	25		Mix 65	65	Gravel G2 75/25C
				CS-G-2	75		25	Mix 66	66	Gravel G2 75/25F
				CS-G-3	100			Mix 67	67	Gravel G3 100
				CS-G-3	75	25		Mix 68	68	Gravel G3 75/25C
				CS-G-3	75		25	Mix 69	69	Gravel G3 75/25F
70-72			Stone	CS-G-1	100			Mix 70	70	Stone G1 100
				CS-G-1	75	25		Mix 71	71	Stone G1 75/25C
				CS-G-1	75		25	Mix 72	72	Stone G1 75/25F
73-81	E	Type IL	Gravel	CS-E-1	100			Mix 73	73	Gravel E1 100
				CS-E-1	75	25		Mix 74	74	Gravel E1 75/25C
				CS-E-1	75		25	Mix 75	75	Gravel E1 75/25F
				CS-E-2	100			Mix 76	76	Gravel E2 100
				CS-E-2	75	25		Mix 77	77	Gravel E2 75/25C
				CS-E-2	75		25	Mix 78	78	Gravel E2 75/25F
				CS-E-3	100			Mix 79	79	Gravel E3 100
				CS-E-3	75	25		Mix 80	80	Gravel E3 75/25C
				CS-E-3	75		25	Mix 81	81	Gravel E3 75/25F
82-84			Stone	CS-E-1	100			Mix 82	82	Stone E1 100
				CS-E-1	75	25		Mix 83	83	Stone E1 75/25C
				CS-E-1	75		25	Mix 84	84	Stone E1 75/25F

Chapter 4 - Laboratory Testing

Aggregate Testing

Typical aggregate testing was conducted on the aggregate samples for use in the concrete mixtures. These tests include; (1) AASHTO T 85 / ASTM C 127 "Specific Gravity and Absorption of Coarse Aggregate", (2) AASHTO T 84 / ASTM C 128 "Specific Gravity and Absorption of Fine Aggregate", (3) AASHTO T 27 / ASTM C 136 "Sieve Analysis of Fine and Coarse Aggregates", and (4) AASHTO T 19 / ASTM C 29 "Bulk Density ("Unit Weight") and Voids in Aggregate."

Concrete Mixing

Laboratory mixing was conducted in 1.25 cubic feet batch quantities using a revolving drum mixer in accordance with ASTM C 192 "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory." Dry specific gravity and absorption values were used to adjust laboratory mixture designs based on aggregates in an oven-dry condition.

In accordance with ASTM C 192, the inside of the revolving-drum mixer received a thin layer of fresh mortar to prevent loss of mortar from the concrete batch. To add consistency to our process, a masonry brush was used to spread the fresh layer of mortar uniformly around the drum. The drum was inverted for a two minute waiting period to allow any free water to fall out before continuing. The mixer was then charged with the coarse and fine oven-dry aggregates along with approximately half of the mixing water. After minimal revolutions of the drum to mix up the aggregates and water, the mixer was stopped and covered to guard against moisture loss. A two minute rest period was introduced to our procedure to accommodate some degree of water absorption by the oven-dry aggregates. After this two minute rest, the remaining materials were added to a mixer. A three minute mixing, three minute rest, two minute final mixing pattern was performed taking steps to guard against moisture loss during the rest period and segregation when discharging to a wheel barrow.

Concrete Plastic Properties

The fresh concrete was tested for density, slump, air content, and temperature. Fresh properties were recorded for each mixture. All testing was performed using ACI Certified Technicians according to the following applicable standards:

- **Density and Yield** – AASHTO T 121 / ASTM C 138 "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete" (Figure 1)
- **Slump** – AASHTO T 119 / ASTM C 143 "Standard Test Method for Slump of Hydraulic-Cement Concrete" (Figure 2)
- **Air Content** – AASHTO T 196 / ASTM C 173 "Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method" (Figure 3)
- **Temperature** – ASTM C 1064 " Standard Test Method For Temperature of Freshly Mixed Hydraulic-Cement Concrete"

Figure 1 - Unit Weight Testing

Figure 2 - Slump Testing

Figure 3 - Air Content Testing

Making, Capping, and Testing Concrete Compressive Strength Specimens

A total of fifteen 4 in. X 8 in. compressive strength specimens were cast immediately following testing of plastic properties. ACI certified technicians made the 4 in. X 8 in. specimens using a vibrating table for consolidation. The same vibrating table was used to consolidate all compressive strength specimens. The specimens were consolidated in two lifts using amplitude on the vibrating element of 15 percent and duration of 20 seconds. Upon completion of consolidation and strike-off finishing of the top surfaces, specimens were stored in a temperature controlled moisture room until time of testing. The only time the specimens were not in the moisture room was during capping operations.

All compressive strength specimens were capped in accordance with AASHTO T 231 / ASTM C 617 "Standard Practice for Capping Cylindrical Concrete Specimens" with sulfur mortar. Bonded capping was used in order to reduce variability in testing that may be introduced with vertical alignment of the specimen with the center of thrust of the testing machine associated with unbounded caps.

Specimens were tested by ACI certified strength technicians in accordance with AASHTO T 22 / ASTM C 39 "Standard Test method for Compressive Strength of Cylindrical Concrete Specimens." Fifteen specimens were tested for each mixture as follows: 3 at 1 day, 3 at 7 days, 3 at 14 days, 3 at 28 days, and 3 at 56 days.

Mortar Cube Mixing

The mixture proportion for mortar cubes made with Type I or Type II cement is found in Table 2 of AASHTO T 106 / ASTM C 109 "Standard Method of Test for Compressive Strength of Hydraulic Cement Mortar." According to these standards, water content for mortar cubes made with other cements such as Type IL cement has to be adjusted for the mixture to produce a flow of 110 ± 5 in 25 drops of the flow table shown in Figure 4. The amount of water needed for the mortar cube mixes for Type IL cement used in this study was 375 ml. The water cement ratio of the mortar cube mixtures for Type I and Type II cements used in the study was 0.458 and the water cement ratio for the Type IL cement was 0.507. Mixture proportions for the mortar cube mixtures are presented in Table 19.

Mixing of mortar was performed is accordance with AASHTO T 106 / ASTM C 109 "Standard Method of Test for Compressive Strength of Hydraulic Cement Mortar" using a mixer meeting the requirements of AASHTO T 162 / ASTM C 305 "Practice of Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency" as shown in Figure 5. Nine cubes were made with each mortar cube mixture as shown in Figure 6.

Table 19 – Mixture Proportions for 2-inch Mortar Cubes

Material	Type I and II Cement	Type IL Cement
Cement, g	740	740
Sand, g	2035	2035
Water, ml	359	375
w/c ratio	0.458	0.507

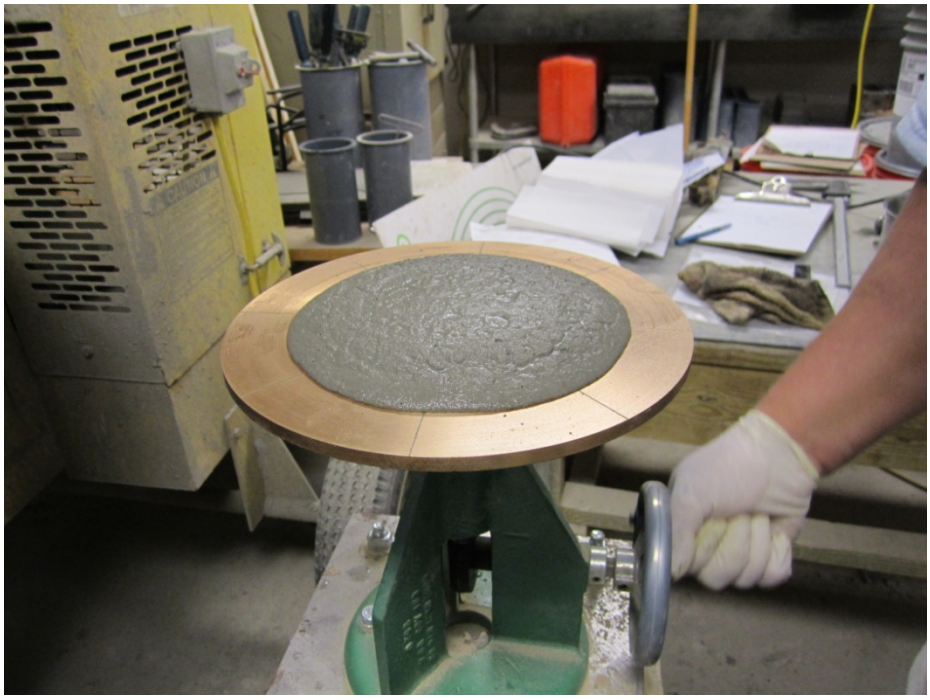

Figure 4 - Flow Table

Figure 5 - Mechanical Mortar Mixer

Figure 6 - Mortar Cubes

Compressive Strength of Hydraulic Cement Mortar

Compressive strength of hydraulic cement mortar was performed on 2 in. cube specimens in accordance with AASHTO T 106 / ASTM C 109 "Standard Method of Test for Compressive Strength of Hydraulic Cement Mortar." Nine specimens were tested for each sample of cement as follows: 2 at 1 day, 2 at 3 days, 3 at 7 days, and 2 at 28 days.

Chemical and Physical Testing of Cement Samples

Samples of cement were provided directly to BCD to be tested and used in the research mixtures. BCD technicians provided a blind sample of each cement sample to Holcim (US), Inc. for chemical and physical testing.

Chapter 5 – Results

Concrete Plastic Properties

Plastic properties of each concrete mixture are presented in Tables 20 through 25. Multiple tables were used to present results in order to divide these data into categories containing similar mixtures.

The two major categories of mixtures are based on the coarse aggregate type, gravel or crushed limestone. Test results from the gravel mixtures are presented in Tables 20 through 22. Tables 23 through 25 present fresh properties for mixtures made with crushed limestone coarse aggregate.

Additionally, test results are separated by type of cementitious materials. Tables 20 and 23 present mixes with 100% cement (100), Tables 21 and 24 present mixes with 25% Class C fly ash (75/25C) and Tables 22 and 25 contain mixtures with 25% Class F fly ash (75/25F). Mixes are sorted by cement and sample of cement in order to group results in alpha and numerical order of cement, not mix number.

Table 20 - Plastic Properties: Gravel Aggregate, (100)

Mix No.	Cement Sample	Slump (in.)	Air (%)	Temp (^{o}F)	Unit Weight (lbs/ft^{3})
Mix 1	CS-A-1	2.50	3.50	70.2	141.9
Mix 4	CS-A-2	5.50	3.25	71.1	141.9
Mix 7	CS-A-3	2.75	3.75	71.0	141.6
Mix 13	CS-B-1	5.25	4.00	64.8	140.7
Mix 16	CS-B-2	4.50	4.00	70.2	141.5
Mix 19	CS-B-3	5.50	4.75	68.7	140.6
Mix 25	CS-C-1	3.00	3.75	70.8	141.6
Mix 28	CS-C-2	3.50	3.00	75.7	141.8
Mix 31	CS-C-3	3.00	3.50	74.8	141.4
Mix 37	CS-D-1	3.00	2.75	75.6	142.4
Mix 40	CS-D-2	3.50	3.00	73.4	142.1
Mix 43	CS-D-3	2.75	3.50	70.7	142.4
Mix 73	CS-E-1	3.25	3.75	70.1	141.6
Mix 76	CS-E-2	3.00	3.00	69.3	142.3
Mix 79	CS-E-3	2.75	2.75	73.3	143.2
Mix 49	CS-F-1	3.00	3.50	66.8	142.0
Mix 52	CS-F-2	3.25	3.50	69.8	142.1
Mix 55	CS-F-3	3.00	3.50	69.6	141.7
Mix 61	CS-G-1	4.50	3.75	68.8	141.1
Mix 64	CS-G-2	4.25	3.00	72.5	142.0
Mix 67	CS-G-3	3.50	3.25	72.7	143.3

Table 21 - Plastic Properties: Gravel Aggregate, (75/25C)

Mix No.	Cement Sample	Slump (in.)	Air (%)	Temp (°F)	Unit Weight (lbs/ft^3)
Mix 2	CS-A-1	6.50	2.00	70.5	143.2
Mix 5	CS-A-2	6.75	2.25	70.0	143.2
Mix 8	CS-A-3	6.75	2.50	70.5	142.4
Mix 14	CS-B-1	8.25	1.60[1]	66.2	143.7
Mix 17	CS-B-2	7.50	2.75	68.0	142.3
Mix 20	CS-B-3	7.50	2.75	67.1	142.1
Mix 26	CS-C-1	5.75	2.50	68.2	142.5
Mix 29	CS-C-2	5.75	2.50	72.2	142.6
Mix 32	CS-C-3	4.50	2.50	70.7	142.8
Mix 38	CS-D-1	6.00	2.25	72.5	143.2
Mix 41	CS-D-2	4.75	2.00	72.7	142.7
Mix 44	CS-D-3	4.50	2.50	71.2	143.7
Mix 74	CS-E-1	5.25	2.50	70.2	143.6
Mix 77	CS-E-2	6.25	2.00	69.0	143.0
Mix 80	CS-E-3	3.75	2.50	69.2	143.4
Mix 50	CS-F-1	6.50	2.00	66.8	143.0
Mix 53	CS-F-2	5.75	2.00	68.5	143.8
Mix 56	CS-F-3	6.00	2.50	69.6	142.4
Mix 62	CS-G-1	7.50	2.50	68.1	142.5
Mix 65	CS-G-2	7.50	2.00	70.7	142.8
Mix 68	CS-G-3	6.25	2.75	72.3	142.9

Table 21 Notes:

1. This number represents the calculated theoretical air content based on unit weight. This calculation had to be made due to a leak in the air meter.

Table 22 - Plastic Properties: Gravel Aggregate, (75/25F)

Mix No.	Cement Sample	Slump (in.)	Air (%)	Temp (°F)	Unit Weight (lbs/ft^3)
Mix 3	CS-A-1	4.25	2.00	69.1	142.2
Mix 6	CS-A-2	8.00	1.75	68.3	142.4
Mix 9	CS-A-3	5.00	2.50	70.0	141.5
Mix 15	CS-B-1	6.50	1.75	67.9	141.8
Mix 18	CS-B-2	6.00	2.25	67.3	142.0
Mix 21	CS-B-3	7.25	2.75	66.0	141.9
Mix 27	CS-C-1	4.75	2.00	71.9	141.9
Mix 30	CS-C-2	4.50	2.00	72.2	142.3
Mix 33	CS-C-3	4.25	2.25	69.8	141.6
Mix 39	CS-D-1	4.50	2.25	70.8	142.2
Mix 42	CS-D-2	5.50	2.00	71.5	142.3
Mix 45	CS-D-3	4.75	2.00	71.9	142.9
Mix 75	CS-E-1	4.75	2.00	73.2	142.0
Mix 78	CS-E-2	4.75	2.00	68.5	141.9
Mix 81	CS-E-3	3.50	2.00	70.8	141.9
Mix 51	CS-F-1	5.50	2.00	68.4	142.5
Mix 54	CS-F-2	5.50	2.00	68.4	142.5
Mix 57	CS-F-3	4.25	2.25	69.9	141.9
Mix 63	CS-G-1	6.75	2.25	71.1	142.3
Mix 66	CS-G-2	6.50	2.00	69.8	142.2
Mix 69	CS-G-3	5.25	2.25	74.1	142.0

Table 23 - Plastic Properties: Crushed Limestone Aggregate, (100)

Mix No.	Cement Sample	Slump (in.)	Air (%)	Temp (°F)	Unit Weight (lbs/ft^3)
Mix 10	CS-A-1	2.50	3.75	68.9	150.2
Mix 22	CS-B-1	3.00	3.75	68.4	150.2
Mix 34	CS-C-1	1.75	3.50	72.5	150.2
Mix 46	CS-D-1	2.50	3.50	70.5	151.0
Mix 82	CS-E-1	1.75	3.50	70.7	150.6
Mix 58	CS-F-1	1.75	3.00	72.2	150.5
Mix 70	CS-G-1	2.25	3.50	68.4	150.4

Table 24 - Plastic Properties: Crushed Limestone Aggregate, (75/25C)

Mix No.	Cement Sample	Slump (in.)	Air (%)	Temp (°F)	Unit Weight (lbs/ft^3)
Mix 11	CS-A-1	4.25	2.50	68.3	150.8
Mix 23	CS-B-1	5.50	2.75	67.8	150.7
Mix 35	CS-C-1	3.00	2.25	71.5	151.6
Mix 47	CS-D-1	4.25	3.50	70.5	151.3
Mix 83	CS-E-1	3.50	2.25	69.8	151.2
Mix 59	CS-F-1	3.00	2.25	72.1	151.2
Mix 71	CS-G-1	3.50	2.50	68.0	150.9

Table 25 - Plastic Properties: Crushed Limestone Aggregate, (75/25F)

Mix No.	Cement Sample	Slump (in.)	Air (%)	Temp (°F)	Unit Weight (lbs/ft^3)
Mix 12	CS-A-1	3.50	2.25	69.1	150.9
Mix 24	CS-B-1	4.00	2.25	68.6	151.3
Mix 36	CS-C-1	3.25	2.25	70.8	150.7
Mix 48	CS-D-1	3.00	3.25	71.5	150.6
Mix 84	CS-E-1	2.50	1.75	69.7	150.8
Mix 60	CS-F-1	2.50	2.00	72.4	150.8
Mix 72	CS-G-1	3.50	2.50	67.1	150.3

Concrete Compressive Strength

Results from testing fifteen compressive strength specimens for each mix are given in this section. These specimens were tested as follows; 3 at 1 day, 3 at 7 days, 3 at 14 days, 3 at 28 days, and 3 at 56 days. Results shown in this report are calculated as the average of specimens tested for each age. Compressive strength results of each specimen were rounded to the nearest 10 psi. These individual tests at each test age were averaged and rounded to the nearest 1 psi for reporting. Individual companion cylinder test results that exceeded the acceptable range of 10.6% as noted in AASHTO T 22 / ASTM C 39 were evaluated and either included in the average or omitted from the average based on the opinion of the author. A detailed evaluation of companion cylinder strengths is presented in Chapter 6 "Discussion of Results."

Tables 26 through 31 present average compressive strength results. The two major categories of mixtures are based on the coarse aggregate type, gravel or crushed limestone. Test results from the gravel mixtures are presented in Tables 26 through 28. Tables 29 through 31 present average compressive strengths for mixtures made with crushed limestone coarse aggregate.

Additionally, average compressive strength test results are separated by type of cementitious materials used in the mixtures. Tables 26 and 29 present mixes with 100% cement (100), Tables 27 and 30 present mixes with 25% Class C Fly Ash (75/25C), and Tables 28 and 31 present mixtures with 25% Class F fly ash (75/25F). Mixes are sorted by cement and sample of cement in order to group results in alpha and numerical order of cement, not mix number.

These tables also include a ranking. A ranking of 1 indicates the highest compressive strength for the table and the highest ranking indicates the lowest average compressive strength for that category of mixes.

Figures 7 through 27 present average compressive strength versus age for all mixes. These figures are specific for cement and type of cementitious materials used. Both crushed limestone and gravel aggregates are included in these figures. The difference between the

highest and lowest 28-day compressive strength for the gravel aggregate concrete mixes, i.e., range is also noted in each of these figures.

Table 26 - Average Compressive Strength: Gravel Aggregate, (100)

Mix No.	Cement Sample	1 Day		7 Day		14 Day		28 Day		56 Day	
		Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank
Mix 1	CS-A-1	1477	20	3730	16	3867	20	4467	16	4807	16
Mix 4	CS-A-2	1647	19	3470	19	4160	16	4303	20	4977	11
Mix 7	CS-A-3	1720	17	3743	15	3900	18	4483	15	5430	4
Mix 13	CS-B-1	1673	18	3747	14	4163	15	4727	8	4927	14
Mix 16	CS-B-2	1883	13	4340	3	4505	6	4867	4	5493	3
Mix 19	CS-B-3	1267	21	3840	11	4305	8	4750	7	4803	17
Mix 25	CS-C-1	2170	6	3693	17	4113	17	4373	18	4790	18
Mix 28	CS-C-2	2233	3	4267	4	4557	4	4667	9	4917	15
Mix 31	CS-C-3	1930	10	3965	6	4183	14	4413	17	4940	13
Mix 37	CS-D-1	1923	11	3780	13	4283	9	4560	14	4960	12
Mix 40	CS-D-2	2063	7	4113	5	4743	1	5333	1	5370	5
Mix 43	CS-D-3	2213	5	3803	12	4507	5	4777	6	5253	6
Mix 73	CS-E-1	2217	4	4350	1	4730	2	4665	10	5167	8
Mix 76	CS-E-2	2280	1	4343	2	4270	10	4950	3	5603	2
Mix 79	CS-E-3	2253	2	3925	7	4633	3	4637	11	5735	1
Mix 49	CS-F-1	1783	15	3907	8	4347	7	4990	2	5217	7
Mix 52	CS-F-2	1793	14	3897	9	4205	12	4615	13	5060	10
Mix 55	CS-F-3	1990	9	3875	10	4203	13	4625	12	5135	9
Mix 61	CS-G-1	1893	12	3213	21	3380	21	4125	21	4303	21
Mix 64	CS-G-2	1733	16	3463	20	4220	11	4370	19	4457	20
Mix 67	CS-G-3	2007	8	3607	18	3870	19	4810	5	4777	19

Table 27 - Average Compressive Strength: Gravel Aggregate, (75/25C)

Mix No.	Cement Sample	1 Day		7 Day		14 Day		28 Day		56 Day	
		Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank
Mix 2	CS-A-1	883	20	3190	8	3497	13	3803	17	3867	19
Mix 5	CS-A-2	863	21	2873	18	3195	19	3383	21	3695	21
Mix 8	CS-A-3	970	19	3130	9	3243	17	4010	12	4415	10
Mix 14	CS-B-1	1023	18	3380	4	3677	6	4120	9	4355	12
Mix 17	CS-B-2	1137	17	3320	6	3625	7	4333	6	4407	11
Mix 20	CS-B-3	1287	11	3335	5	3540	8	4073	10	4340	13
Mix 26	CS-C-1	1373	5	3093	10	3510	10	3815	16	4150	16
Mix 29	CS-C-2	1360	7	3595	1	3720	5	4130	7	4453	9
Mix 32	CS-C-3	1280	12	3013	11	4457	1	4863	1	4720	7
Mix 38	CS-D-1	1437	2	2877	17	3507	11	3740	18	3890	18
Mix 41	CS-D-2	1343	9	2947	15	3465	14	3935	14	4205	14
Mix 44	CS-D-3	1420	4	2965	13	3227	18	3860	15	4180	15
Mix 74	CS-E-1	1350	8	3463	3	4160	2	3940	13	5053	4
Mix 77	CS-E-2	1707	1	3593	2	3917	4	4830	2	5330	1
Mix 80	CS-E-3	1373	5	2890	16	3503	12	4580	3	5300	2
Mix 50	CS-F-1	1263	13	2965	13	4067	3	4545	4	4850	6
Mix 53	CS-F-2	1197	14	3255	7	3360	16	4530	5	4885	5
Mix 56	CS-F-3	1317	10	2515	21	3453	15	4130	7	5155	3
Mix 62	CS-G-1	1177	15	2765	19	2937	21	3740	18	3830	20
Mix 65	CS-G-2	1170	16	2745	20	2940	20	3473	20	4043	17
Mix 68	CS-G-3	1437	2	3000	12	3530	9	4073	10	4607	8

Table 28 - Average Compressive Strength: Gravel Aggregate, (75/25F)

Mix No.	Cement Sample	1 Day		7 Day		14 Day		28 Day		56 Day	
		Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank
Mix 3	CS-A-1	910	20	3140	1	3715	2	3910	11	4700	7
Mix 6	CS-A-2	890	21	2657	15	2985	19	3360	21	4107	20
Mix 9	CS-A-3	967	19	2557	17	3040	17	3530	19	4133	19
Mix 15	CS-B-1	1130	16	2970	6	3563	5	4295	4	4387	13
Mix 18	CS-B-2	1283	11	3015	5	3503	6	4103	7	4160	17
Mix 21	CS-B-3	1820	1	2940	7	3190	15	3800	14	4375	14
Mix 27	CS-C-1	1330	9	3053	4	3390	10	3880	12	4323	15
Mix 30	CS-C-2	1353	8	3100	2	3427	8	4020	9	4430	11
Mix 33	CS-C-3	1283	11	2880	10	4400	1	4930	1	4777	3
Mix 39	CS-D-1	1407	6	2703	11	3327	12	3635	17	4440	10
Mix 42	CS-D-2	1327	10	2690	12	3450	7	4000	10	4580	9
Mix 45	CS-D-3	1487	4	2430	19	3125	16	3760	15	4390	12
Mix 75	CS-E-1	1357	7	2883	9	3367	11	3850	13	4765	5
Mix 78	CS-E-2	1500	3	3063	3	3397	9	4375	3	4897	1
Mix 81	CS-E-3	1560	2	2680	13	3625	3	4050	8	4777	3
Mix 51	CS-F-1	1113	18	2677	14	3580	4	4473	2	4783	2
Mix 54	CS-F-2	1123	17	2657	15	3323	13	4160	6	4587	8
Mix 57	CS-F-3	1243	14	2365	21	3210	14	3747	16	4717	6
Mix 63	CS-G-1	1270	13	2393	20	2640	21	3573	18	4003	21
Mix 66	CS-G-2	1133	15	2510	18	2880	20	3513	20	4210	16
Mix 69	CS-G-3	1460	5	2885	8	3017	18	4235	5	4157	18

Table 29 - Average Compressive Strength: Crushed Limestone Aggregate, (100)

Mix No.	Cement Sample	1 Day		7 Day		14 Day		28 Day		56 Day	
		Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank
Mix 10	CS-A-1	2637	7	5833	3	6787	2	7237	2	7593	3
Mix 22	CS-B-1	2740	6	6170	1	6463	3	7023	3	7623	2
Mix 34	CS-C-1	3320	1	5693	4	6153	7	6577	7	7110	6
Mix 46	CS-D-1	3267	2	5657	5	6430	4	6910	4	7147	5
Mix 82	CS-E-1	2890	4	5907	2	6953	1	7300	1	7870	1
Mix 58	CS-F-1	2913	3	5573	6	6350	5	6603	6	7257	4
Mix 70	CS-G-1	2790	5	5373	7	6210	6	6740	5	6833	7

Table 30 - Average Compressive Strength: Crushed Limestone Aggregate, (75/25C)

Mix No.	Cement Sample	1 Day		7 Day		14 Day		28 Day		56 Day	
		Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank
Mix 11	CS-A-1	1467	6	5340	6	6660	3	7920	1	8570	1
Mix 23	CS-B-1	1413	7	5647	4	6550	6	7277	5	8067	3
Mix 35	CS-C-1	2295	2	5997	1	6590	5	7657	3	7993	4
Mix 47	CS-D-1	2313	1	5780	3	6780	1	7133	7	7553	7
Mix 83	CS-E-1	1943	4	5573	5	6730	2	7470	4	7943	5
Mix 59	CS-F-1	2043	3	5330	7	6530	7	7737	2	8327	2
Mix 71	CS-G-1	1750	5	5957	2	6657	4	7210	6	7850	6

Table 31 - Average Compressive Strength: Crushed Limestone Aggregate, (75/25F)

Mix No.	Cement Sample	1 Day		7 Day		14 Day		28 Day		56 Day	
		Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank
Mix 12	CS-A-1	1567	7	4720	4	5513	2	6573	1	7313	3
Mix 24	CS-B-1	1700	6	4730	2	5323	5	6023	5	7357	2
Mix 36	CS-C-1	2210	1	4810	1	5243	7	5783	7	6720	7
Mix 48	CS-D-1	2203	2	4727	3	5610	1	6350	3	7243	4
Mix 84	CS-E-1	1877	5	4557	5	5420	4	6103	4	7150	5
Mix 60	CS-F-1	1887	4	4533	6	5437	3	6387	2	7860	1
Mix 72	CS-G-1	1920	3	4380	7	5287	6	5933	6	7137	6

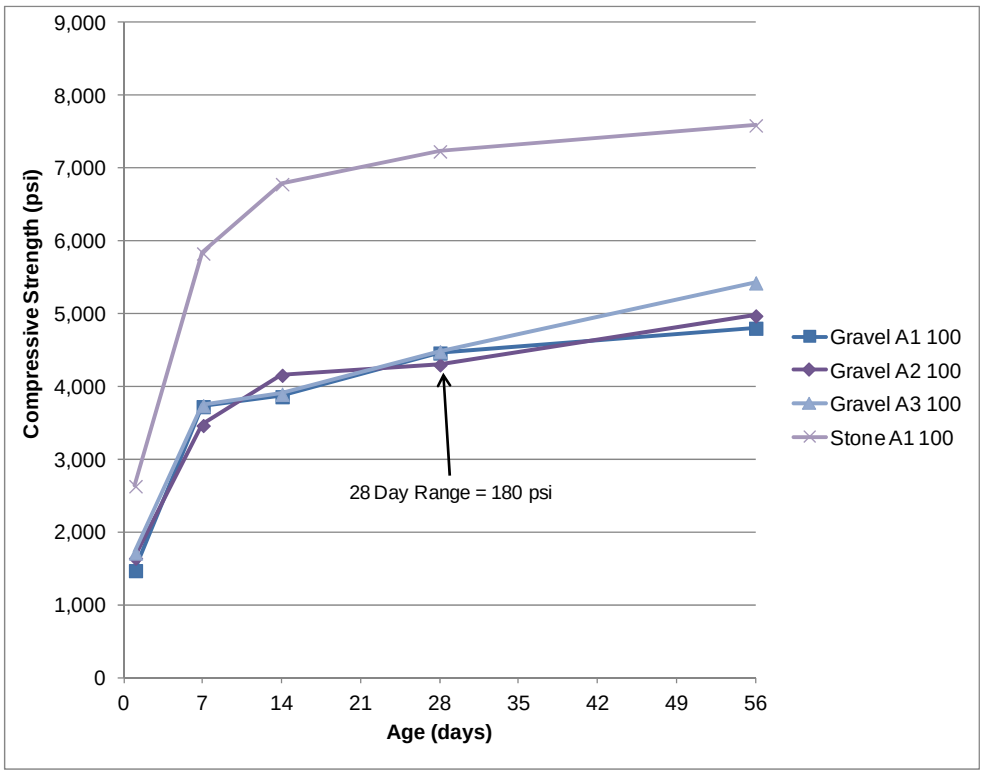

Figure 7 - Compressive Strength vs Age: Cement A 100

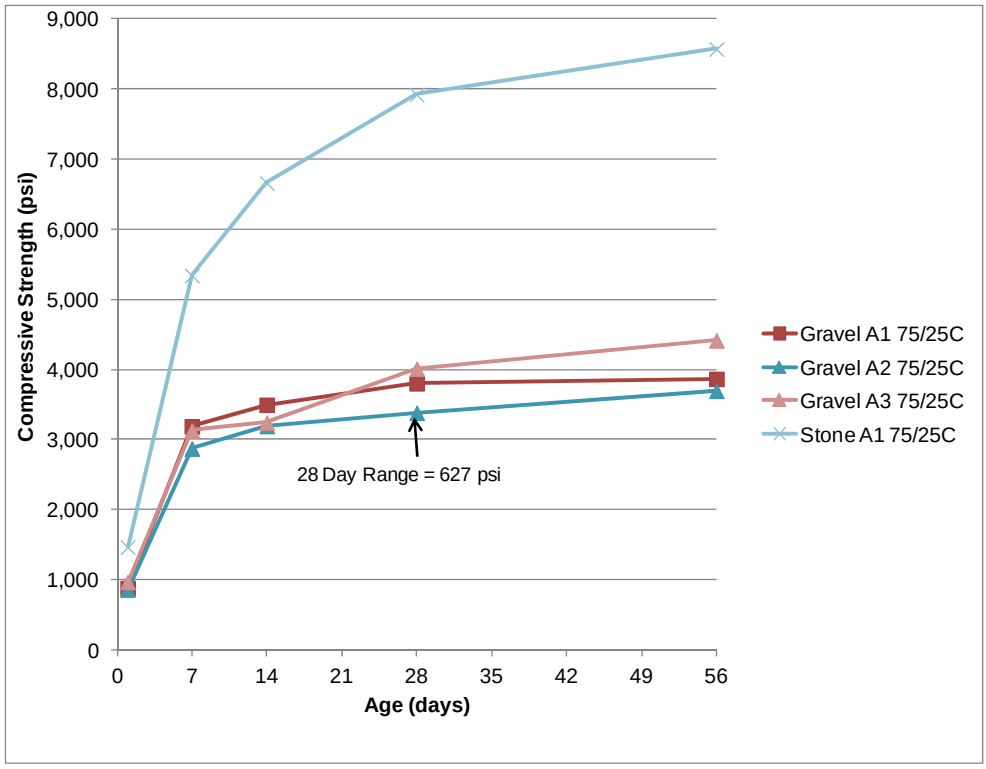

Figure 8 - Compressive Strength vs Age: Cement A 75/25C

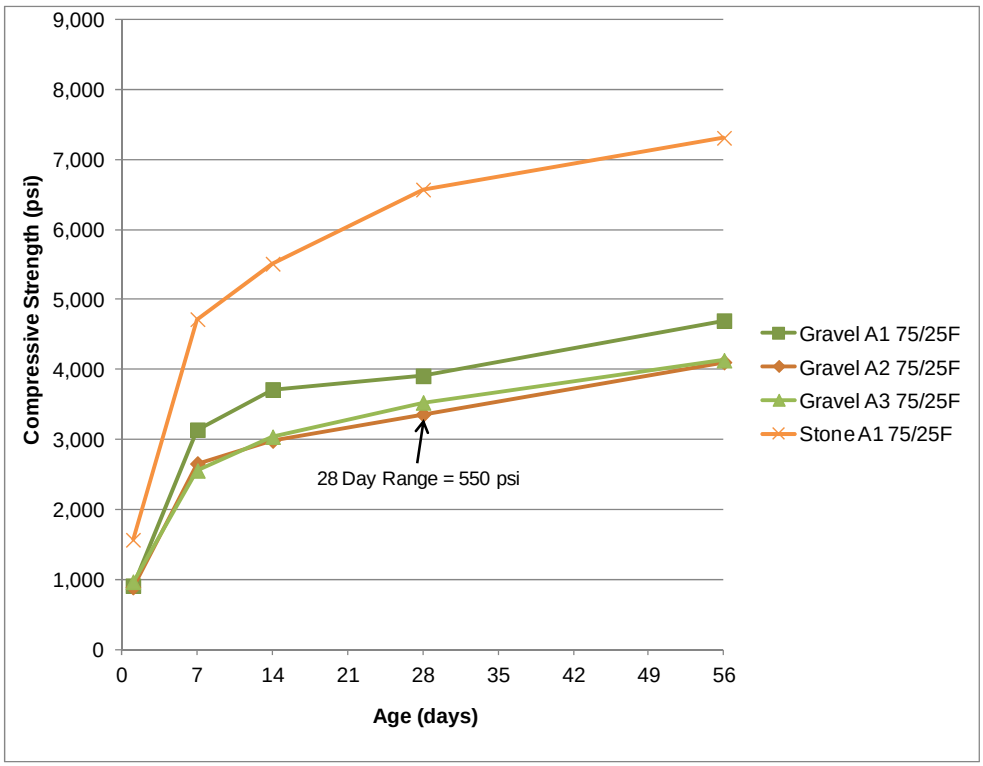

Figure 9 - Compressive Strength vs Age: Cement A 75/25F

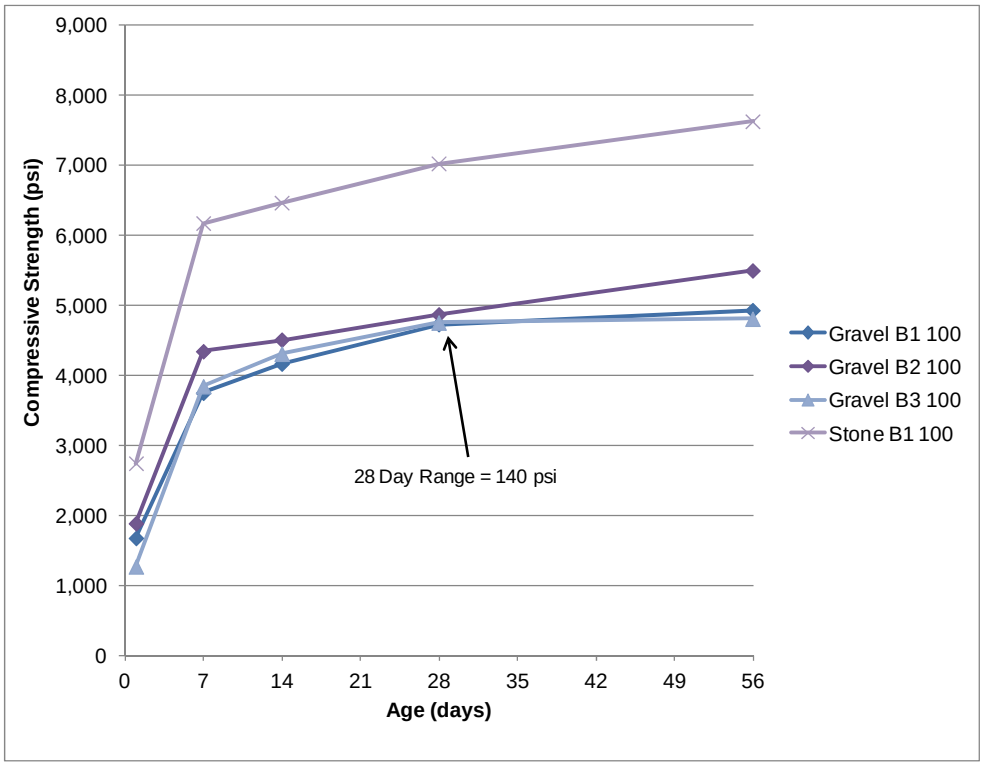

Figure 10 - Compressive Strength vs Age: Cement B 100

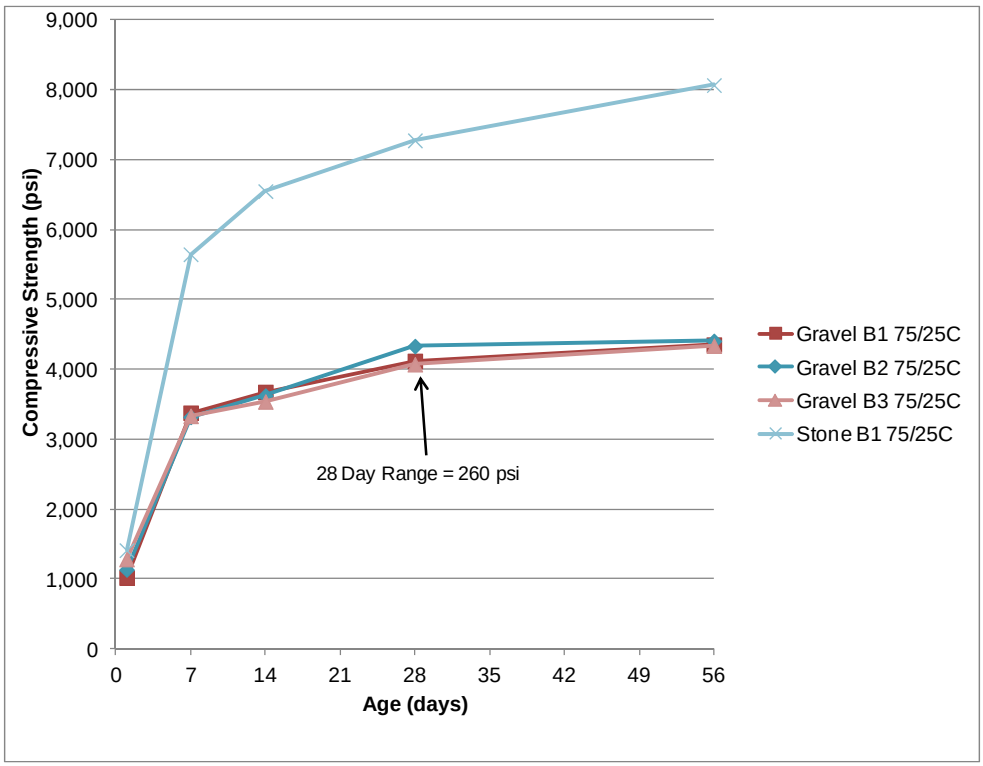

Figure 11 - Compressive Strength vs Age: Cement B 75/25C

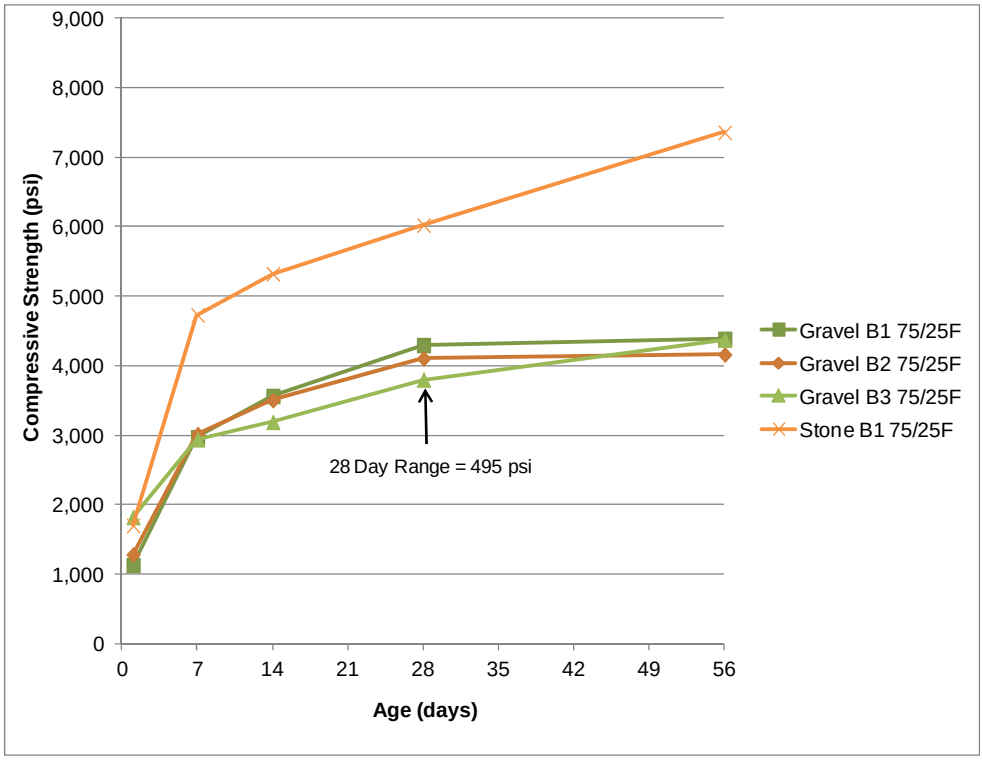

Figure 12 - Compressive Strength vs Age: Cement B 75/25F

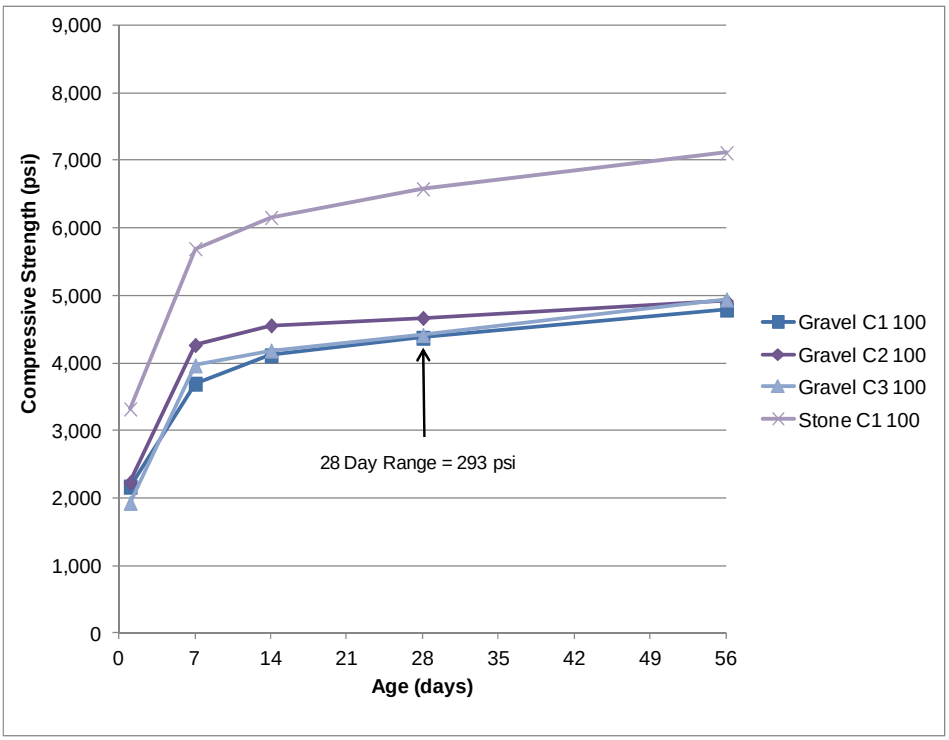

Figure 13 - Compressive Strength vs Age: Cement C 100

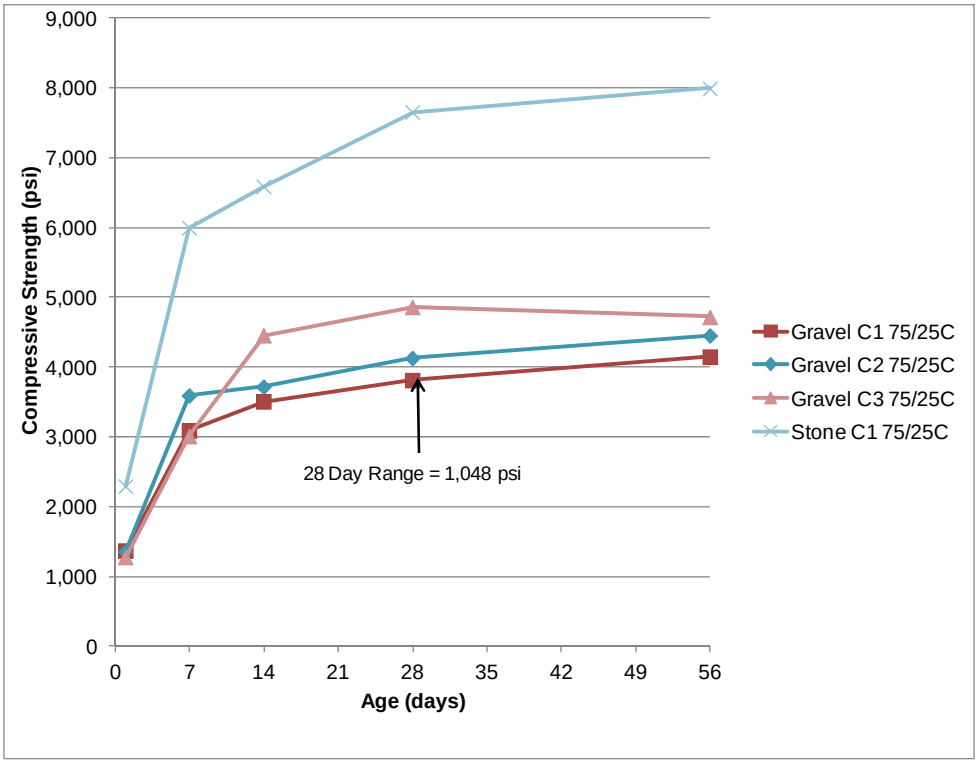

Figure 14 - Compressive Strength vs Age: Cement C 75/25C

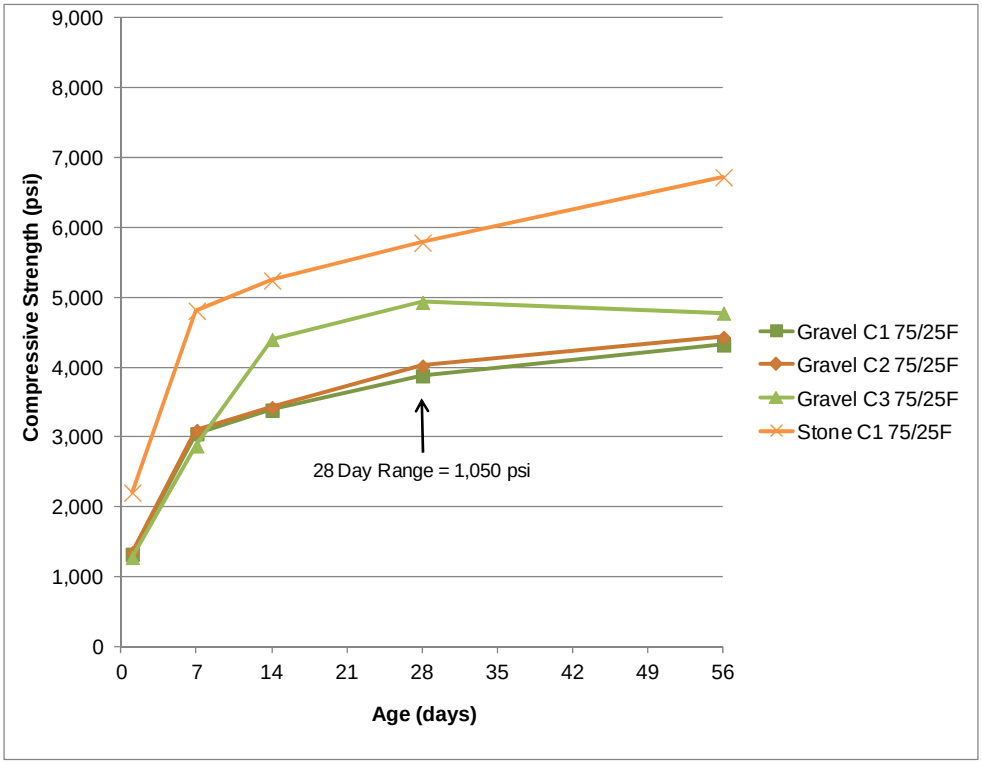

Figure 15 - Compressive Strength vs Age: Cement C 75/25F

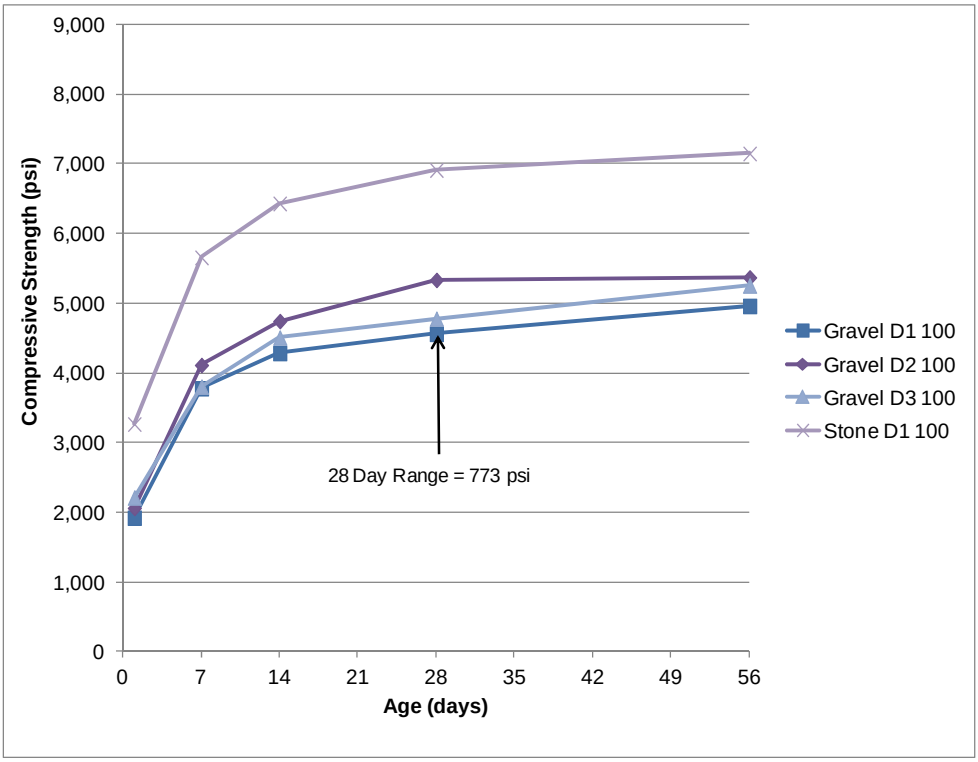

Figure 16 - Compressive Strength vs Age: Cement D 100

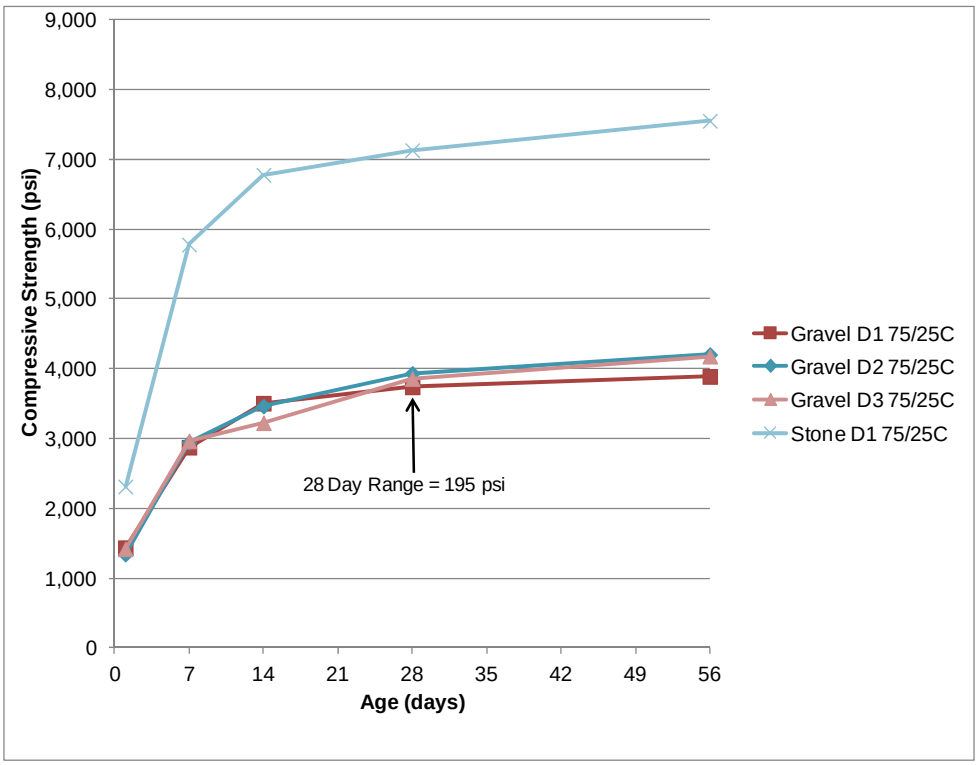

Figure 17 - Compressive Strength vs Age: Cement D 75/25C

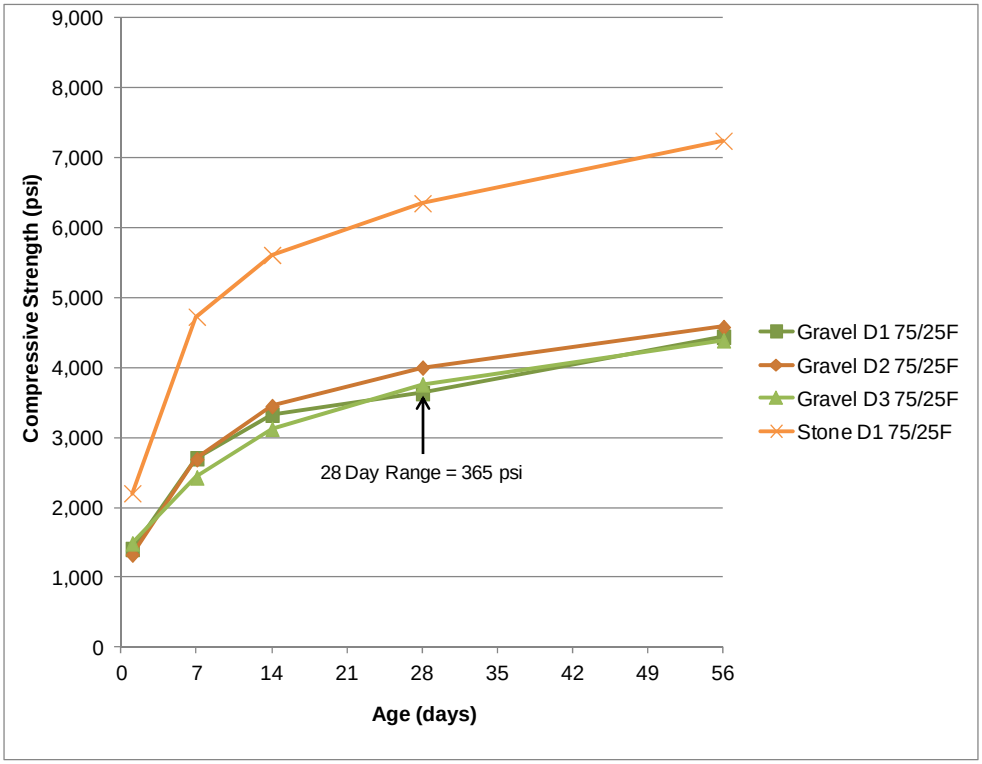

Figure 18 - Compressive Strength vs Age: Cement D 75/25F

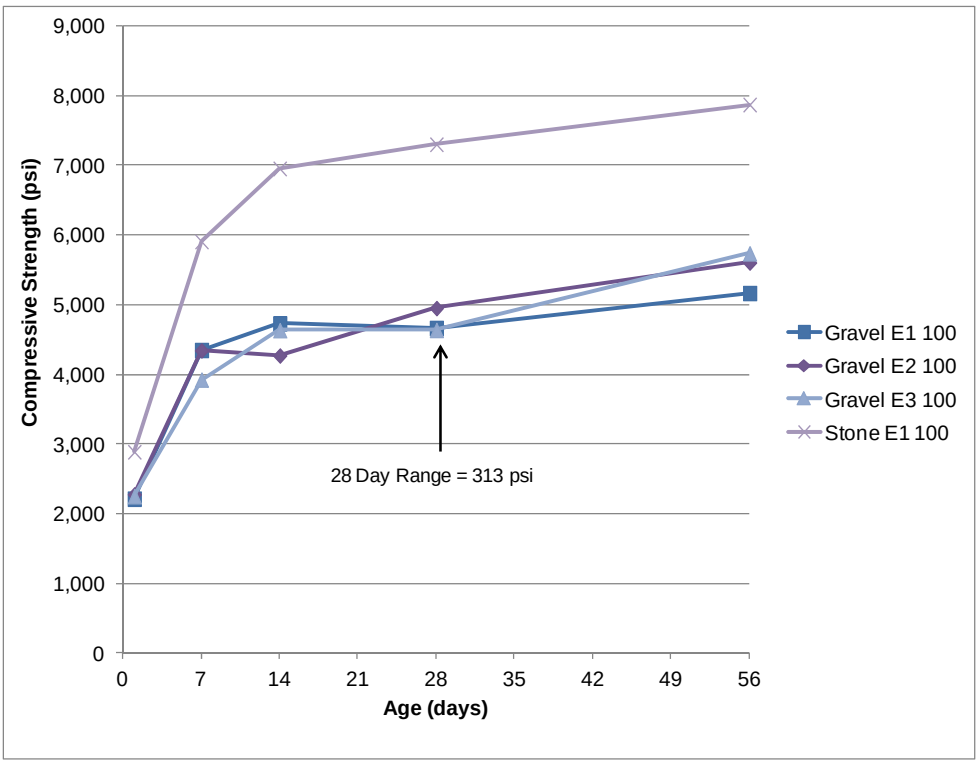

Figure 19 - Compressive Strength vs Age: Cement E 100

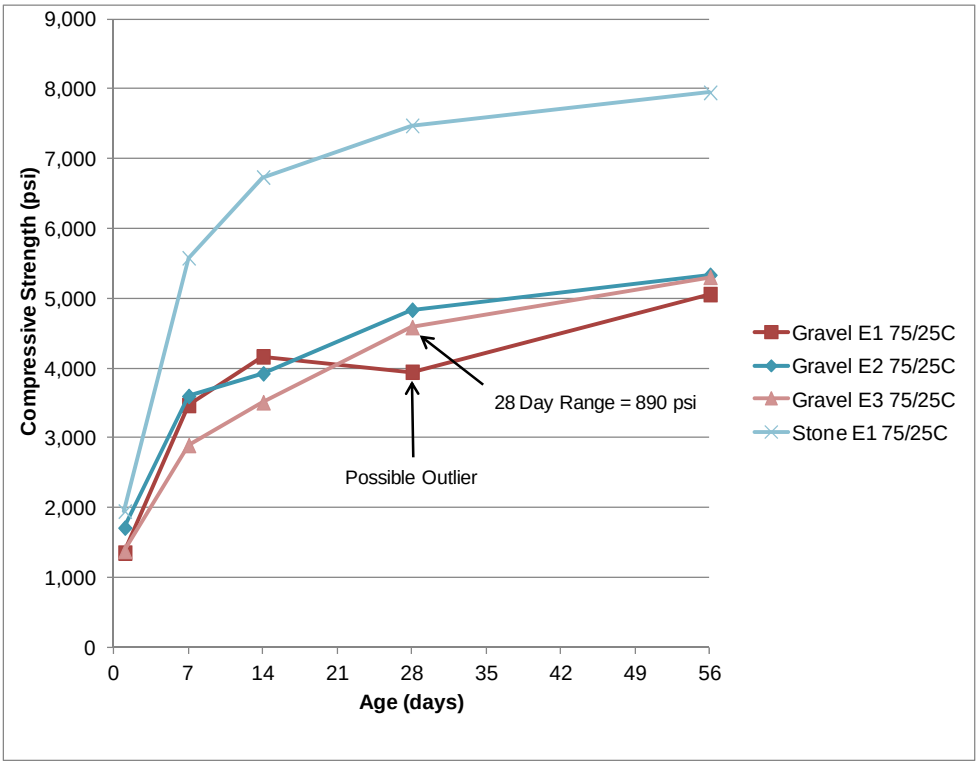

Figure 20 - Compressive Strength vs Age: Cement E 75/25C

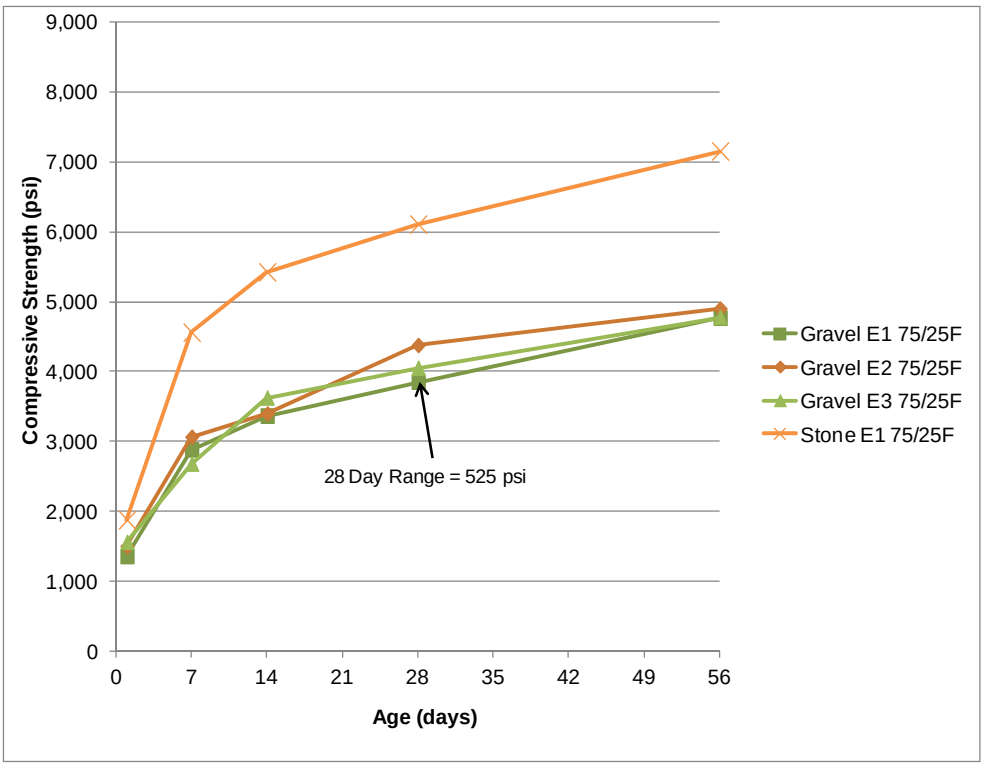

Figure 21 - Compressive Strength vs Age: Cement E 75/25F

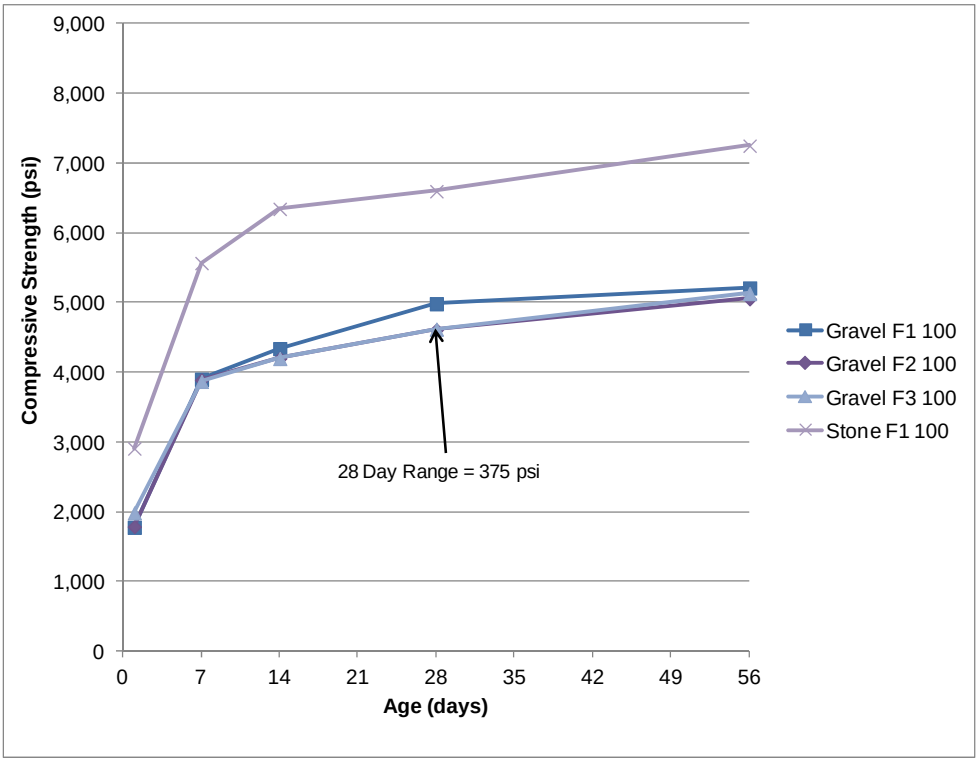

Figure 22 - Compressive Strength vs Age: Cement F 100

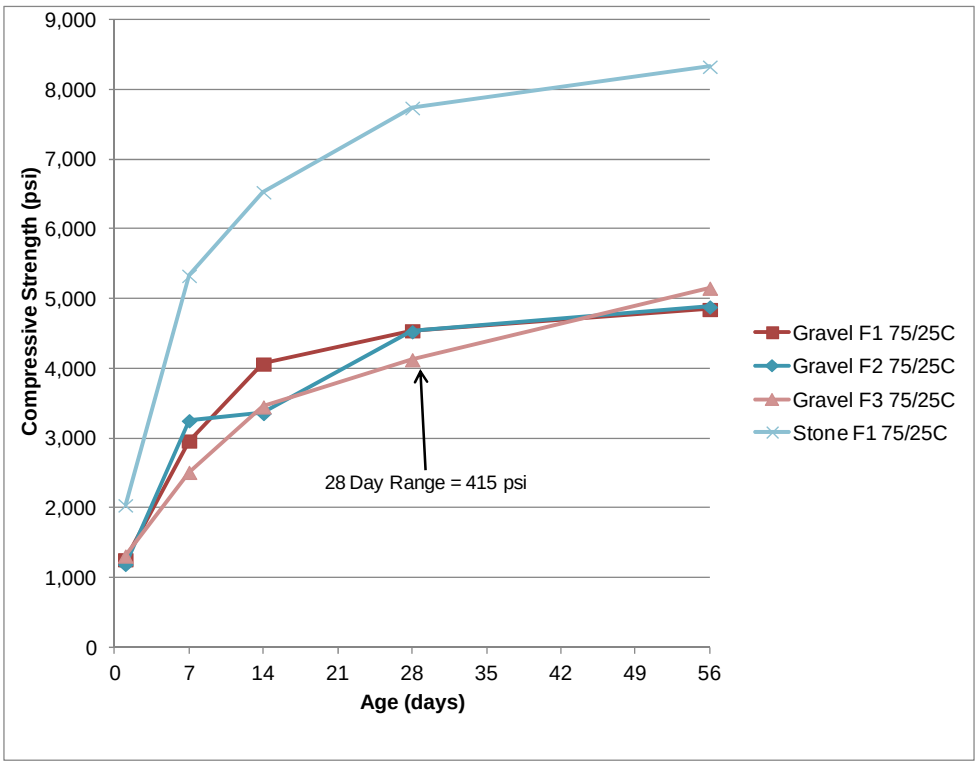

Figure 23 - Compressive Strength vs Age: Cement F 75/25C

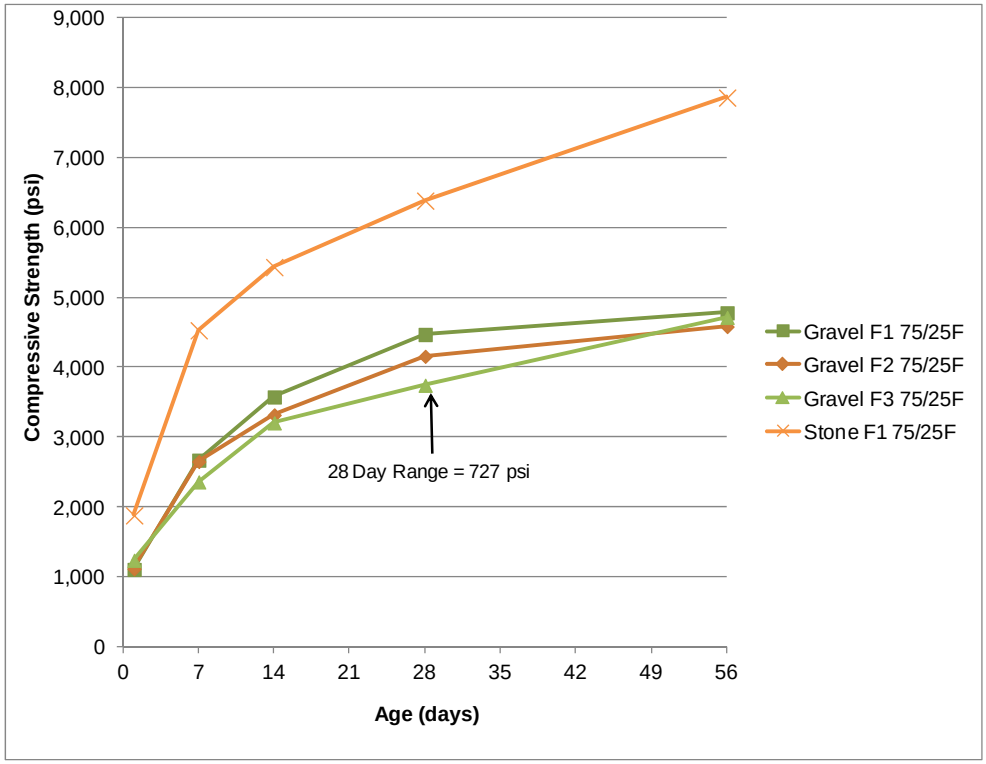

Figure 24 - Compressive Strength vs Age: Cement F 75/25F

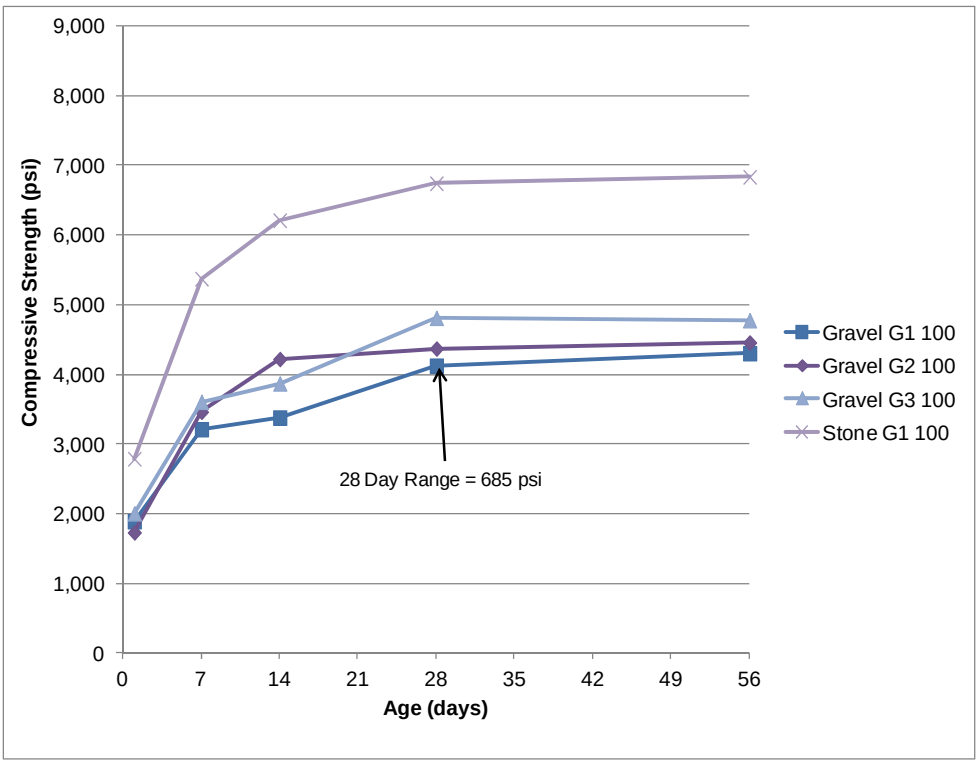

Figure 25 - Compressive Strength vs Age: Cement G 100

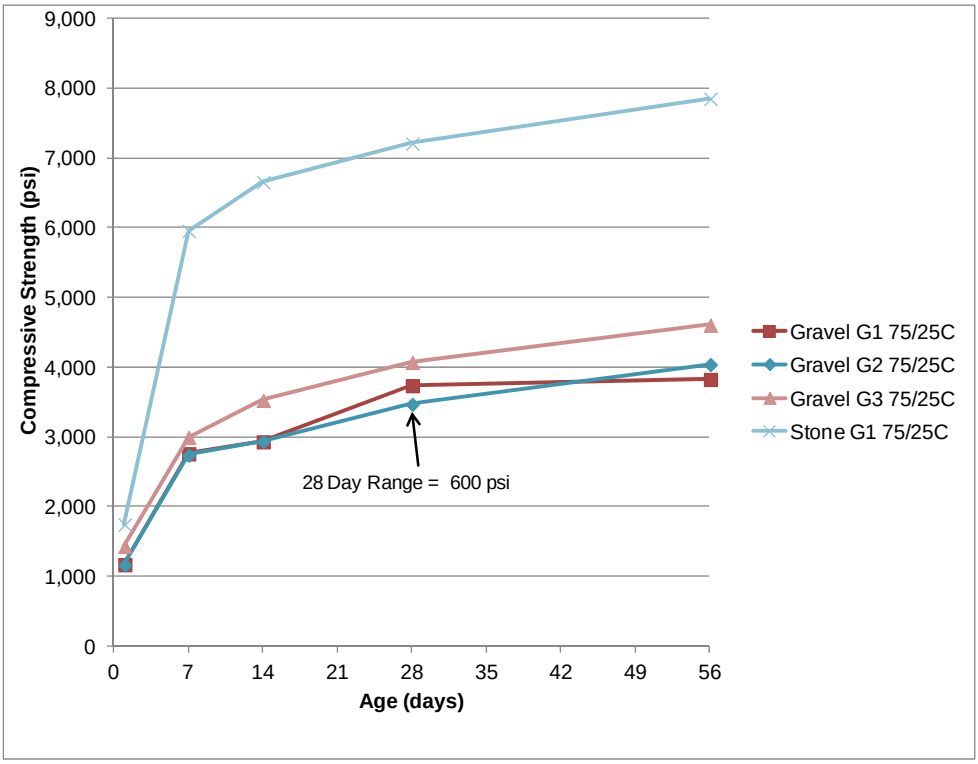

Figure 26 - Compressive Strength vs Age: Cement G 75/25C

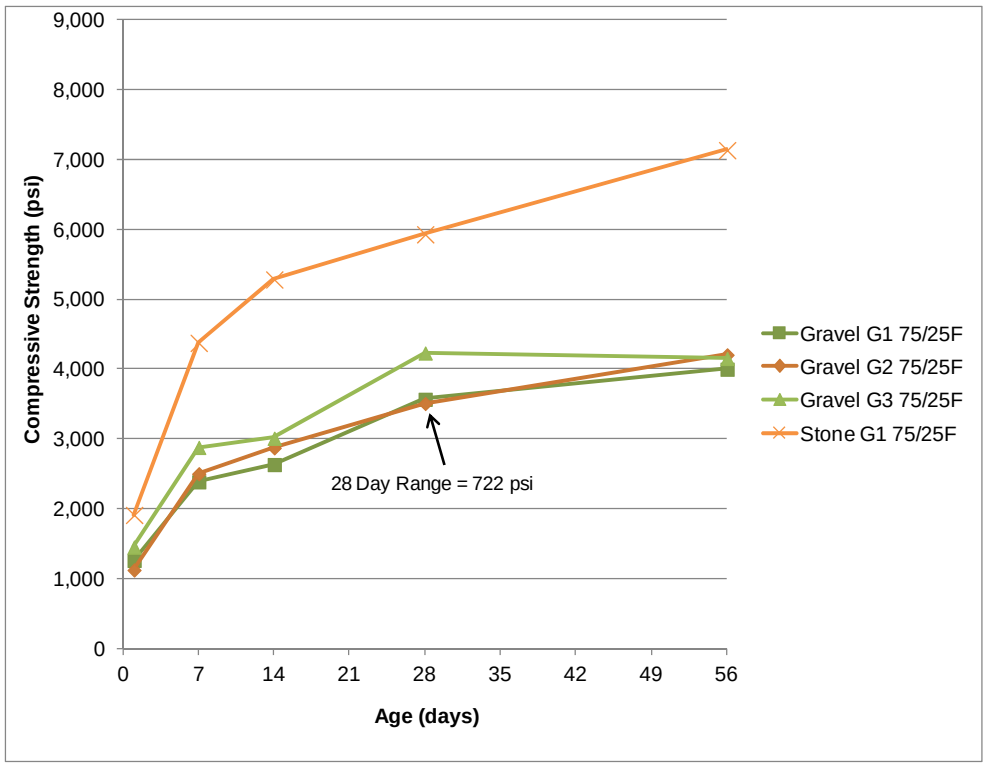

Figure 27 - Compressive Strength vs Age: Cement G 75/25F

Mortar Cube Compressive Strength

Results from BCD's testing of nine compressive strength specimens per cement sample are given in this section. These specimens were tested as follows; 2 at 1 day, 2 at 3 days (except for cement samples CS-A-2, CS-B-2, and CS-C-2 tested at 5 days), 3 at 7 days and 2 at 28 days. Results shown in this report are calculated as the average of specimens tested at each age. Compressive strength results of each specimen were rounded to the nearest 1 psi. These individual tests at each test age were then averaged and the average was rounded to the nearest 10 psi for reporting. The results from testing mortar cube specimens for compressive strength are presented in Table 32. This table also includes ranking. A ranking of 1 indicates the highest compressive strength for the table and a ranking of 21 indicates the lowest average compressive strength for the mortar cubes.

Table 32 - Average Compressive Strength for Mortar Cubes

Cement Sample	1 Day		3 Day		7 Day		28 Day	
	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank	Avg. (psi)	Rank
CS-A-1	2140	19	3740	7	4790	4	6020	1
CS-A-2	1970	21	3210[1]	18	4950	1	5470	11
CS-A-3	2280	15	3950	4	4510	7	5800	4
CS-B-1	2030	20	3620	10	4220	16	5720	6
CS-B-2	2260	16	2710[1]	21	4540	6	5260	16
CS-B-3	2290	14	3800	6	4300	15	5540	9
CS-C-1	2340	12	3840	5	4330	13	5370	13
CS-C-2	2390	11	3030[1]	19	4470	9	5290	15
CS-C-3	3030	2	3620	10	4190	17	4760	20
CS-D-1	2540	8	3680	8	4360	12	5390	12
CS-D-2	2560	7	3590	12	4320	14	5540	9
CS-D-3	2770	4	4060	3	4400	10	5360	14
CS-E-1	2770	4	4190	2	4920	2	5670	8
CS-E-2	3140	1	4380	1	4850	3	5890	3
CS-E-3	2780	3	3470	14	4740	5	5940	2
CS-F-1	2180	18	3460	15	4110	19	5700	7
CS-F-2	2330	13	3440	16	4140	18	5750	5
CS-F-3	2470	10	3290	17	4080	20	5090	19
CS-G-1	2680	6	3640	9	4370	11	5240	17
CS-G-2	2250	17	2770	20	3940	21	4760	20
CS-G-3	2480	9	3580	13	4490	8	5170	18

Notes for Table 32:

1. This compressive strength is at 5 days in lieu of 3 days. Therefore, the 3 day ranking for mortar cubes may not be valid.

Chapter 6 – Discussion of Results

Acceptable Range of Compressive Strengths for Companion Cylinders

Properly fabricated and tested companion cylinders almost always produce different compressive strength results creating a range in the individual test results. The range of companion specimen results for this research was as low as 10 psi and as high as 1,100 psi for three specimens tested at an age of 7 days, 14 days, 28 days, or 56 days. AASHTO T 22 / ASTM C 39 provides an acceptable range for companion cylinders of 10.6 percent when three 4 in. X 8 in. cylinders are tested in laboratory conditions. According to AASHTO T 22 / ASTM C 39, this acceptable range in companion cylinder strength is applicable for compressive strengths ranging between 2,500 psi and 4,700 psi. Since the majority of the mixes in this research had one day compressive strengths less than 2,500 psi, one day compressive strengths were not evaluated based on acceptable range.

Influence of Coarse Aggregate Type on Companion Cylinder Strength

A total of 336 sets of cylinders were evaluated for acceptable range in this research including 84 sets made with crushed limestone coarse aggregate and 252 sets made with gravel aggregate. There were only two sets of companion cylinders out of 84 sets of specimens made with crushed limestone that exceeded the 10.6 percent range. That is 2.4 percent of companion cylinder sets made from mixes proportioned with crushed limestone coarse aggregate exceeded the acceptable range. There were 84 sets of companion cylinders out of 252 sets made from mixtures proportioned with gravel aggregate concrete that exceeded the acceptable range for companion cylinders. Therefore, 33.3 percent of gravel aggregate concrete companion cylinders exceeded the acceptable range. It is apparent that the acceptable range provided in AASHTO T 22 / ASTM C 39 may not be applicable for gravel aggregate concrete because 66.7 percent of the companion cylinders made with gravel aggregates were within the acceptable range versus 97.6 percent for the crushed limestone.

Influence of Cementitious Materials on Companion Cylinder Strength

Cementitious materials were also evaluated for their influence on acceptable range of compressive strength for companion cylinders. There were 112 sets of companion cylinders

made with 100, 112 sets made with 72/25C, and 112 sets made with 75/25F. There were 21 out of 112 sets (or 18.8 percent) of companion cylinders made from mixtures with 100% cement that exceeded the acceptable range. There were 32 out of 112 sets (or 28.6 percent) of companion cylinders made from mixtures with 75/25C that exceeded the acceptable range. There were 33 out of 112 sets (or 29.5 percent) of companion cylinders made from mixtures with 75/25F that exceeded the acceptable range. Mixtures proportioned with 75% cement and either 25% Class C or 25% Class F fly ash introduce more variability in concrete compressive strength than mixtures proportioned with 100% cement.

Evaluating Acceptable Range of Companion Cylinders for 28-Day Compressive Strengths

Figures 28 through 33 present average 28-day compressive strength versus strength range of companion cylinders. These figures also show acceptable range limits provided in AASHTO T 22 / ASTM C 39 for two and three companion cylinders of 9.0 percent and 10.6 percent, respectfully. Each point to the left of the limit indicates that the set is within the acceptable range. Each point to the right of the acceptable limit indicates that the set is outside the acceptable range.

Figure 28 presents all 28-day compressive strength data before removing individual test results that exceeded the acceptable range for three 4 in. X 8 in. cylindrical specimens. There were 21 out of 84 of the 28-day companion cylinder sets that exceeded the acceptable range before removing outliers. Individual compressive test results that exceeded the acceptable range were considered to be outliers. Figures 29 through 32 show these 28-day strength data divided into four categories including; 1) all crushed limestone mixes (Figure 29), 2) all 100% cement gravel aggregate mixes (Figure 30), 3) all 75/25C gravel aggregate mixes (Figure 31), and 4) all 75/25F gravel aggregate mixes (Figure 32). These figures show that mixtures made with crushed limestone aggregate produce 4.8 percent of companion sets of cylinders that exceed the acceptable range. The percentage companion cylinders made with gravel aggregate and 100% cement or 75/25C that exceeded the acceptable range is 23.8 percent and 28.6 percent, respectfully. Gravel aggregate mixture proportioned with 75/25F had 47.6 percent of their

companion sets of 28-day cylinders that exceed the acceptable range for three companion cylinders.

Figure 33 presents ranges of companion cylinders for 28-day compressive strengths after removing individual test results that exceeded the acceptable range for three 4 in. X 8 in. cylindrical specimens. Only one set of companion cylinders exceeded the acceptable limit for three 4 in. X 8 in. cylindrical specimens after removing the outlier test.

The acceptable ranges of AASHTO T 22 / ASTM C 39 have been challenged by a recent National Cooperative Research Program (NCHRP) Project 9-26A (11). The NCHRP research found that the acceptable range of two test results for 4 in. X 8 in. cylinders is 12.1 percent for single-operator precision. This 12.1 percent limit is also shown in Figures 28 through 33 for reference.

Adjusting Average Compressive Strength for Outliers

Data in this research show that ranges in individual compressive strength test results of companion cylinders is influenced by aggregate type and cementitious materials. Ranges of individual compressive strength results of companion specimens of all 7, 14, 28, and 56 day cylinder sets were evaluated. Individual cylinder test results of sets of companion cylinders that caused the range between the minimum and maximum strengths to exceed the acceptable range were considered outliers and removed. In these cases, the average compressive strength of the set is the average of two cylinders in lieu of three cylinders. A summary of these companion cylinder outliers is presented in Table 33. These outliers were removed and not included in the average calculation for the set of cylinders unless noted in the next paragraph.

There were 6 sets of companion cylinders that exceeded the acceptable range, but were not removed from the average for the set. These are noted in Table 33 with an "X". These individual tests remain in the average for the set because taking these out would cause the strength versus age curve of the data set to be erratic. For example, taking an individual test out of the set may cause the 14 day strength to be higher than the 28-day for the mix. Therefore, engineering judgment was used in these cases to determine whether or not an individual test was

used in the average for the strength results. Table 33 also provides the revised calculation of range percent if applicable.

Table 33 - Summary of Outliers Removed

	7 Day					14 Day					28 Day					56 Day				
Mix No.	A	B	C	Strength Discarded	Range (%)	A	B	C	Strength Discarded	Range (%)	A	B	C	Strength Discarded	Range (%)	A	B	C	Strength Discarded	Range (%)
Mix 1																				
Mix 2																				
Mix 3		3080	3200	2850	3.8	3670	3760		3360	2.4	4090	3730		3520	8.8					
Mix 4						4230		4090	3760	3.3										
Mix 5						3100		3290	2850	5.8						3510		3880	4340	9.5
Mix 6							2950	3020	2640	2.3	3420	3300		3890	3.5					
Mix 7																	5300	5560	4780	4.7
Mix 8	3340	2810	3240	X	15.9							3840	4180	3310	8.1		4350	4480	3620	2.9
Mix 9							3030	3050	3450	0.7	3600	3460		3220	3.9					
Mix 10																				
Mix 11																				
Mix 12																				
Mix 13																				
Mix 14																	4300	4410	3930	2.5
Mix 15												4370	4220	3860	3.4	4350	4160	4650	X	10.5
Mix 16		4410	4270	3720	3.2		4330	4680	3950	7.5										
Mix 17						3580	3670		3120	2.5										
Mix 18	3090		2940	3280	4.9												4360	3960	3690	9.2
Mix 19							4120	4490	3670	8.2										
Mix 20	3330		3340	2970	0.3	3530	3550		3140	0.6						4320		4360	3720	0.9
Mix 21																4570		4180	3720	8.5
Mix 22																				
Mix 23																				
Mix 24																				
Mix 25																				
Mix 26						3570		3450	3190	3.4	3830		3800	4380	0.8	4020		4280	3630	6.1
Mix 27												4000	3760	3400	6.0					
Mix 28																				
Mix 29	3570	3620		3170	1.4															
Mix 30																				
Mix 31		4010	3920	3530	2.2															
Mix 32																4380	5060		4150	13.4
Mix 33																				
Mix 34																				
Mix 35																				
Mix 36	4670	4950		4400	5.7															
Mix 37											4690		4430	4960	5.5					
Mix 38																				
Mix 39												3530	3740	4080	5.6		4260	4620	3870	7.8
Mix 40																				
Mix 41						3570	3360		3050	5.9	3740		4130	4840	9.4		4260	4150	4750	2.6
Mix 42	2820	2560		2300	9.2												4690	4470	5090	4.7
Mix 43																				
Mix 44		2870	3060	2630	6.2							3980	3740	3460	6.0	4230		4130	4910	2.4
Mix 45		2380	2480	2770	4.0	3130	3120		2750	0.3						4240	4540		3790	6.6
Mix 46																				
Mix 47																				
Mix 48											6380	6320		7250	0.9					

Table 33 - Summary of Outliers Removed (Continued)

	7 Day					14 Day					28 Day					56 Day				
Mix No.	A	B	C	Strength Discarded	Range (%)	A	B	C	Strength Discarded	Range (%)	A	B	C	Strength Discarded	Range (%)	A	B	C	Strength Discarded	Range (%)
Mix 49																				
Mix 50		3080	2850	2690	7.5						4600		4490	4040	2.4					
Mix 51							3570	3590	3970	0.6										
Mix 52							4490	3920	4850	12.7		4500	4730	5110	4.9					
Mix 53	3220	3290		2940	2.1	3370	3350		3860	0.6							5170	4600	4370	11.0
Mix 54																				
Mix 55	4040		3710	3360	8.2							4610	4640	5340	0.6	5040	5230		6110	3.6
Mix 56		2570	2460	2890	4.3											5150		5160	4630	0.2
Mix 57		2350	2380	2660	1.3															
Mix 58																				
Mix 59																				
Mix 60																				
Mix 61												4160	4090	4570	1.7					
Mix 62	2760	2770		3490	0.4															
Mix 63																				
Mix 64							4310	4130	3800	4.2	4510	4700	3900	X	17.0					
Mix 65	2740	2750		3200	0.4	2820		3060	3480	7.8										
Mix 66																	4060	4360	3870	6.9
Mix 67						3930		3810	4240	3.1										
Mix 68	3000		3000	3410	0.0															
Mix 69	2840		2930	2620	3.1	3290	2940	2820	X	14.3		4310	4160	3750	3.5					
Mix 70																				
Mix 71																				
Mix 72																				
Mix 73		4380	4320	3720	1.4						4420		4910	4360	10.0					
Mix 74						4150	3930	4400	X	10.7										
Mix 75											3810		3890	4250	2.1	4750		4780	4280	0.6
Mix 76																				
Mix 77																				
Mix 78											4460	4290		3920	3.8					
Mix 79	3860		3990	3520	3.3	4350	4670	4880	X	10.9						5700		5770	4970	1.2
Mix 80																				
Mix 81	2640		2720	2950	2.9	3550		3700	3310	4.1										
Mix 82																				
Mix 83																				
Mix 84																				

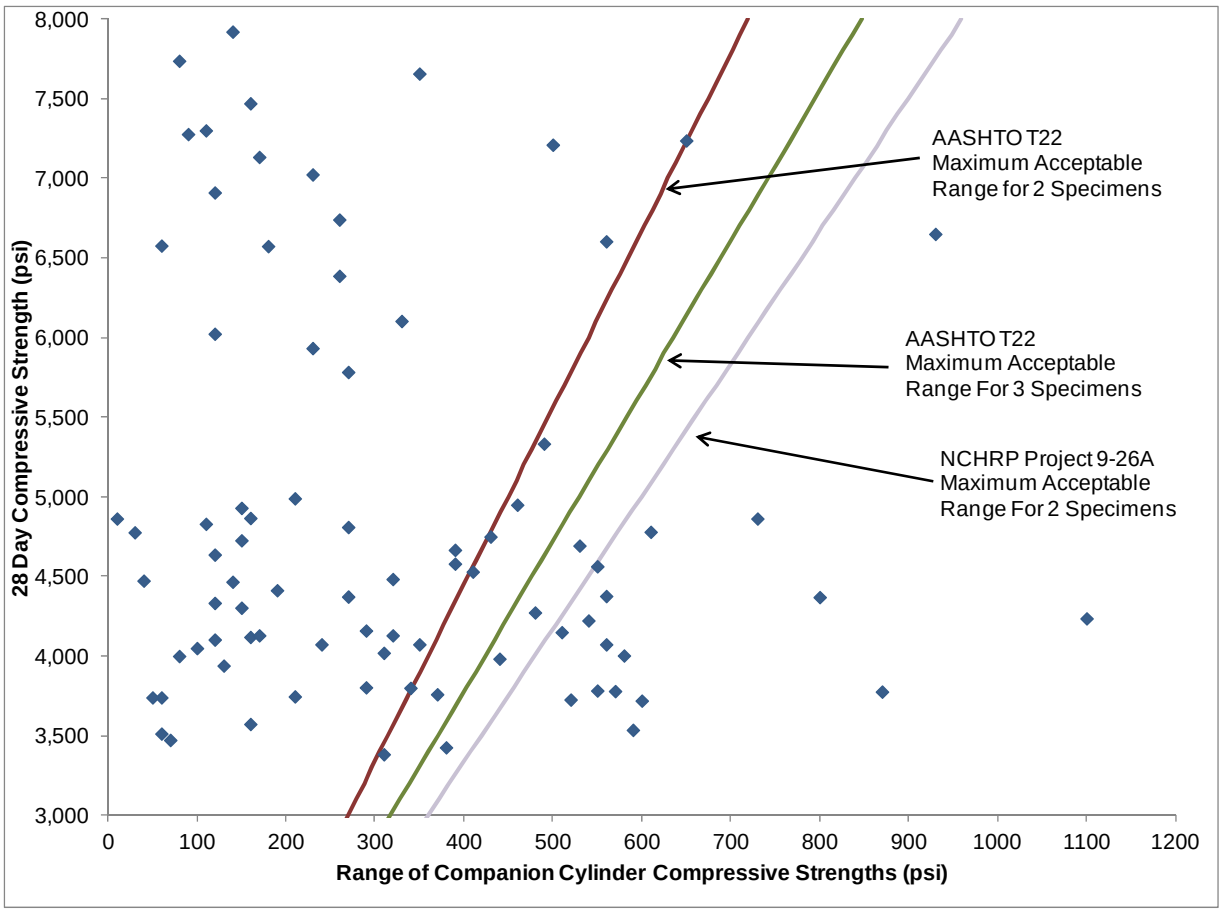

Figure 28 – 28-Day Companion Cylinder Strength Ranges for All Mixes Before Removing Outliers

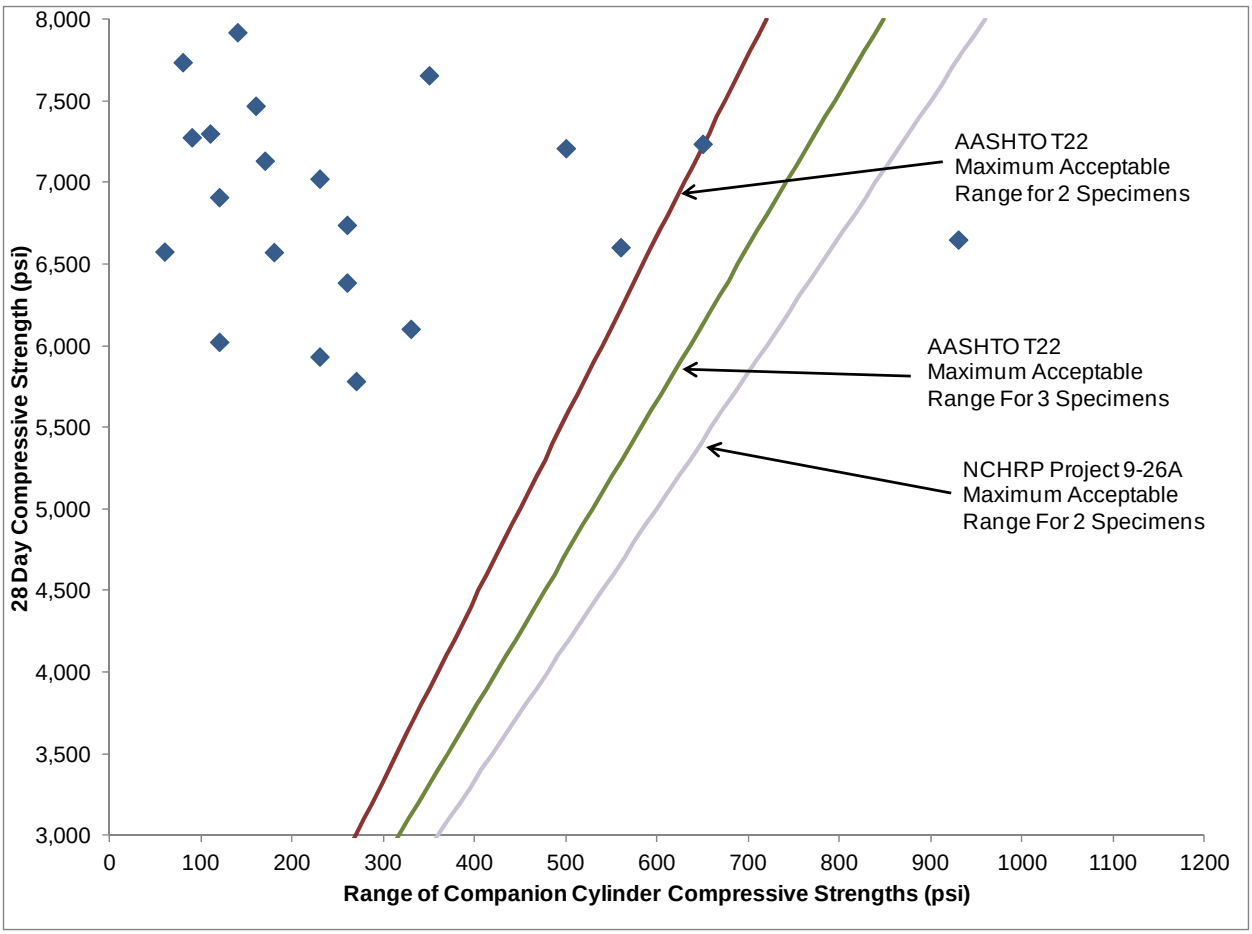

Figure 29 - 28-Day Companion Cylinder Strength Ranges for All Crushed Limestone Mixes Before Removing Outliers

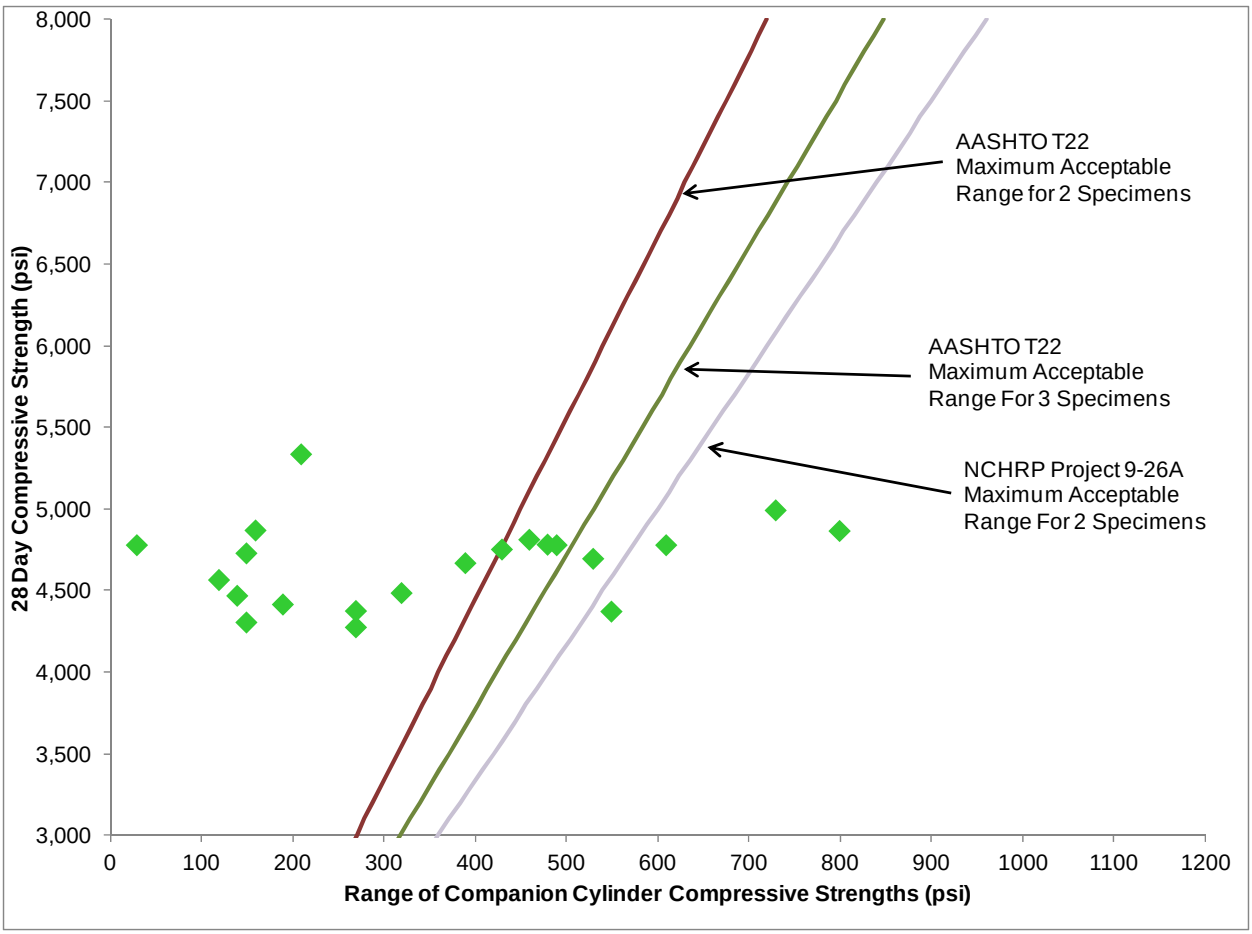

Figure 30 - 28-Day Companion Cylinder Strength Ranges for Gravel Aggregate Concrete Mixes (100) Before Removing Outliers

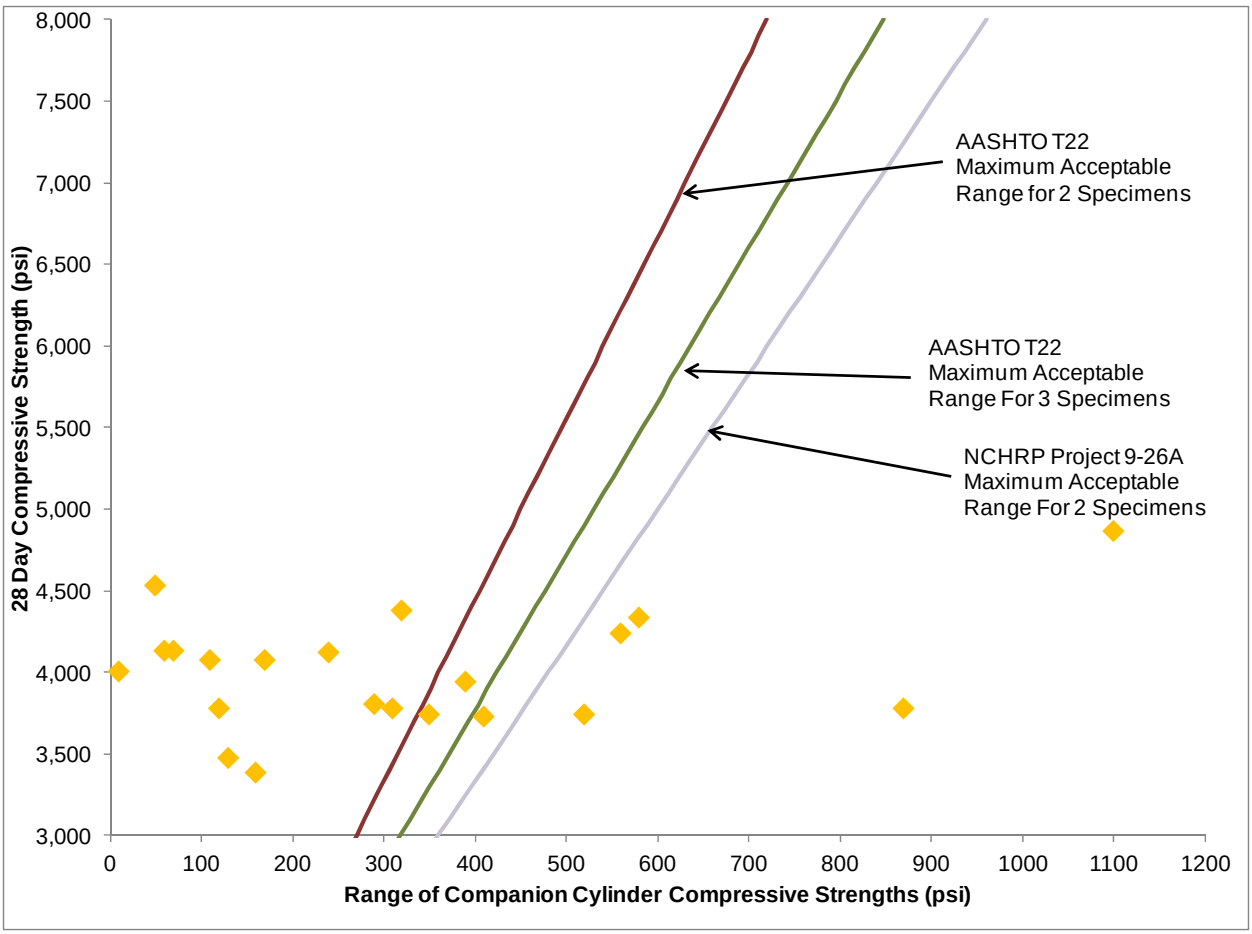

Figure 31 - 28-Day Companion Cylinder Strength Ranges for Gravel Aggregate Concrete Mixes (75/25C) Before Removing Outliers

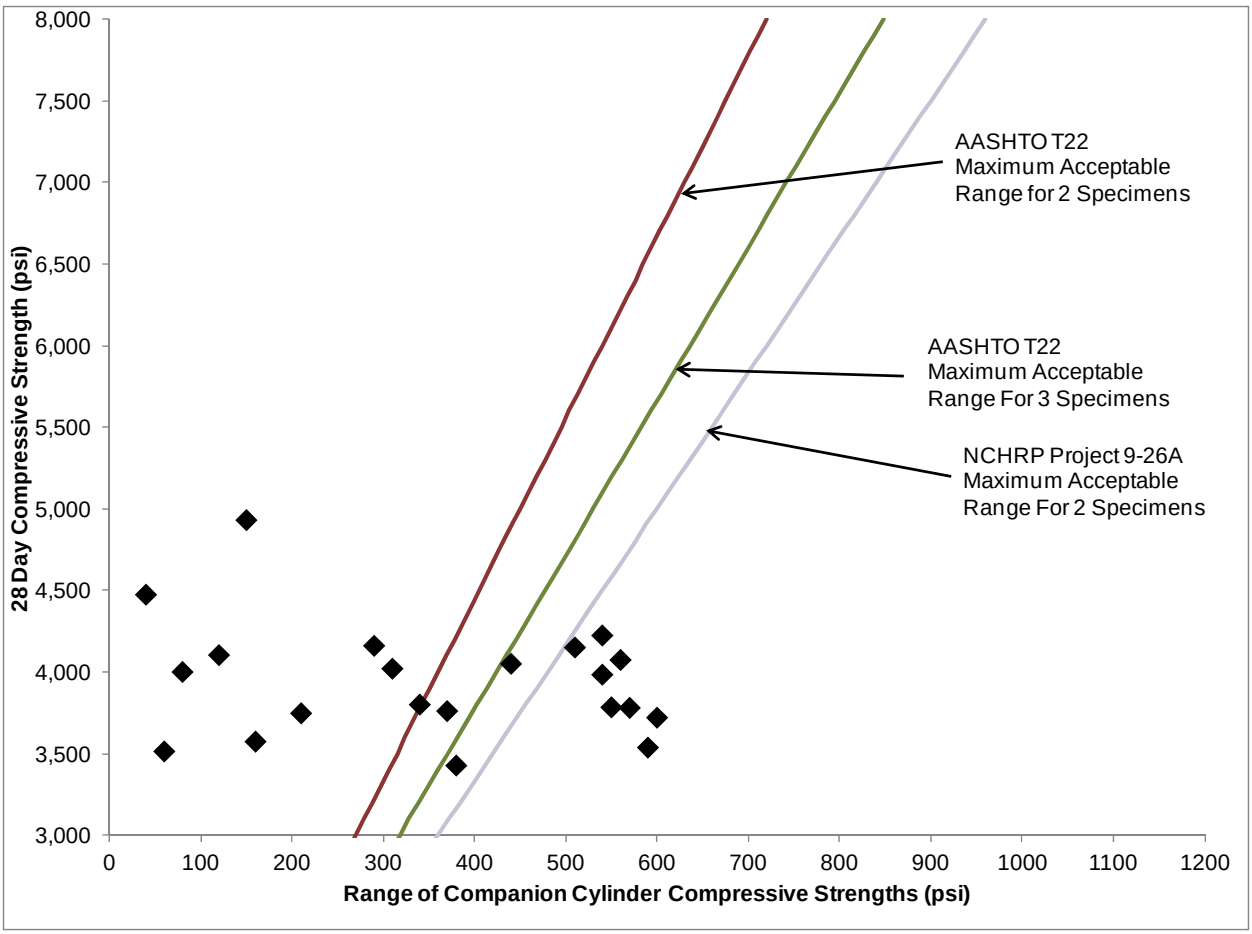

Figure 32 - 28-Day Companion Cylinder Strength Ranges for Gravel Aggregate Concrete Mixes (75/25F) Before Removing Outliers

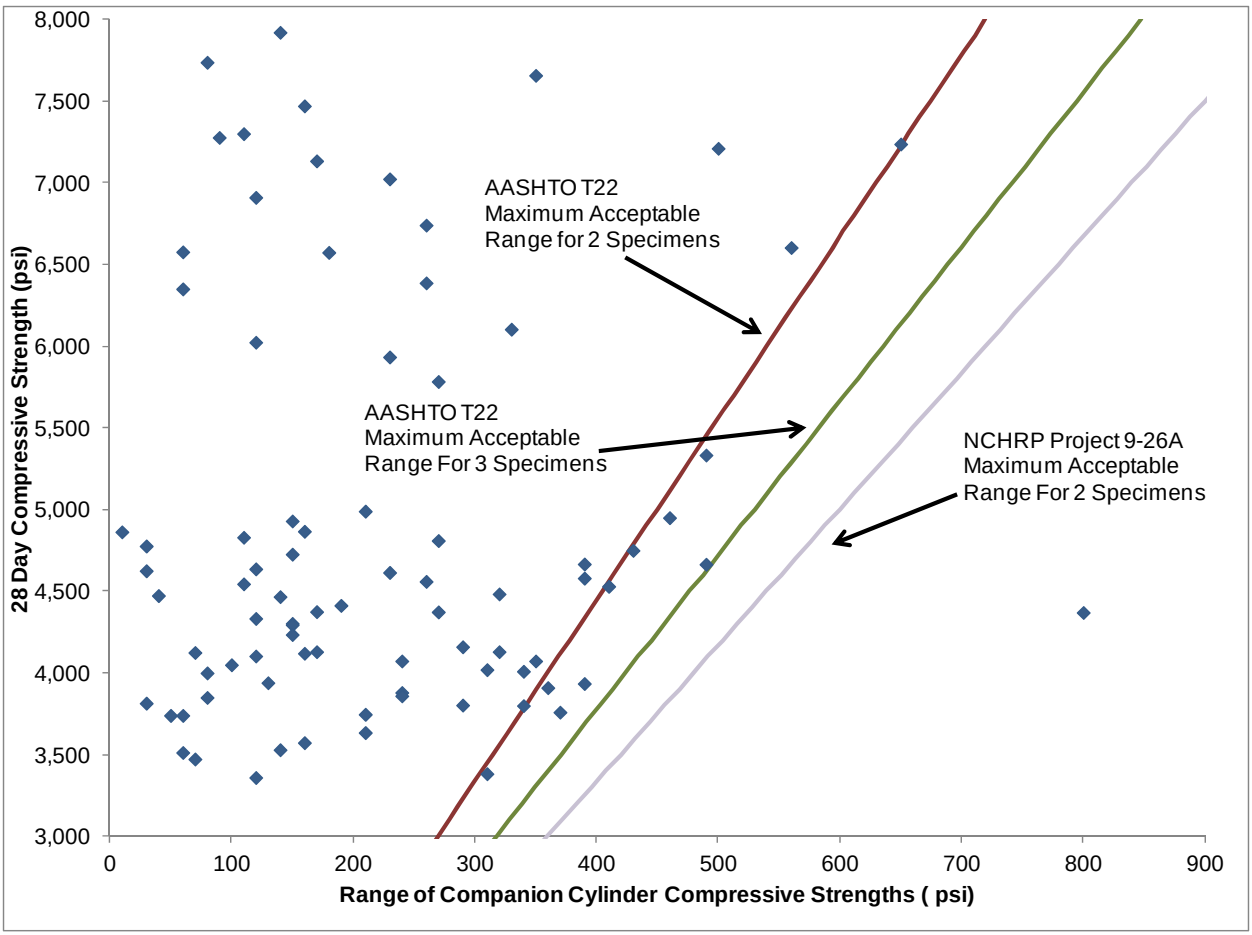

Figure 33 – 28-Day Companion Cylinder Strength Range After Removing Outliers

Mix 74 (Gravel E1 75/25C) – Possible Outlier

The 28-day compressive strength of mix 74 (Gravel E1 75/25C) was lower than the 14 day compressive strength. The compressive strength versus age for this mix is presented in Figure 20. The 28-day companion cylinders were within the acceptable range. None of the 28-day companion cylinders could either be averaged with another cylinder or used individually to change these erratic results. In addition, removing individual test results from the 14 day or the 56 day set of cylinders would not correct this erratic compressive strength. Therefore, all individual test results from mix 74 are included in average compressive strength of this mix. Figures that show compressive strength data for mix 74 are noted with "possible outlier." These figures include Figures 20, 39, and 41.

Comparison of Average Compressive Strength Data From Each Cement Source

General

Compressive strengths from mixes made with each of the three samples of cement that were taken approximately one month apart were compiled and the average compressive strength was determined for each mix category, i.e., 100% Cement (100), 75% Cement and 25% Class C fly ash (75/25C), and 75% Cement and 25% Class F fly ash (75/25F). There were seven cements used in this study including three types; Type I, II, and IL. Average compressive strength verses age graphs were then developed to show the performance of each of the seven cements with respect to compressive strength. These data are presented in Figures 34 through 36. Crushed limestone mixes shown in these tables were established as control mixes, but were proportioned with only the first month's sample of each cement. The crushed limestone data represents average compressive strength results from each of the seven cements.

100 Percent Cement (100)

Average compressive strength results for all mixes that were proportioned with 100% cement are presented in Figure 34. The highest average 28-day compressive strength made with gravel aggregates was 4,890 psi and this mix used Cement D (Type II). The lowest average 28-day compressive made with gravel aggregates was 4,418 psi and this mix used Cement A (Type II). The highest average gravel aggregate 28-day compressive strength in this category of mixes was 70.7 percent of the average crushed limestone control mixes. The lowest average gravel aggregate 28-day compressive strength in this category of mixes was 69.9 percent of the control mixes. The range between the highest and lowest 28-day compressive strength of gravel aggregate concrete is 472 psi. This range is 10.2 percent of the average 28-day compressive strength of all mixes made with gravel aggregates and 100 percent cement. Therefore, a cement source change can change the 28-day compressive strength by 10.2 percent when using 100% cement. Cement E (Type IL) had the highest average 56 day compressive strength.

75 Percent Cement and 25 Percent Class C Fly Ash (75/25C)

Average compressive strength results versus age of all mixes that were proportioned with 75% cement and 25% Class C fly ash are presented in Figure 35. The highest average 28-day compressive strength made with gravel aggregates was 4,450 psi and this mix used Cement E (Type IL). The lowest average 28-day compressive strength made with gravel aggregates was 3,732 psi and this mix used Cement A (Type II). The highest average gravel aggregate 28 compressive strength in this category of mixes was 59.4 percent of the average crushed limestone control mixes. The lowest average gravel aggregate 28-day compressive strength in this category of mixes was 49.9 percent of the control mixes. The compressive strength range between the highest and lowest gravel aggregate concrete mix in this category was 718 psi. This range is 17.6 percent of the average 28-day compressive strength of all mixes made with gravel aggregates and 75% cement and 25% Class C fly ash. Therefore, a cement source change can change the 28-day compressive strength by 17.6 percent when using 75% cement and 25% Class C fly ash. Cement E (Type IL) was the best performer with respect to compressive strength of these mixes proportioned with 25% Class C fly ash. Cement E (Type IL) had the highest average 56 day strength in this category.

75 Percent Cement and 25 Percent Class F Fly Ash (75/25F)

Average compressive strength results versus age of all mixes that were proportioned with 75% cement and 25% Class F fly ash are presented in Figure 36. The highest average 28-day compressive strength made with gravel aggregates was 4,277 psi and this mix used Cement C (Type I). The lowest average 28-day compressive strength made with gravel aggregates was 3,600 psi and this mix used Cement A (Type II). The highest average gravel aggregate 28 compressive strength in this category of mixes was 69.4 percent of the average crushed limestone control mixes. The lowest average gravel aggregate 28-day compressive strength in this category of mixes was 58.4 percent of the control mixes. The compressive strength range between the highest and lowest gravel aggregate concrete mixture in this category was 677 psi. This range is 17.1 percent of the average 28-day compressive strength of all mixes made with gravel aggregates and 75% cement and 25% Class F fly ash. Therefore, a cement source change can change the 28-day compressive strength by 17.1 percent when using 75% cement and 25% Class F fly ash. Cement E (Type IL) had the highest average 56 day strength.

Gravel Aggregate Concrete - 100% Cement Versus 25% Fly Ash

Average compressive strength results versus age of all gravel aggregate mixes are presented in Figure 37. In all cases, gravel aggregate mixes proportioned with either 25% Class C or Class F fly ash produce less compressive strength than gravel aggregate mixes proportioned with 100% cement. The average 28-day compressive strength results for mixes with 25% Class C were 88.1 percent of the average 28-day compressive strength of mixes proportioned with 100% cement. The average 28-day compressive strength results for mixes with 25% Class F were 85.3 percent of the average 28-day compressive strength of mixes proportioned with 100% cement.

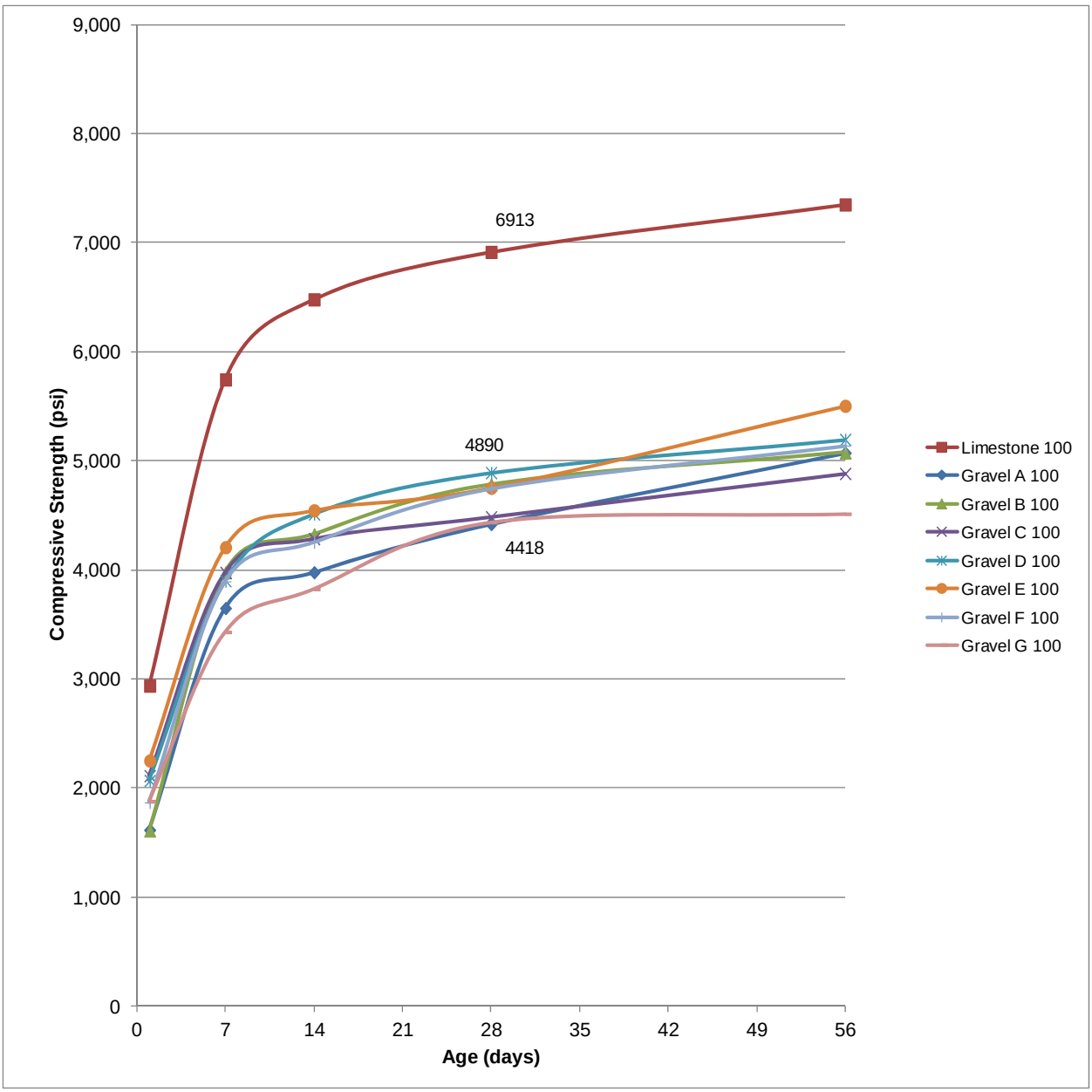

Figure 34 - Average Compressive Strength vs Age: 100

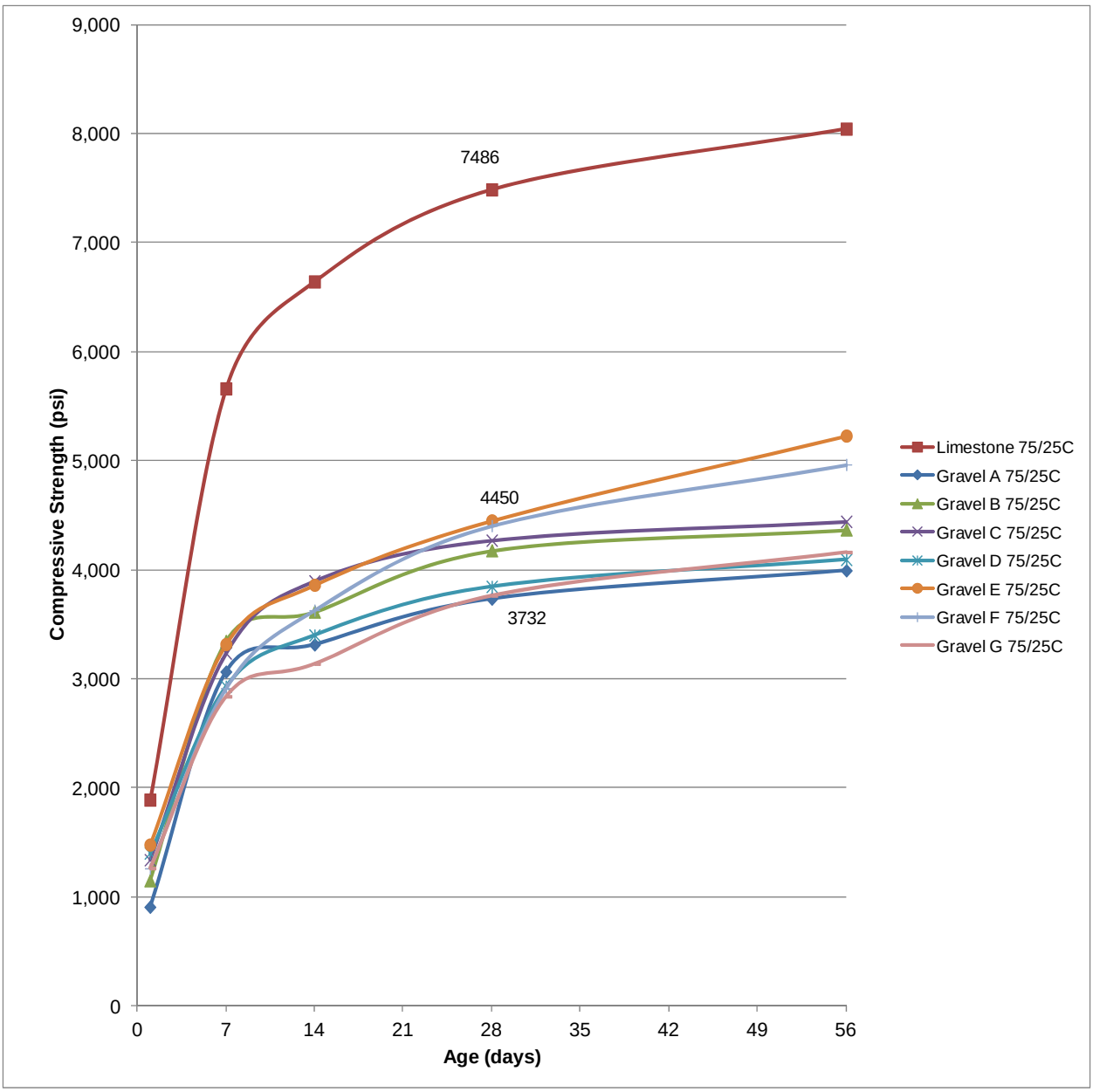

Figure 35 - Average Compressive Strength vs Age: 75/25C

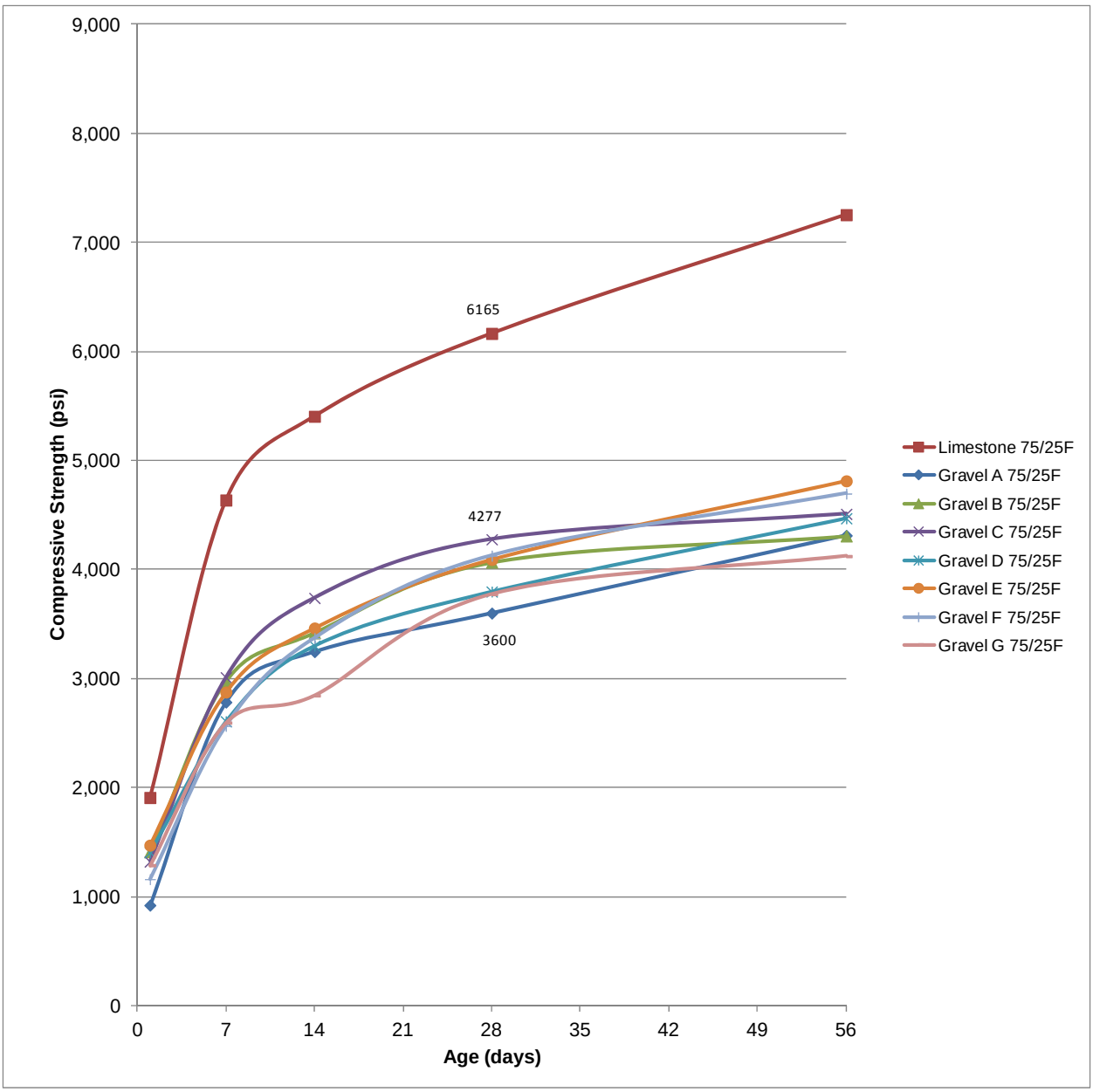

Figure 36 - Average Compressive Strength vs Age: 75/25F

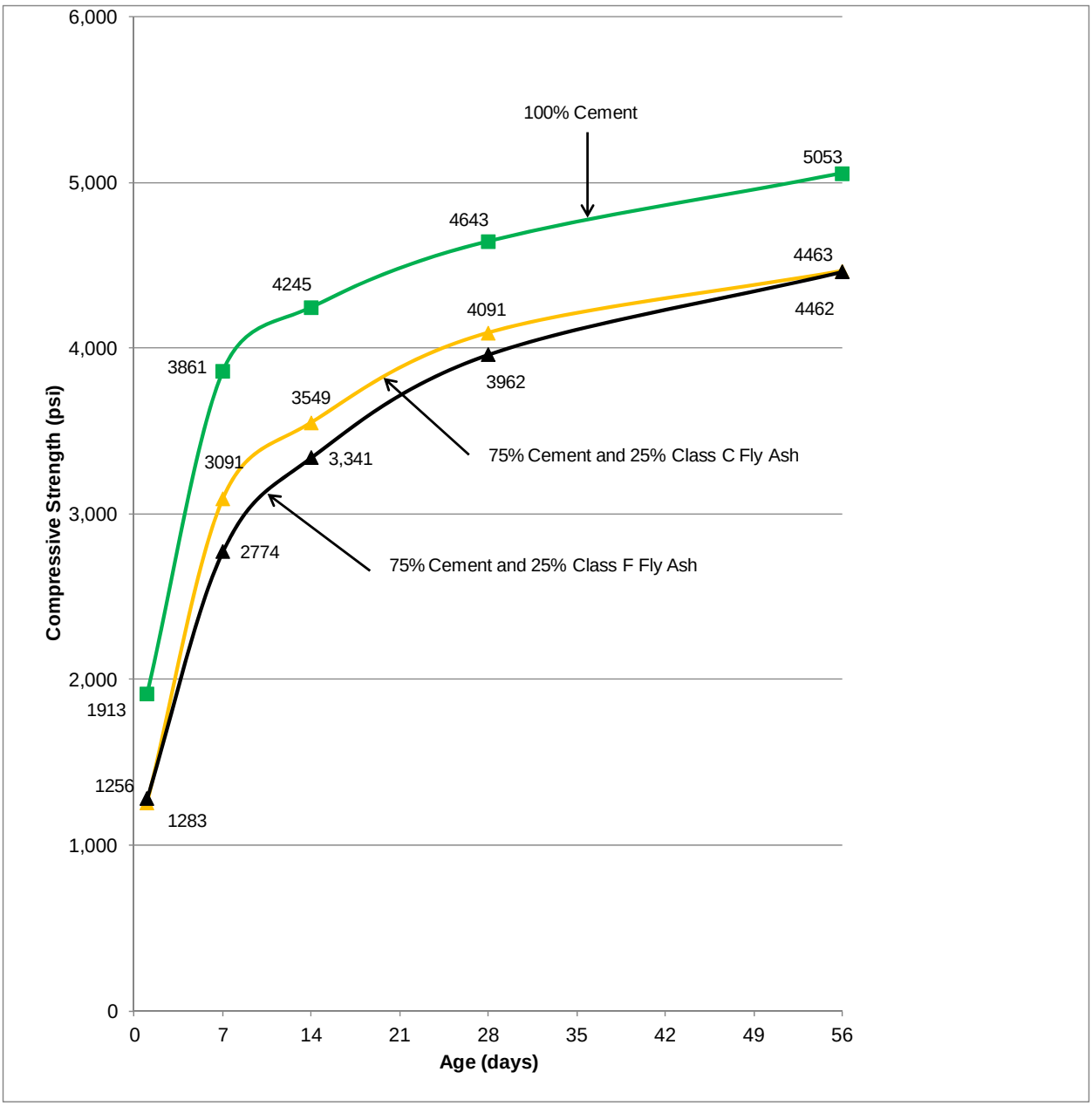

Figure 37 - Average Compressive Strength vs Age: Gravel Aggregate

Influence of Cement and Cement Sample on Compressive Strength

General

Figures 38 through 45 present 28-day compressive strength data for each mixture category as a function of cement and cement sample. These figures were developed to show compressive strength variability that can be attributed to cement source and cement sample. Each of these figures, except for Figures 41 and 45, also present 28-day mortar cube strength data developed from BCD's laboratory.

Mortar Cube Compressive Strengths

Figures 38, 39, 40, 42, 43, and 44 show that compressive strengths of mortar cubes do not always indicate concrete compressive strength tends. For example, Figures 39 and 40 show cube strength decreasing by approximately 10 percent from sample CS-C-2 to CS-C-3. The concrete strengths for these samples increased by 17.8 percent for the mixes with 75/25C and increased by 22.6 percent for mixes with 75/25 F.

Influence of Cement Source and Sample of Cement Source on Compressive Strength of Gravel Aggregate Concrete

One of the most interesting points of Figures 38 through 45 is that these figures show the extent of concrete strength variability when making concrete from the same cement, i.e., same source and same Type, but different samples. The greatest percent change in concrete compressive strength that can be attributed to different samples of the same cement was 21.6 percent. The percent change was calculated by taking the lowest compressive strength for each cement sample, subtracting the highest compressive strength for each cement sample, and then dividing by the highest compressive strength for the cement sample. This highest percent change occurred with Cement C in mixes made with 75/25C. This can be seen in Figure 39. A percent change of 21.3 was calculated for that same cement with 75/25F mixes. This can be seen in Figure 40. Similar percent change calculations were made for all test ages and all seven cements used in this research using three samples of each cement taken approximately one month apart. These percent changes are shown in Table 34. The overall average percent change for all 28-day compressive strengths of gravel aggregate concrete was 11.8 percent. Therefore, on average, one

can expect either an 11.8 percent increase or decrease in 28-day compressive strength on gravel aggregate concrete mixtures when using the same cement, but different sample.

Influence of Cement Source and Sample of Cement Source on Compressive Strength of Gravel Aggregate Concrete

Variability of concrete compressive strength increases as the cement source changes. The percent change in 28-day compressive strengths that resulted from changing cement source and sample of cement source ranged from 22.7 to 31.8 for gravel aggregate concrete. The highest percent change for 28-day compressive strength was in mixes proportioned with 75/25F. The next highest percent change was in mixes made with 75/25C. Percent change in average compressive strength of gravel aggregate concrete made from three different samples from seven different cements is tabulated in Table 35.

There was less variability in the percent change in compressive strength when results of each of the three samples were averaged together and that average is used to compare compressive strength results between cement sources. The percent change in 28-day compressive strengths that resulted from using these average data and comparing to other cement sources ranged from 9.7 to 16.1 for gravel aggregate concrete. The highest percent change for 28-day compressive strength was in mixes proportioned with 75/25C. The next highest percent change (15.8) was in mixes made with 75/25F. These data are presented in Table 36.

Influence of Cement Source on Compressive Strength of Crushed Limestone Aggregate Concrete

Table 37 presents the percent change in average 28-day compressive strength of crushed limestone aggregate concrete made from one sample from each of the seven cements. The percent change of compressive strength of concrete made with crushed limestone aggregate ranged from 9.9 to 12.0 percent. This percent change is much less with the crushed limestone than with the mixes made with gravel aggregates. However, only one sample of the cement from each source was used for the crushed limestone control mixes and this may account for some of the difference in percent change between gravel and crushed limestone aggregate concrete.

Influence of Cementitious Materials and Coarse Aggregate Type

Figures 41 and 45 present 28-day compressive strength versus cement source and sample number for gravel and limestone aggregate, respectfully. For gravel aggregate concrete, the 100% cement mixes performed better than the 75/25C or 75/25F mixes with respect to 28-day compressive strengths except for mixes made with cement sample number CS-C-3. Mixes made with sample number CS-C-3, when combined with 25% Class C or F fly ash, produced 28-day compressive strengths that exceeded the compressive strength of the mix made with 100% cement.

For crushed limestone aggregate concrete, all mixes made with 25% Class C fly ash exceeded the 28-day compressive strengths of mixes produce with 100% cement. All mixes made with 25% Class F fly ash produced 28-day compressive strengths that were lower than compressive strength of crushed limestone aggregate concrete made with 100% cement.

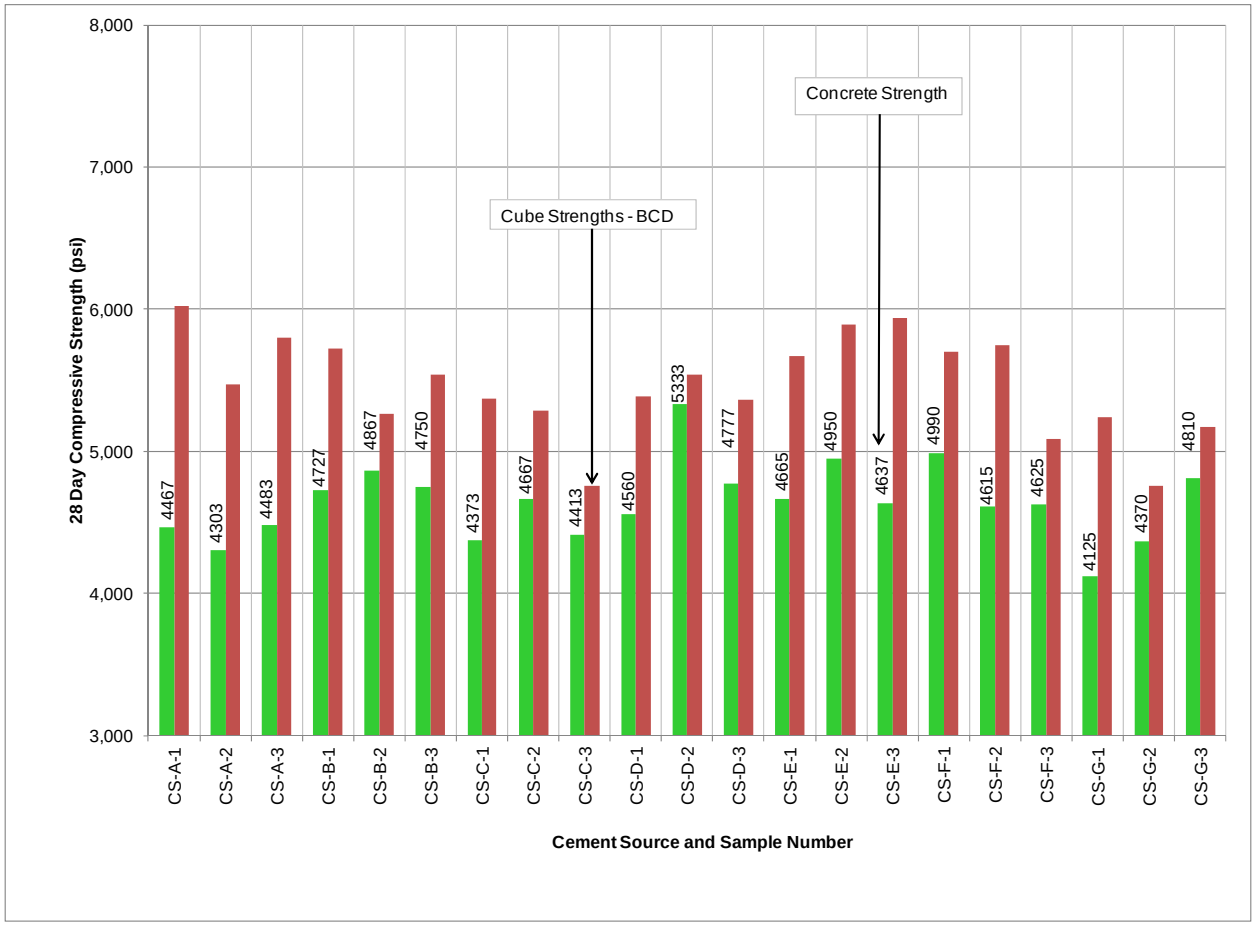

Figure 38 - Average Compressive Strength vs Cement Sample: Gravel Aggregate, 100

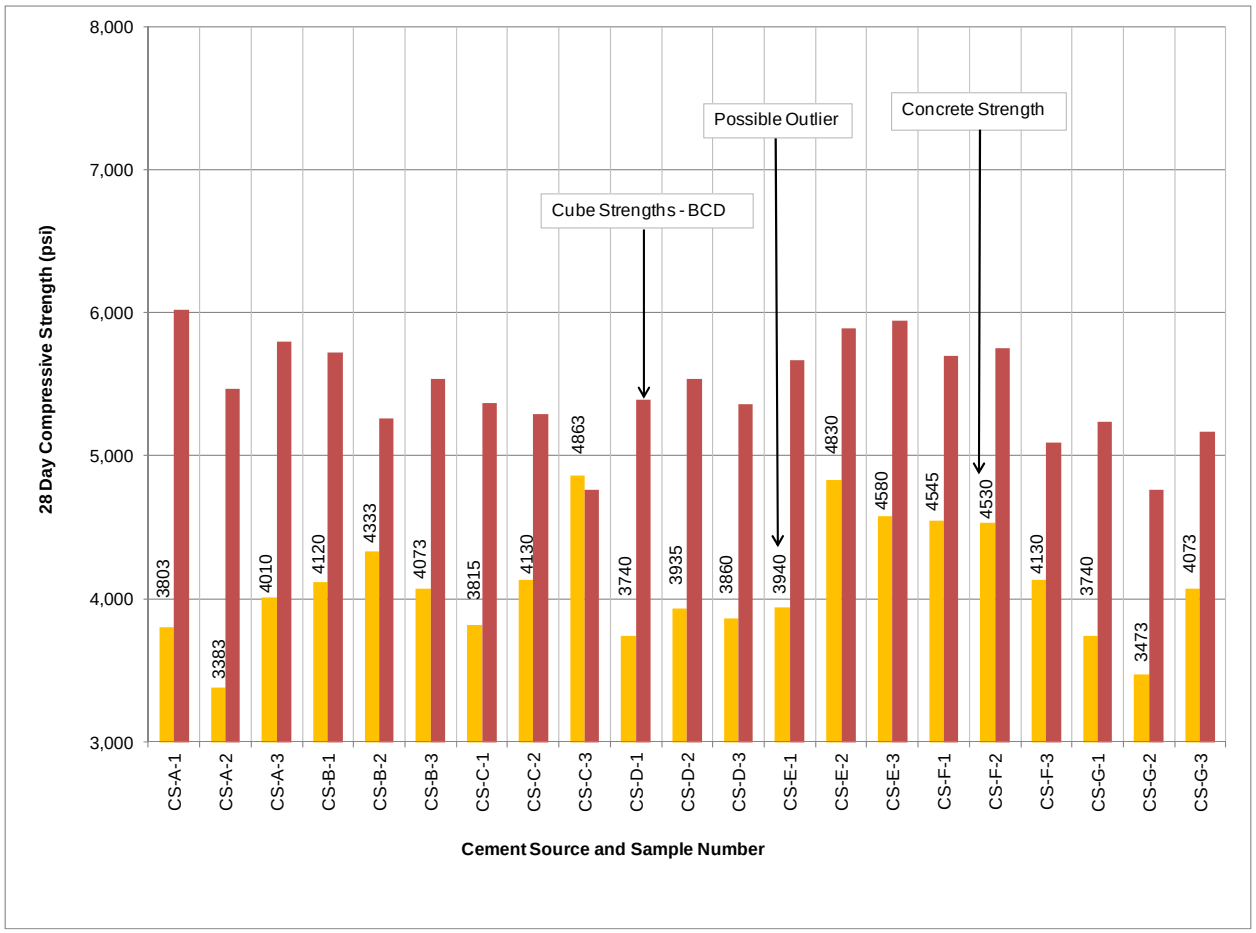

Figure 39 - Average Compressive Strength vs Cement Source: Gravel Aggregate, 75/25C

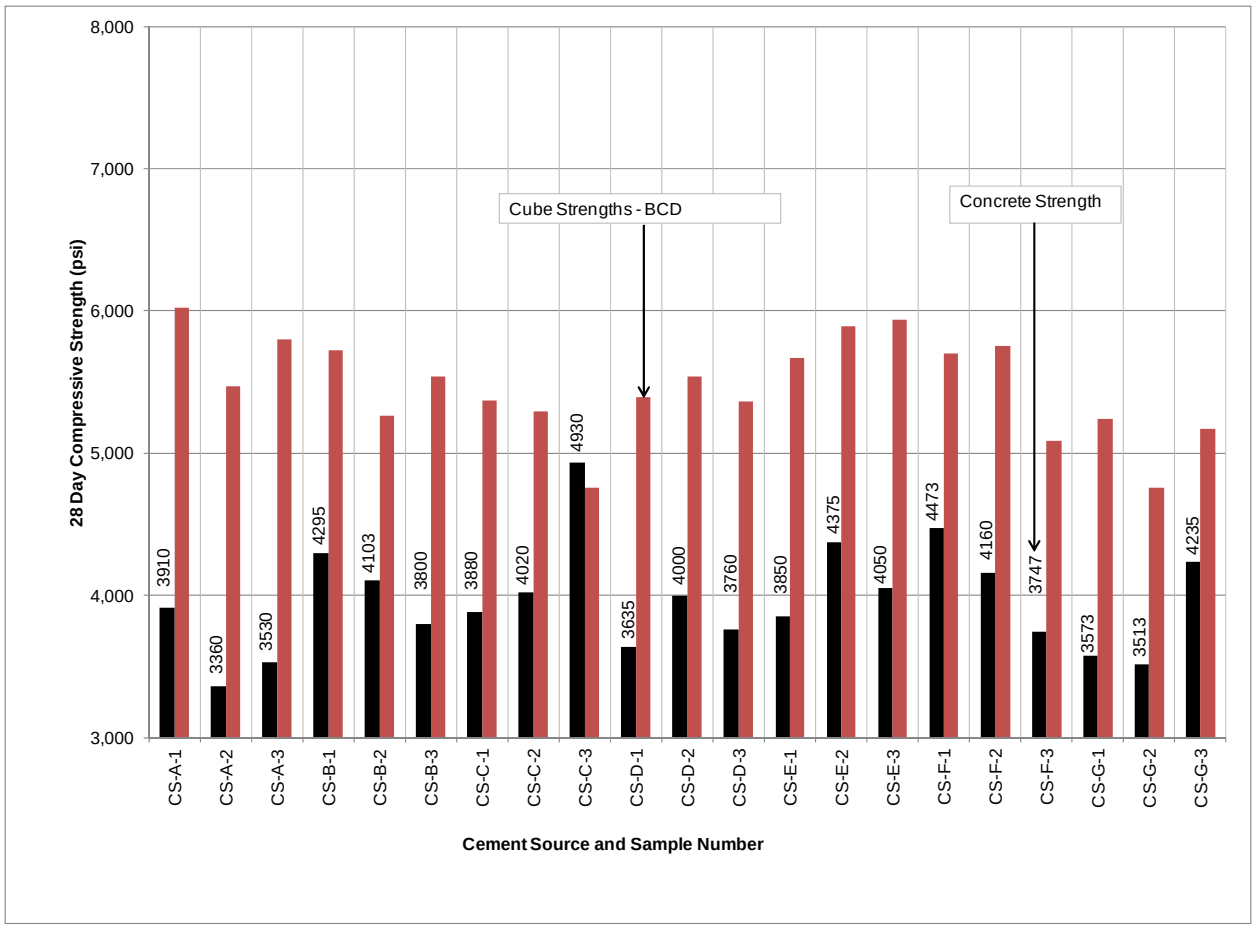

Figure 40 - Average Compressive Strength vs Cement Sample: Gravel Aggregates, 75/25F

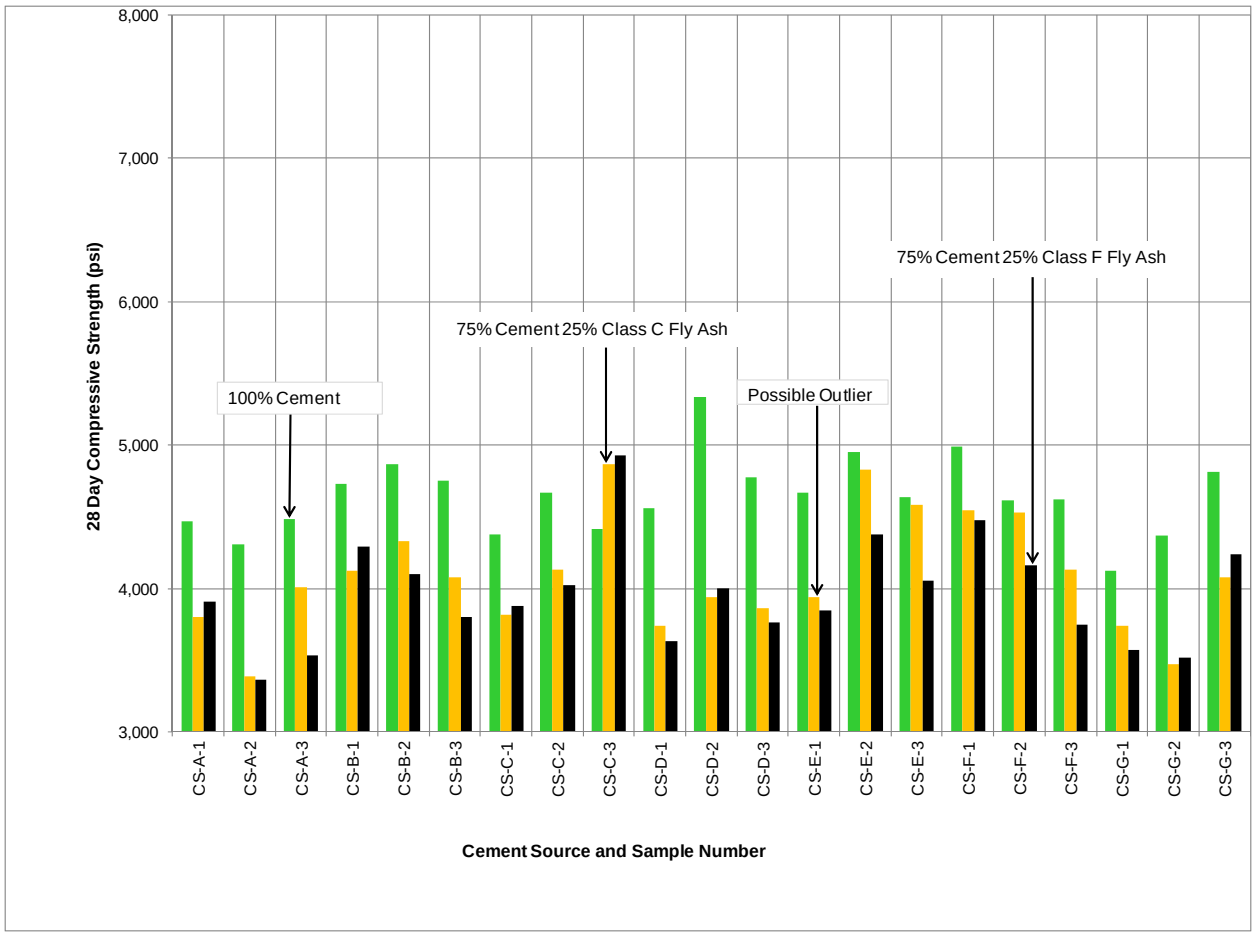

Figure 41 - Average Compressive Strength vs Cement Sample: Gravel Aggregates, All Mixes

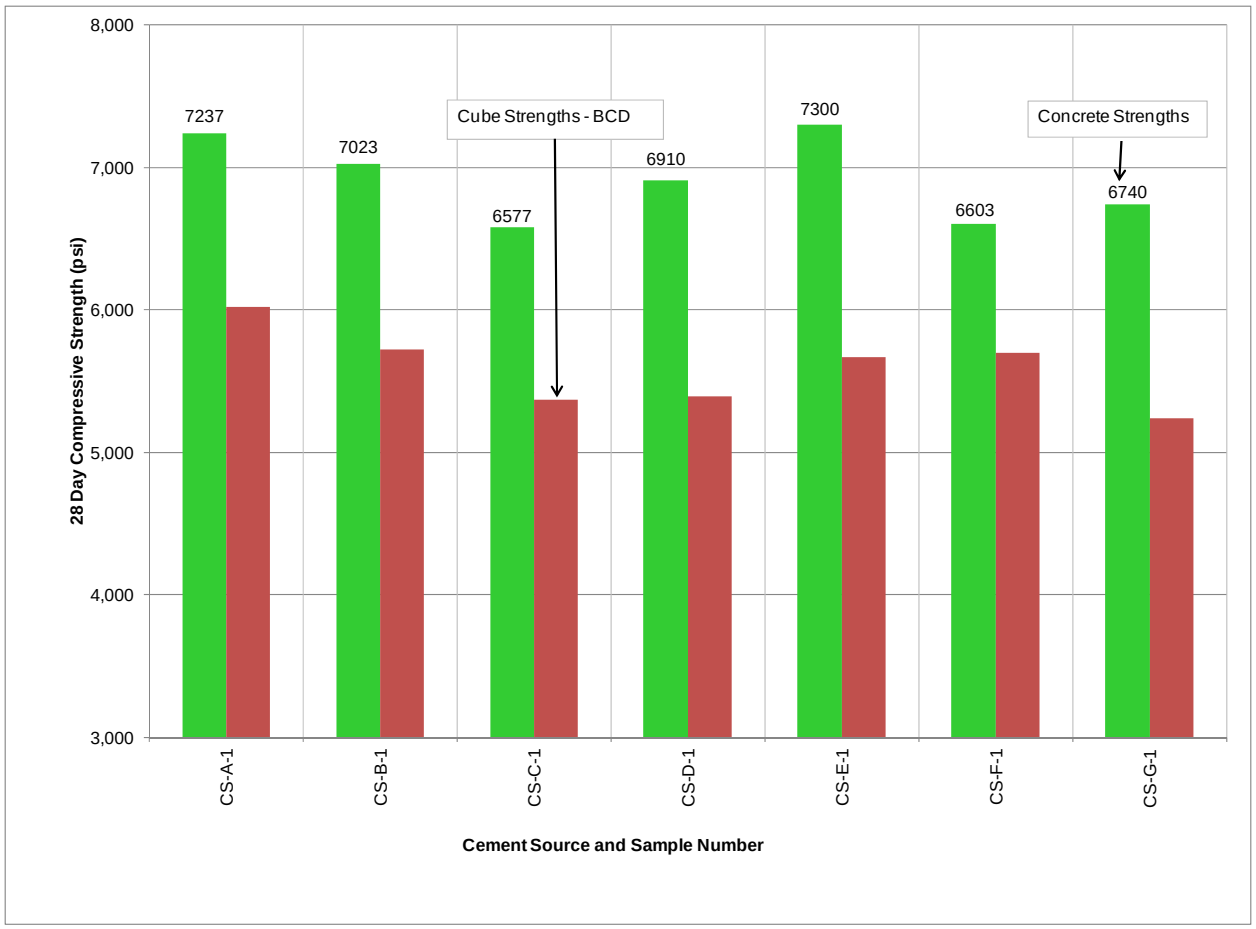

Figure 42 - Compressive Strength vs Cement Sample: Crushed Limestone Aggregates, 100

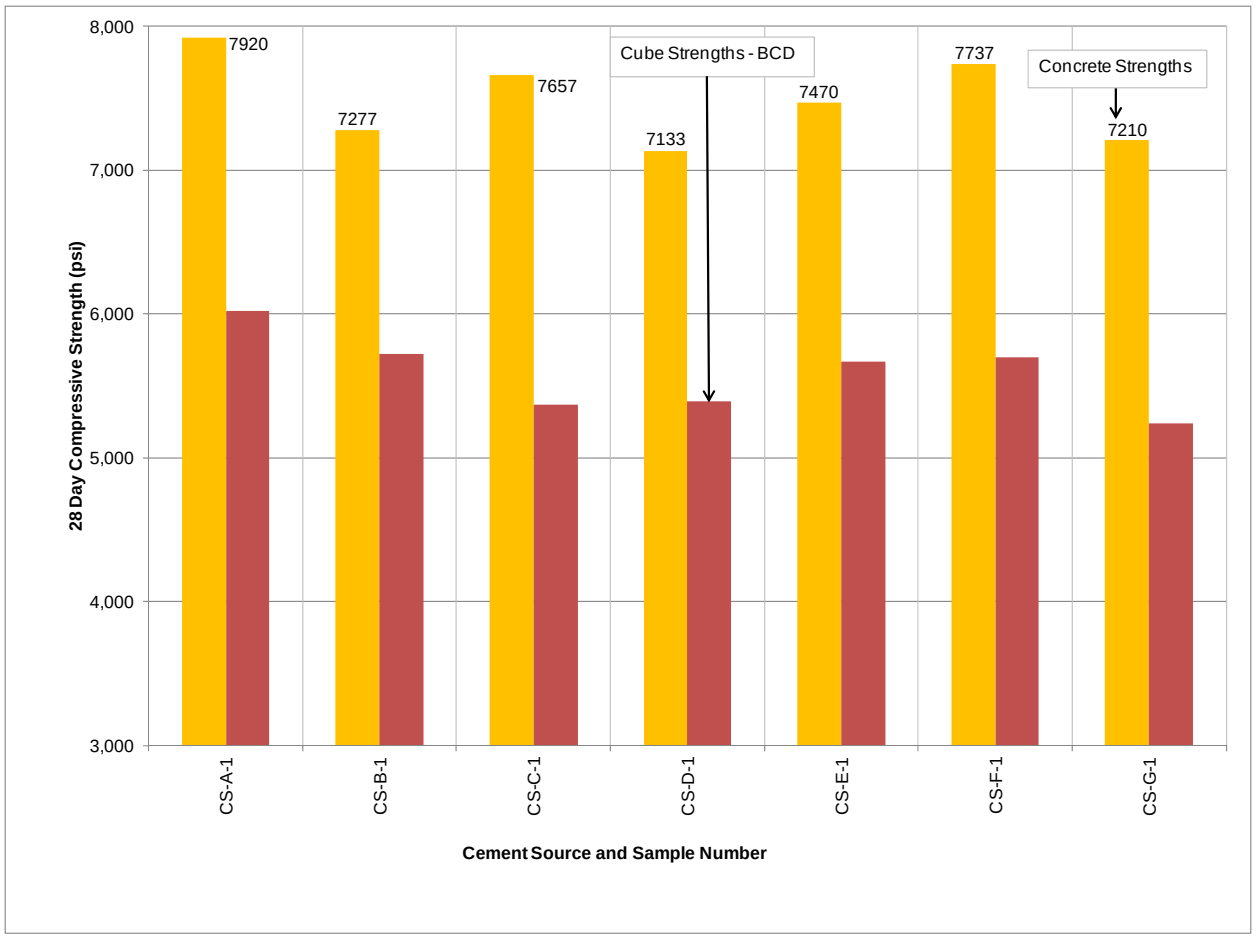

Figure 43 - Compressive Strength vs Cement Sample: Crushed Limestone Aggregates, 75/25C

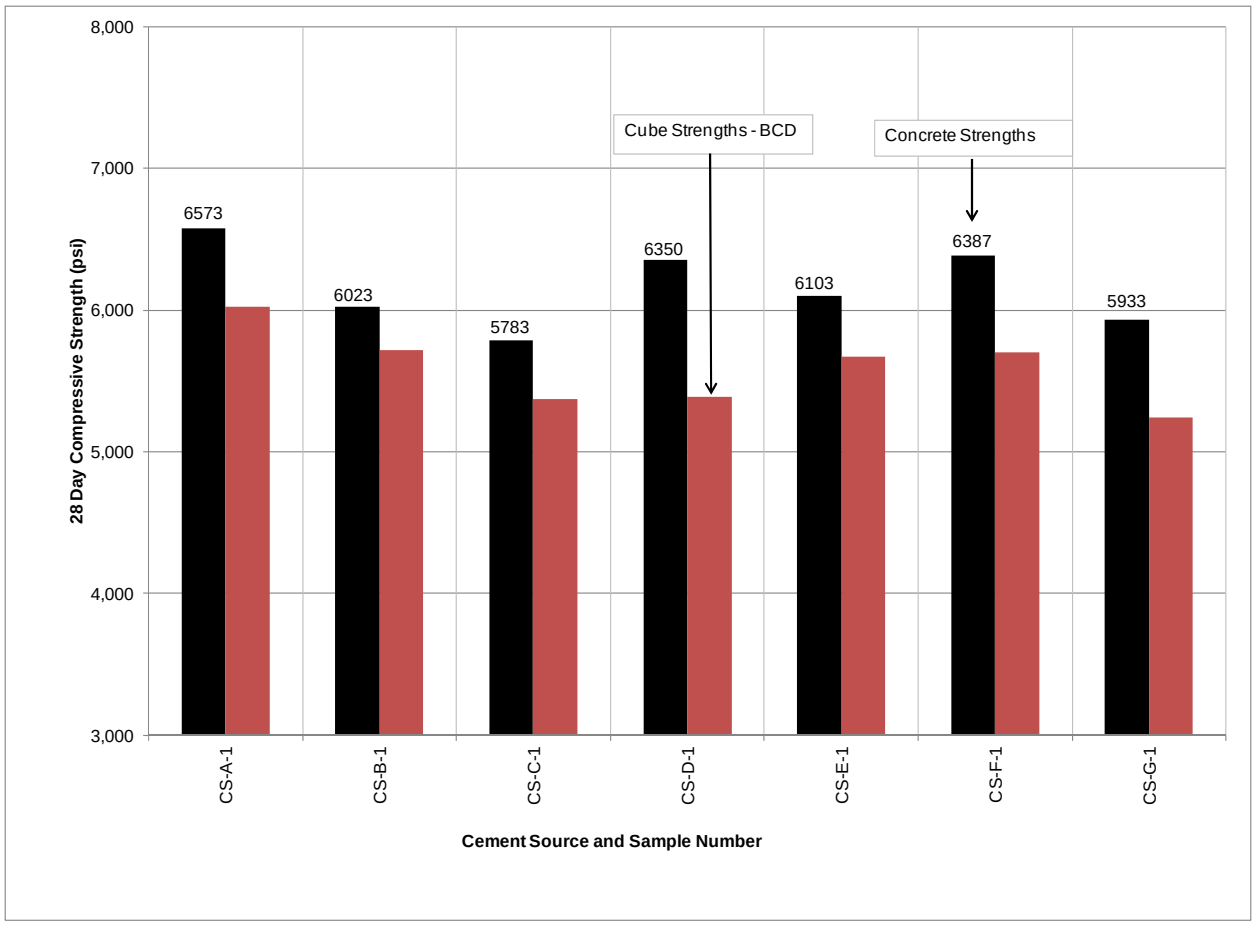

Figure 44 - Compressive Strength vs Cement Sample: Crushed Limestone Aggregates, 75/25F

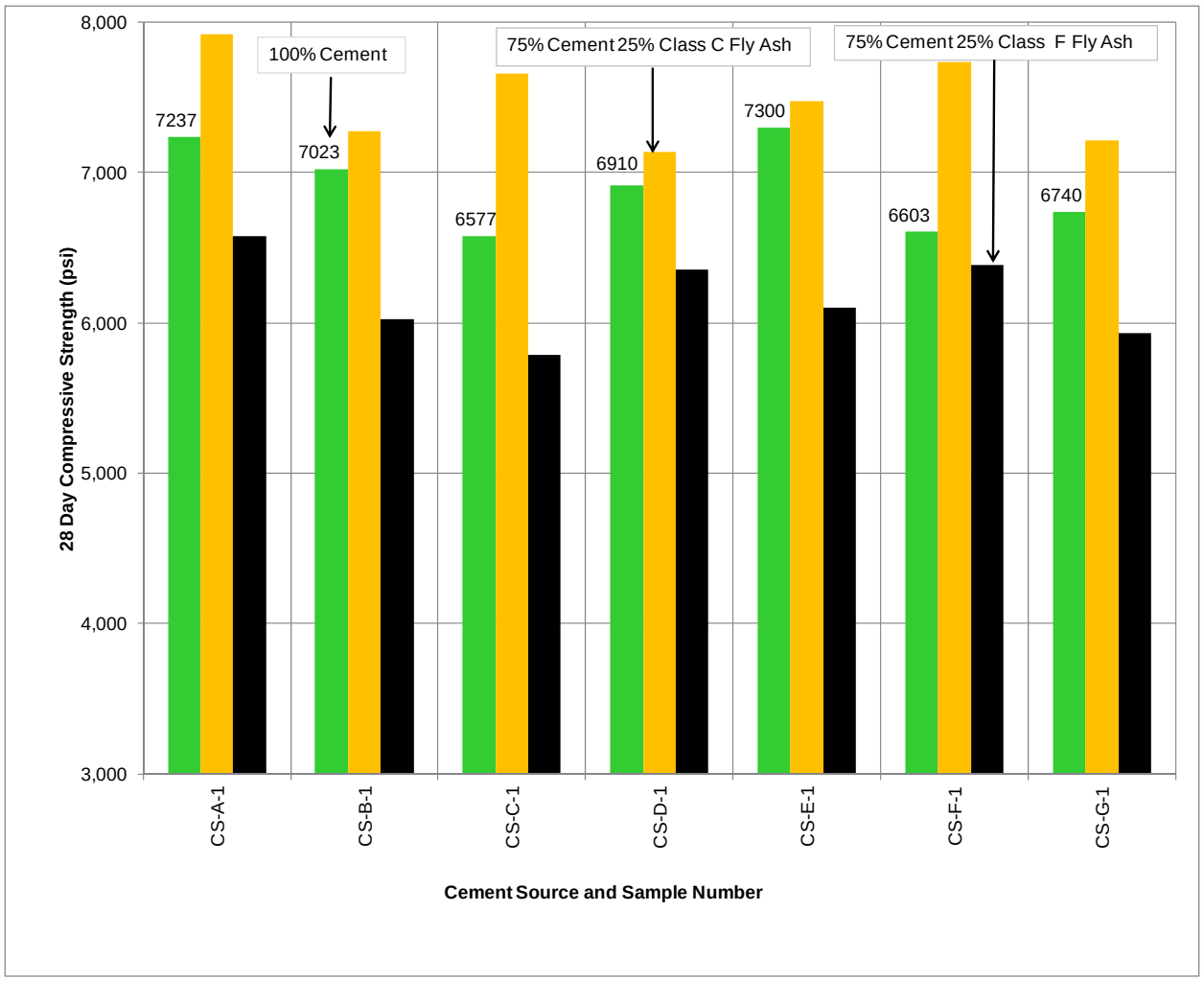

Figure 45 - Compressive Strength vs Cement Sample: Crushed Limestone Aggregates, All Mixes

Table 34 – Maximum Percent Change in Average Compressive Strength of Gravel Aggregate Concrete When Changing Cement Samples

Cement	Percent Cement	Percent Class C Fly Ash	Percent Class F Fly Ash	1 Day	7 Day	14 Day	28 Day	56 Day
A	100			-14.1	-7.3	-7.1	-4.0	-11.5
	75	25		-11.0	-9.9	-8.6	-15.6	-16.3
	75		25	-7.9	-18.6	-19.7	-14.1	-12.6
B	100			-32.7	-13.7	-7.6	-2.9	-12.6
	75	25		-20.5	-1.8	-3.7	-6.0	-1.5
	75		25	-37.9	-2.5	-10.5	-11.5	-5.2
C	100			-13.6	-13.4	-9.7	-6.3	-3.0
	75	25		-6.8	-16.2	-21.2	-21.6	-12.1
	75		25	-5.2	-7.1	-23.0	-21.3	-9.5
D	100			-13.1	-8.1	-9.7	-14.5	-7.6
	75	25		-6.5	-3.0	-8.0	-5.0	-7.5
	75		25	-10.8	-10.1	-9.4	-9.1	-4.1
E	100			-2.8	-9.8	-9.7	-6.3	-9.9
	75	25		-20.9	-19.6	-15.8	-18.4	-5.2
	75		25	-13.0	-12.5	-7.1	-12.0	-2.7
F	100			-10.4	-0.8	-3.3	-7.5	-3.0
	75	25		-9.1	-22.7	-17.4	-9.1	-5.9
	75		25	-10.5	-11.6	-10.3	-16.2	-4.1
G	100			-13.6	-10.9	-19.9	-14.2	-9.9
	75	25		-18.6	-8.5	-16.8	-14.7	-16.9
	75		25	-22.4	-17.0	-12.5	-17.0	-4.9
Average				-14.3	-10.7	-12.0	-11.8	-7.9

Table 35 - Maximum Percent Change in Average Compressive Strength of Gravel Aggregate Concrete Based on Changing Both Cement Source and Sample of Cement Source

Percent Cement	Percent Class C Fly Ash	Percent Class F Fly Ash	1 Day	7 Day	14 Day	28 Day	56 Day
100			-44.4	-26.1	-28.7	-22.7	-25.0
75	25		-49.4	-30.0	-34.1	-30.4	-30.7
75		25	-51.1	-24.7	-40.0	-31.8	-18.2

Table 36 - Maximum Percent Change in Average Compressive Strength of Gravel Aggregate Concrete based on Changing Cement Source

Percent Cement	Percent Class C Fly Ash	Percent Class F Fly Ash	1 Day	7 Day	14 Day	28 Day	56 Day
100			-28.5	-18.5	-15.9	-9.7	-18.0
75	25		-38.7	-15.2	-19.5	-16.1	-23.6
75		25	-37.4	-14.8	-23.9	-15.8	-14.3

Table 37 – Maximum Percent Change in Average Compressive Strength of Crushed Limestone When Changing Cement Source

Percent Cement	Percent Class C Fly Ash	Percent Class F Fly Ash	1 Day	7 Day	14 Day	28 Day	56 Day
100			-20.6	-12.9	-11.5	-9.9	-13.2
75	25		-38.9	-11.1	-3.7	-9.9	-11.9
75		25	-29.1	-8.9	-6.5	-12.0	-14.5

Influence of Cement Source and Cement Sample on Slump

General

The amount of water used in the research mixtures included herein was held constant at 236.88 pcy. This water content was that amount needed to produce a 3 in. slump in the trial batches used to establish mixture proportions as described in Chapter 3 "Concrete Mixtures." Measured slump ranged from a minimum of 1 ¾ to a maximum of 8 ¼ in. The magnitude of the

slump was influenced by coarse aggregate type, cement sample, and type of cementitious materials used in the mixture. Because slump varied with changes in cement source and sample, this indicates that water demand also changes with cement source and sample.

Gravel Aggregate Concrete and Slump

Figure 46 presents the influence of cement source and sample on slump of gravel aggregate concrete made with 100% cement. In general, slump changed between a range of ½ in. and 1 in. due to changes in cement samples. The greatest change in slump that can be attributed to changing cement sample for gravel aggregate concrete proportioned with 100% cement occurred when changing from sample CS-A-1 to sample CS-A-2. This slump change was 3 in. The maximum change in slump that can be attributed to changing cement source for gravel aggregate concrete proportioned with 100% cement was 3 in.

Figure 47 presents the influence of cement source and sample on slump of gravel aggregate concrete made with 75/25C. In general, slump changed between ¼ in. to 1 ½ in. due to a change in cement sample. The greatest change in slump that can be attributed to changing cement samples for gravel aggregate concrete proportioned with 75/25C occurred when changing from sample CS-E-2 to sample CS-E-3. This slump change was 2 ½ in. The maximum change in slump that can be attributed to changing cement source for gravel aggregate concrete proportioned with 75/25C was 4 ½ in.

Figure 48 presents the influence of cement source and sample on slump of gravel aggregate concrete made with 75/25F. In general, slump changed between ½ in. to 1 ½ in. due to a change in cement sample. The greatest change in slump that can be attributed to changing cement samples for gravel aggregate concrete proportioned with 75/25F occurred when changing from sample CS-A-1 to sample CS-A-2. This slump change was 3 ¾ in. The maximum change in slump that can be attributed to changing cement source for gravel aggregate concrete proportioned with 75/25F was 4 ½ in.

Figure 49 presents the influence of cement sample on all gravel aggregate concrete mixes of this research. In all cases, the slump of these mixtures increased when either Class C of Class

F fly ash was used to replace 25 percent of the cement. On average, replacing cement with 25 percent Class C fly ash increased the slump by 2 ½ in. while replacing cement with 25 percent Class F fly ash increased the slump by 1 ¾ in.

Crushed Limestone Aggregate Concrete and Slump

Only one sample of each of the seven cements was used to proportion the crushed limestone aggregate control mixtures. Figures 50 through 53 present the influence of cement source on slump of crushed limestone aggregate concrete. The greatest change in slump that can be attributed to changing cement source for crushed limestone aggregate concrete proportioned with 100% cement was 1 ¼ in. The greatest change in slump that can be attributed to changing cement source for crushed limestone aggregate concrete proportioned with 75/25C was 2 ½ in. The greatest change in slump that can be attributed to changing cement samples for crushed limestone aggregate concrete proportioned with 75/25F was 1 ½ in.

Figure 53 presents the influence of cement source on slump for all crushed limestone aggregate concrete mixes of this research. In all cases, the slump of these mixtures increased when either Class C of Class F fly ash was used to replace 25 percent of the cement. On average, replacing cement with 25 percent Class C fly ash increased the slump by 1 ¾ in. while replacing cement with 25 percent Class F fly ash increased the slump by 1 in.

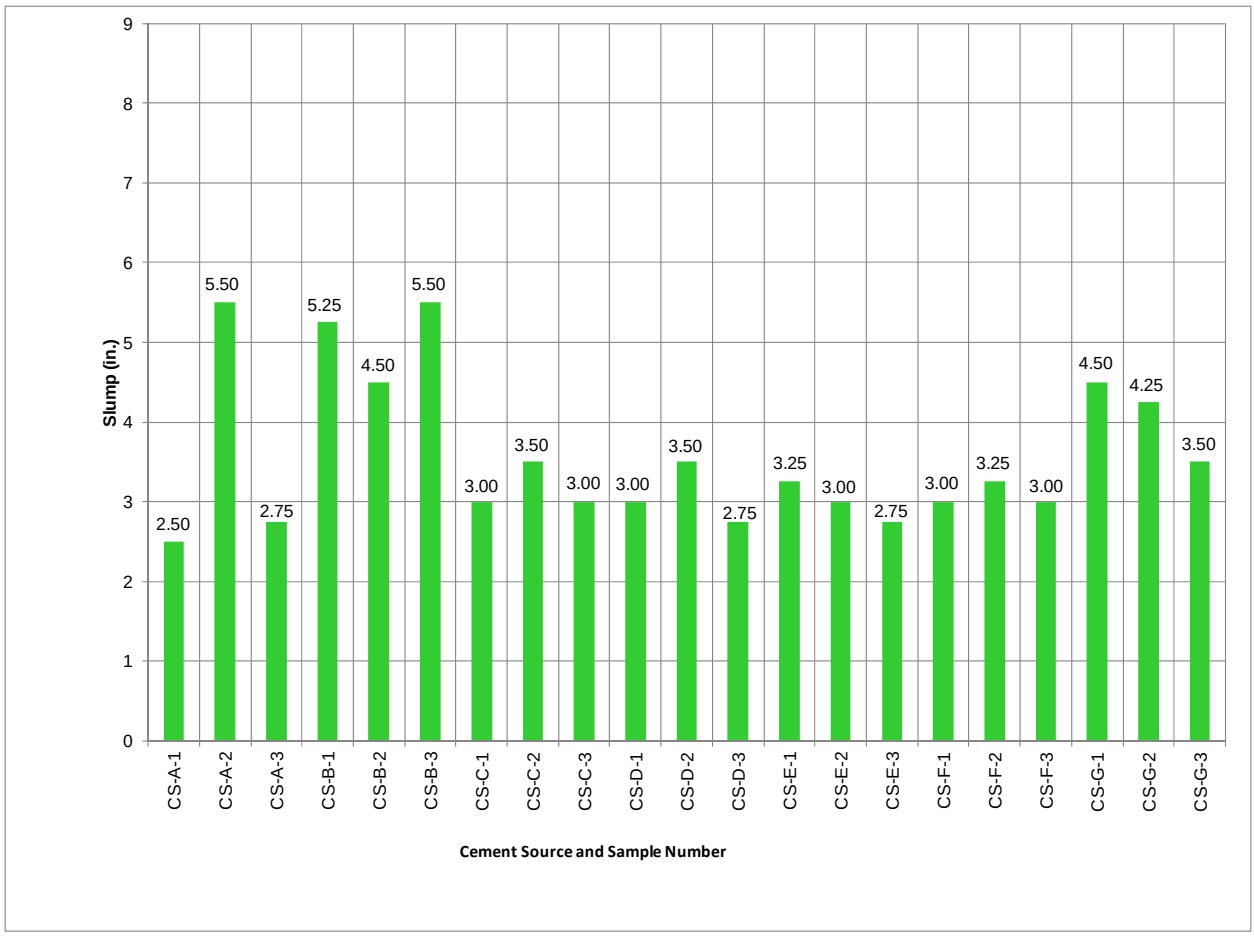

Figure 46 – Influence of Cement Source on Slump of Gravel Aggregate Concrete: 100

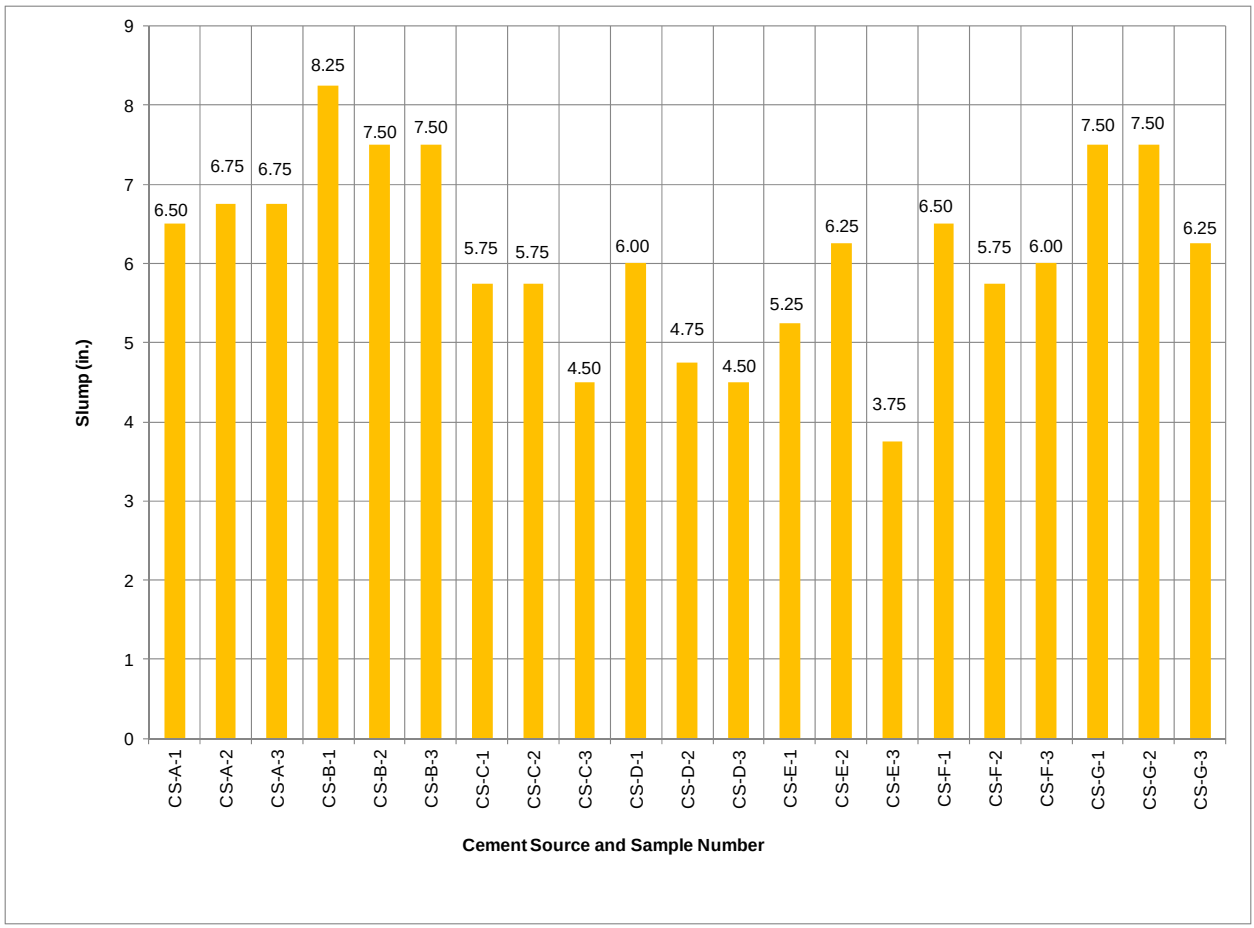

Figure 47 – Influence of Cement Source on Slump of Gravel Aggregate Concrete: 75/25C

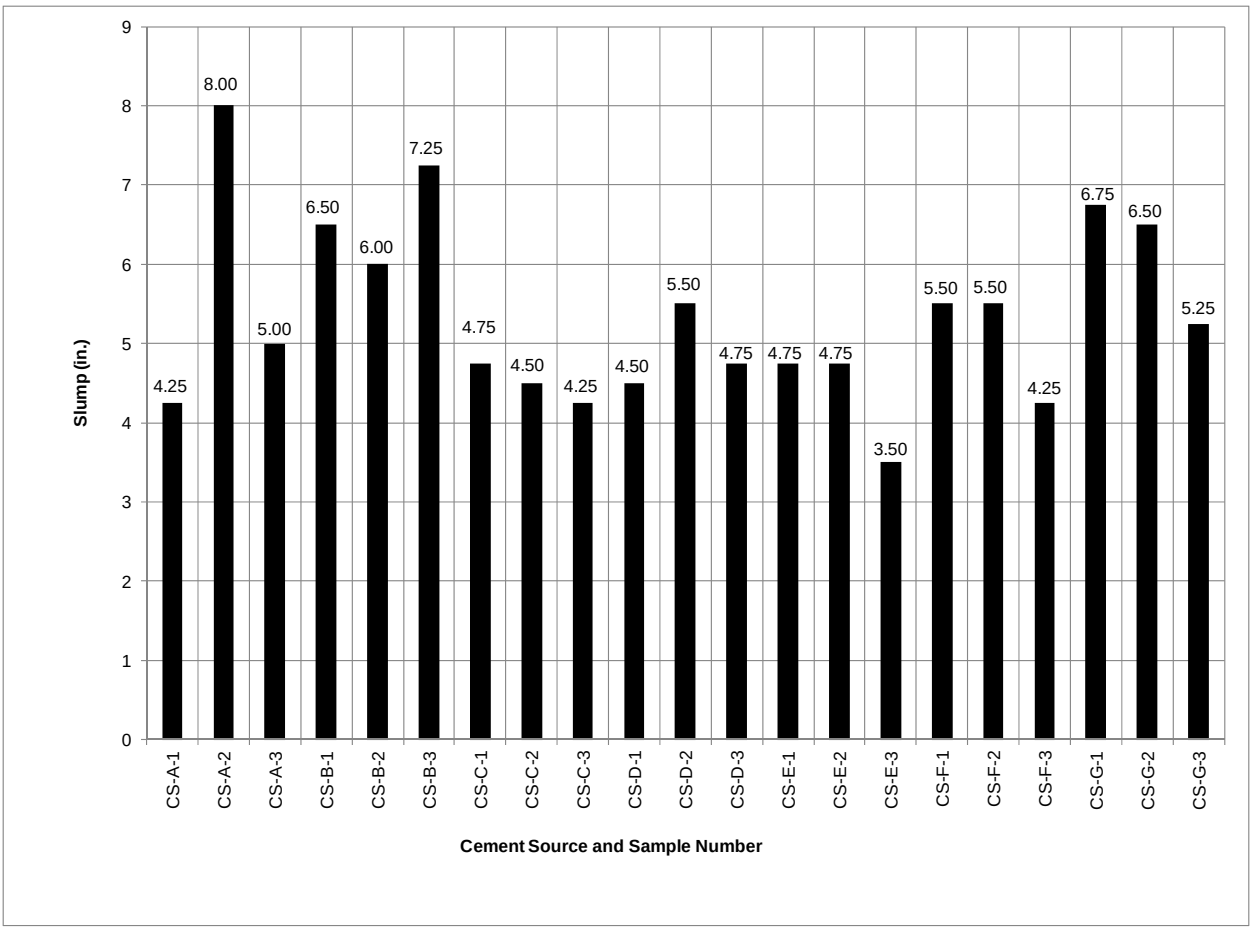

Figure 48 - Influence of Cement Source on Slump of Gravel Aggregate Concrete: 75/25F

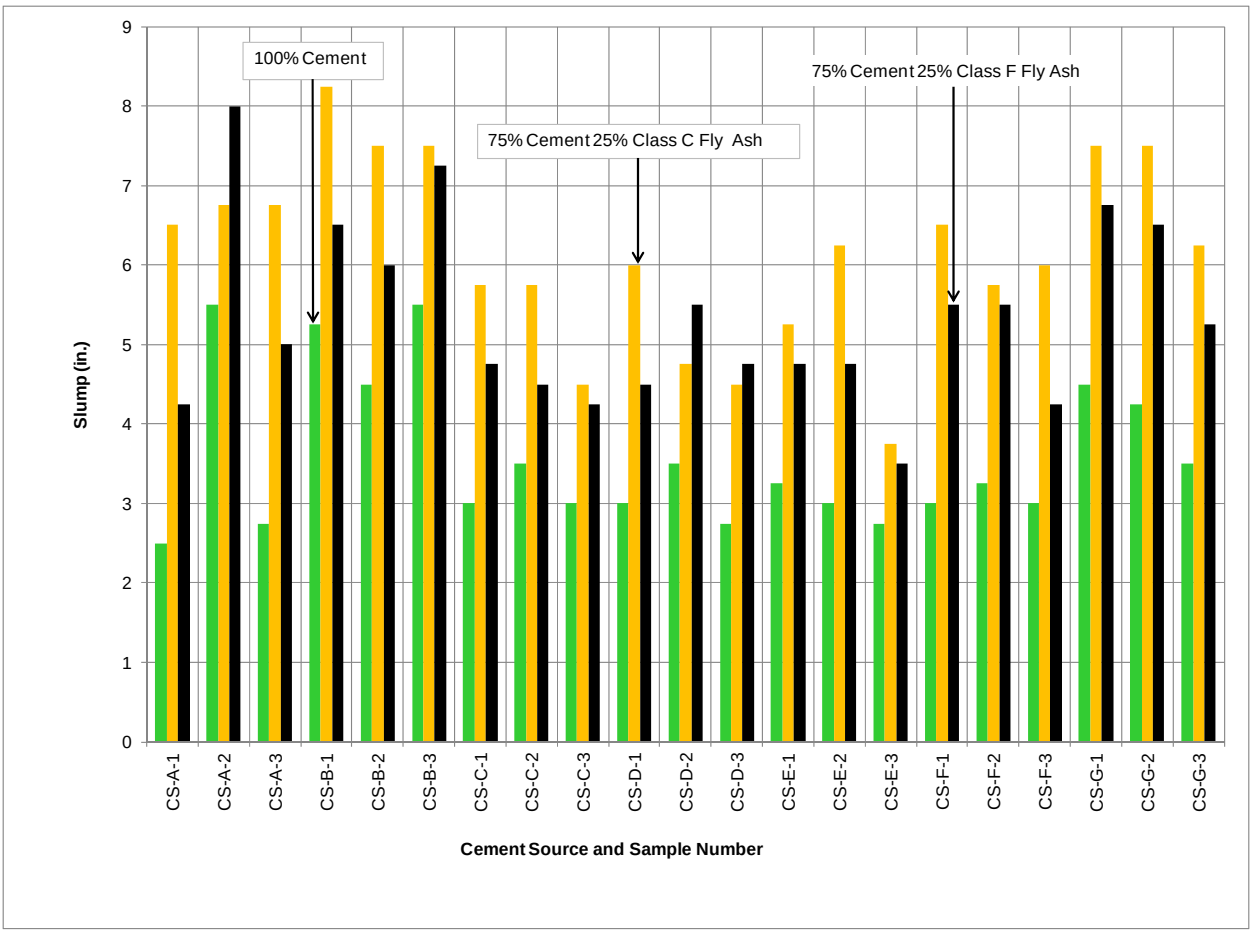

Figure 49 - Influence of Cement Source on Slump of Gravel Aggregate Concrete: All Mixes

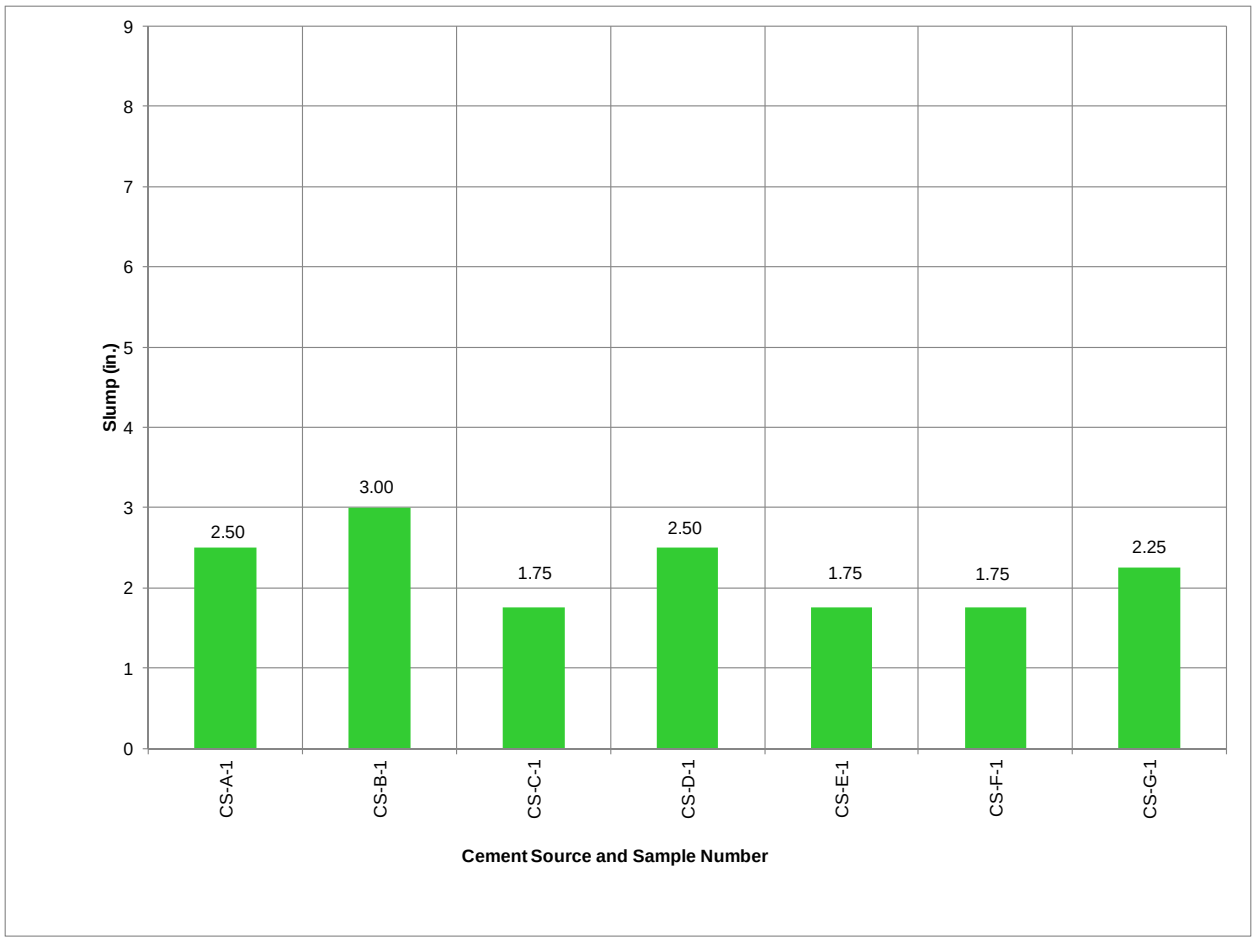

Figure 50 - Influence of Cement Source on Slump of Crushed Limestone Aggregate Concrete: 100

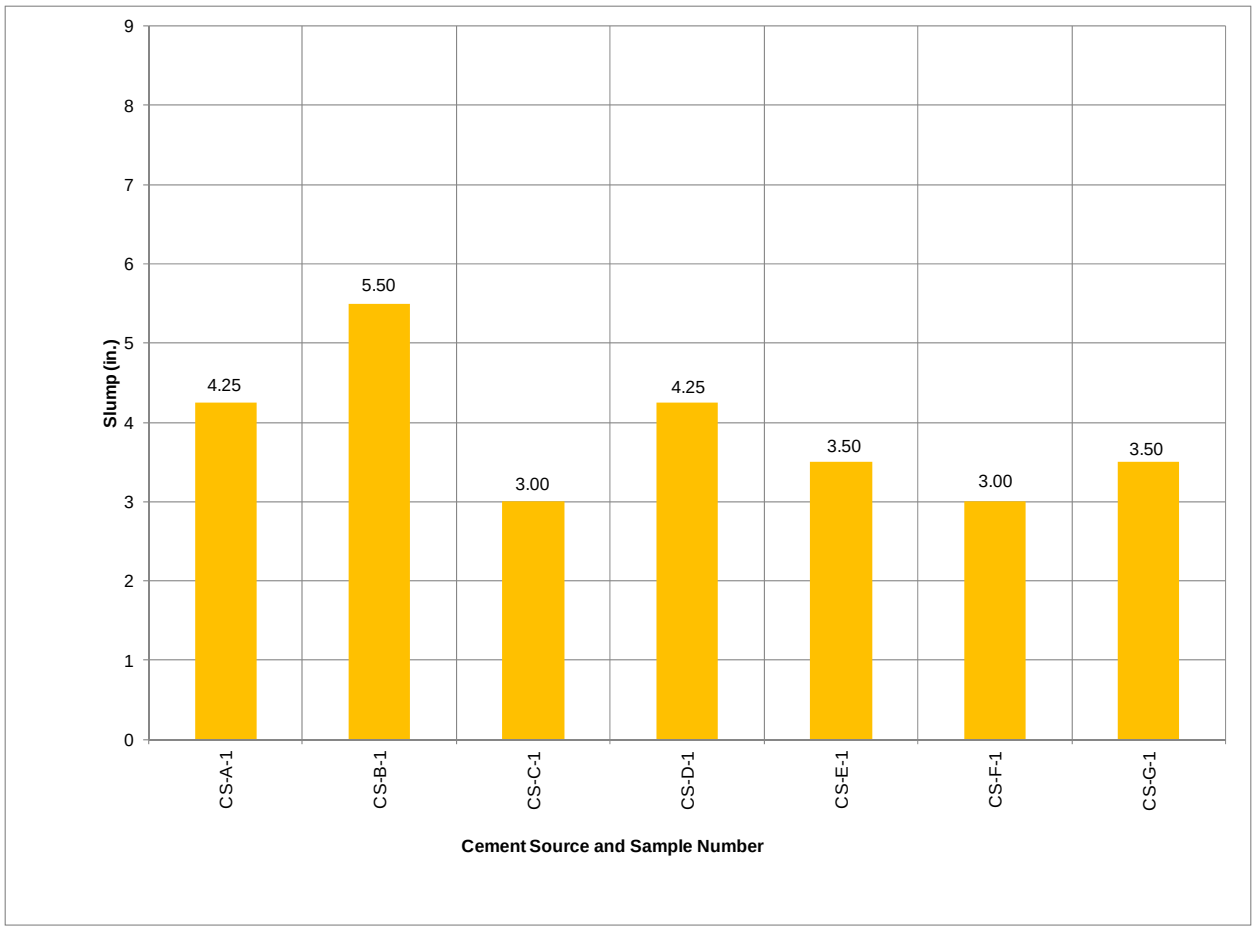

Figure 51 - Influence of Cement Source on Slump of Crushed Limestone Aggregate Concrete: 75/25C

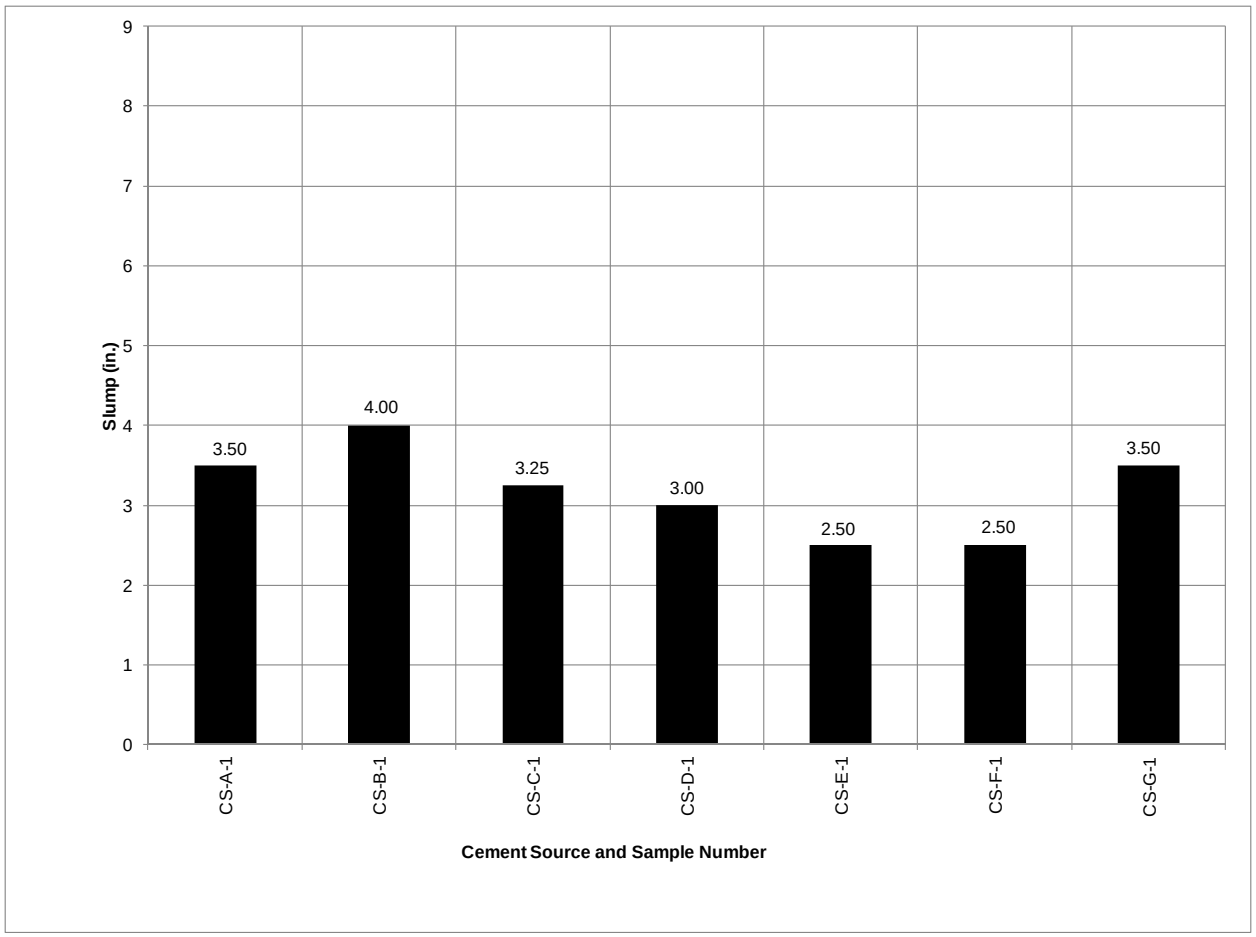

Figure 52 - Influence of Cement Source on Slump of Crushed Limestone Aggregate Concrete: 100/25F

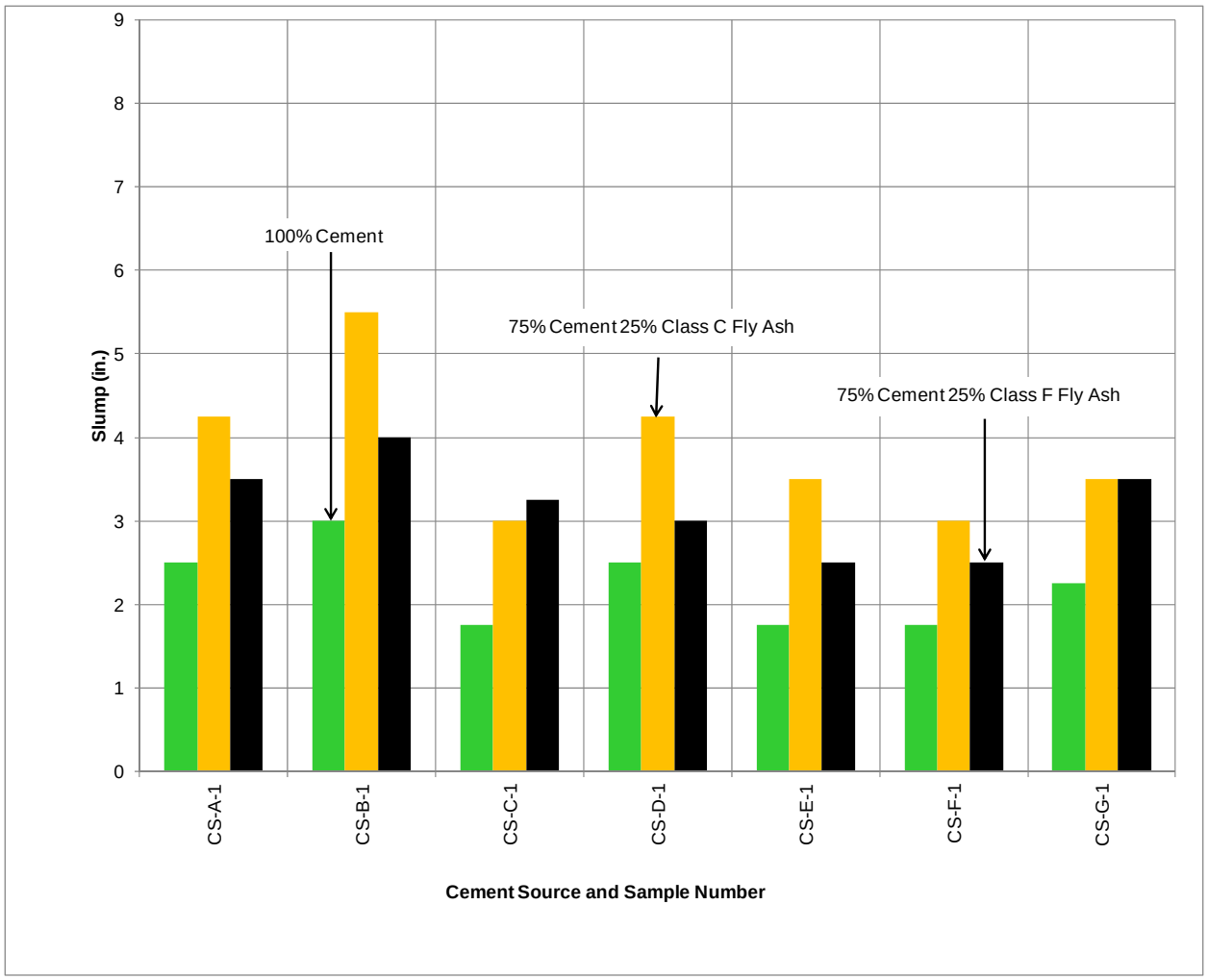

Figure 53 – Influence of Cement Source on Slump of Crushed Limestone Aggregate Concrete: All Mixes

Chapter 7 – Analysis of Results

General

Analysis of results was performed on mixes separated into categories by aggregate type including; Mississippi gravel and crushed limestone. These categories were further divided into three sub-categories related to the cementitious materials including; 100% cement (100), 75% cement and 25% Class C fly ash (75/25C), and 75% cement and 25% Class F fly ash (75/25F). These categories were established due to the wide range of compressive strengths obtained from mixes with identical w/cm ratios and similar mixture proportions.

The compressive strength data of this research shows that gravel aggregate produces compressive strengths that are lower than similar mixtures with crushed limestone aggregate. When comparing results of average 28-day compressive strengths from all cement samples, mixtures proportioned with 100% cement and gravel aggregate had compressive strengths of 67.2 percent of the crushed limestone mixes. Similar results occurred for the 75/25C and 75/25F gravel aggregate mixes of 54.6 percent and 63.3, respectfully.

Statistical Data for Gravel Aggregate Concrete

Table 38 presents a summary of descriptive statistical data for each category of gravel aggregate mixes based on all 21 cement samples. The standard deviation for all gravel aggregate concrete proportioned with 100% cement is 270 psi. The standard deviation increased for mixtures proportioned with 75/25C and 75/25F to 402 psi and 372 psi, respectfully. These data show the standard deviation that can be attributed to changing cements and cement samples. In addition, some of the standard deviation can also be attributed to testing under ideal laboratory conditions. The author did not attempt to distinguish between these two. However, standard deviation attributed to testing was minimized in this study because of laboratory procedures implemented for this research and by evaluating acceptable range of companion cylinder tests as described in Chapter 6 “Discussion of Results.” These data also show that standard deviation increases when using fly ash to replace cement.

Coefficient of variability (Cv) is calculated and provided in Table 38 for each category of gravel aggregate mixture. Cv represents the ratio of the standard deviation to the mean and is

shown as a percentage in this research. It is used herein for comparing the degree of variation from one data set to another. The author is not aware of acceptable values or ranges of values for Cv for properties determined from compressive strength testing. However, it is important to note that the higher the value the more variability in the data set and the lower the value the less variability in the data set.

The Cv for all gravel aggregate concrete proportioned with 100% cement is 5.81 percent. The Cv increased for mixtures proportioned with 75/25C and 75/25F to 9.84 percent and 9.39 percent, respectfully. These data show the Cv that can be attributed to changing cements and cement samples.

Table 38 - Statistical Data for 28-Day Compressive Strength of Gravel Aggregate Concrete Cement Sample

Statistic	100	75/25C	75/25F
Mean	4643	4091	3962
Standard Error	59	88	81
Median	4637	4073	3910
Mode	NA	4073	NA
Standard Deviation	270	402	372
Range	1208	1480	1570
Minimum	4125	3383	3360
Maximum	5333	4863	4930
Count	21	21	21
Coefficient of Variability	5.81	9.84	9.39

Relationship Between Fresh Properties and 28-Day Concrete Strength

A linear regression analysis was performed and plotted for all of the gravel aggregate concrete mixes to determine correlations between fresh properties of concrete and the 28-day compressive strengths. These correlations for gravel aggregate concrete are presented in Figures 54 through 62. The best correlation of 28-day compressive strength was with slump. The highest R squared value was 0.1233 indicating that when mixture proportions are held constant, fresh properties have little to no influence on 28-day compressive strengths of non-air entrained concrete.

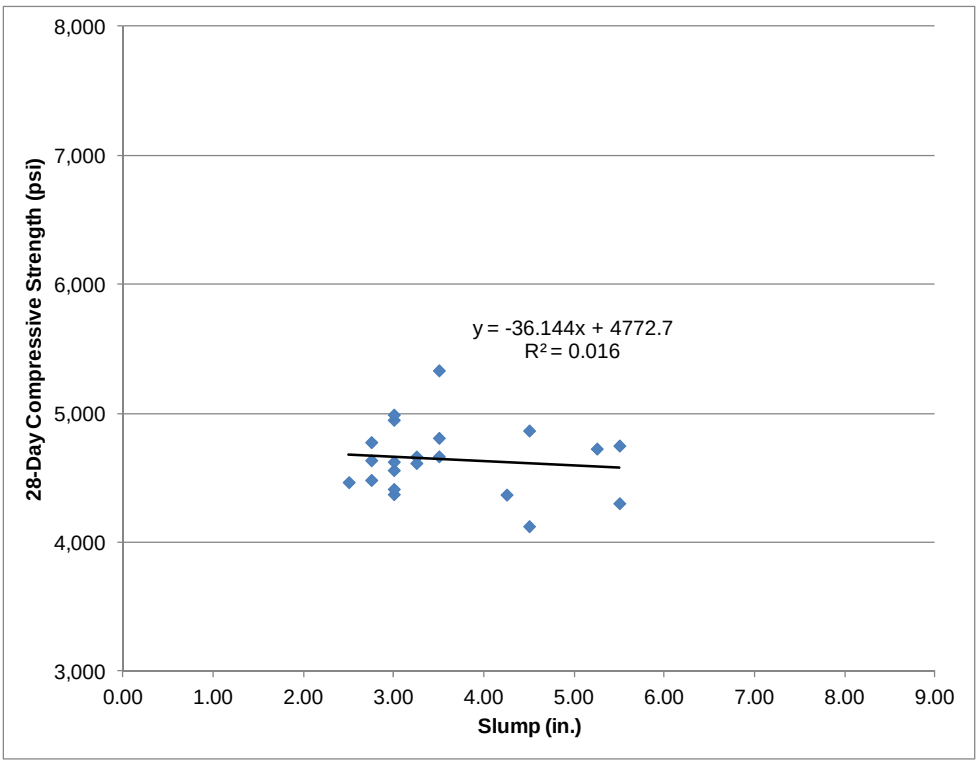

Figure 54 - 28-Day Compressive Strength vs Slump: Gravel Aggregate, 100

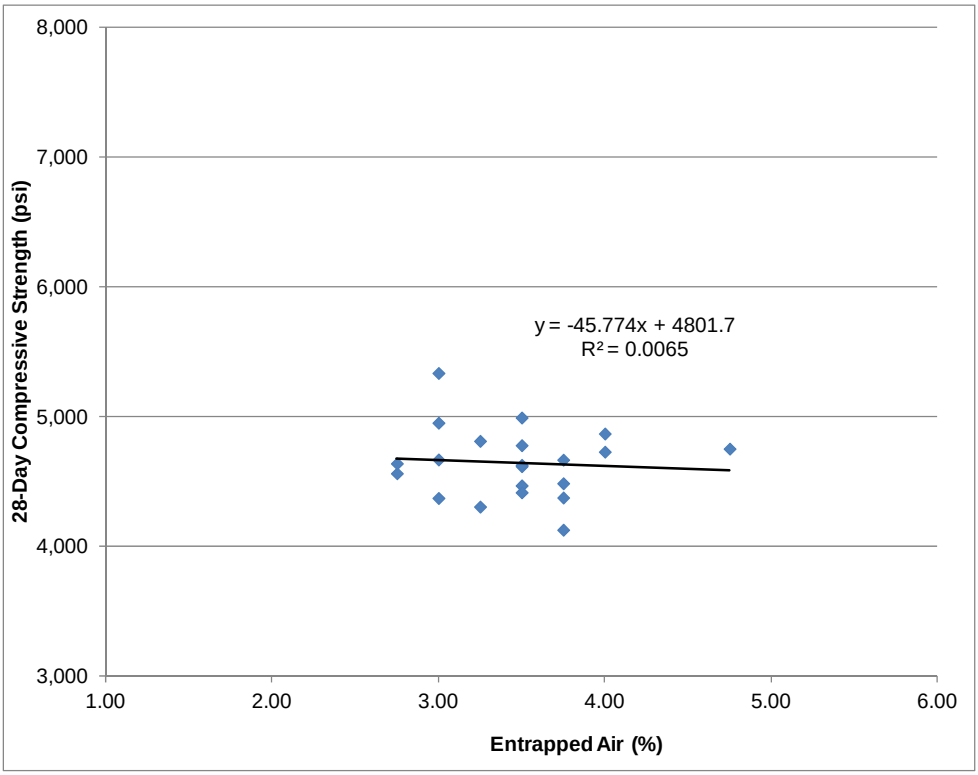

Figure 55 – 28-Day Compressive Strength vs Entrapped Air: Gravel Aggregate, 100

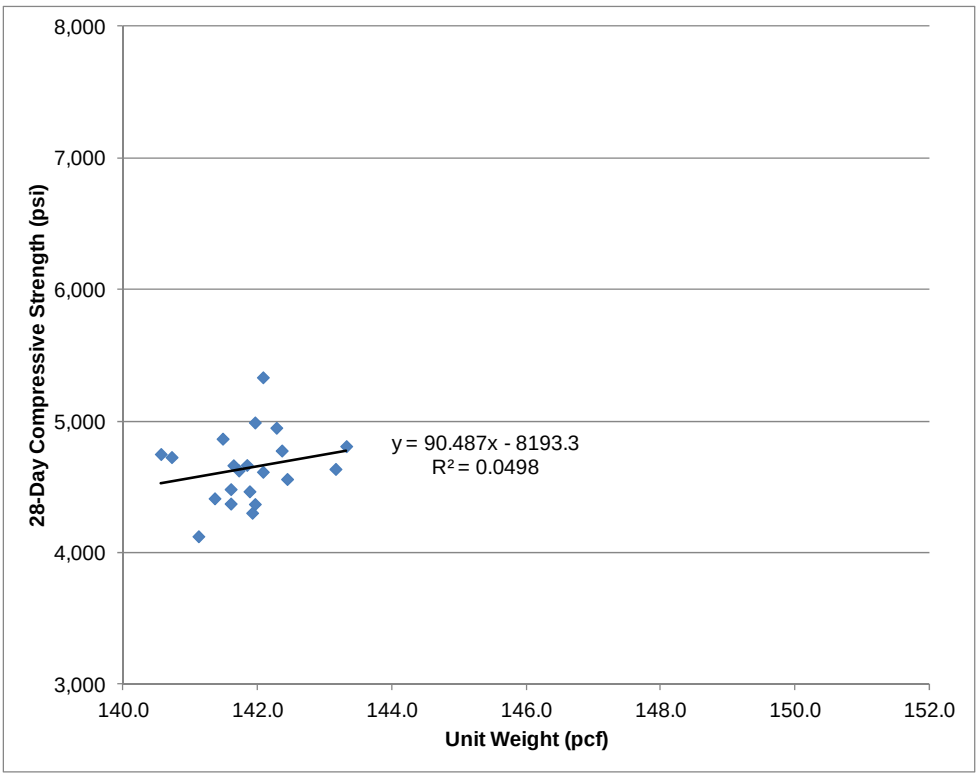

Figure 56 – 28-Day Compressive Strength vs Unit Weight: Gravel Aggregate, 100

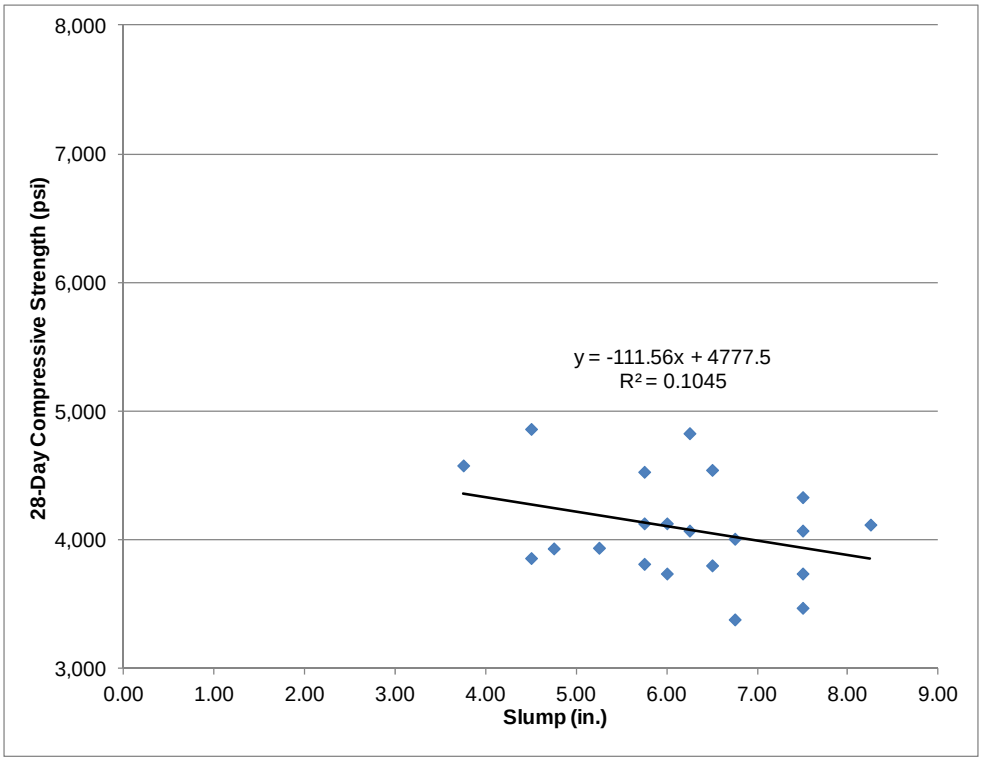

Figure 57 – 28-Day Compressive Strength vs Slump: Gravel Aggregate, 75/25C

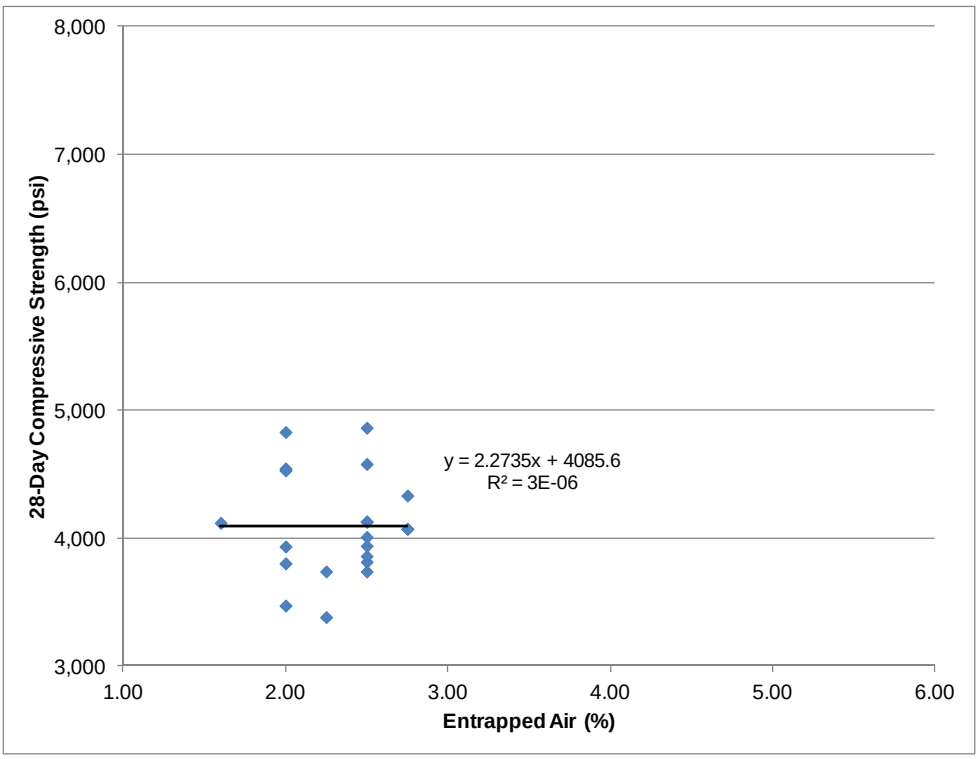

Figure 58 – 28-Day Compressive Strength vs Entrapped Air: Gravel Aggregate, 75/25C

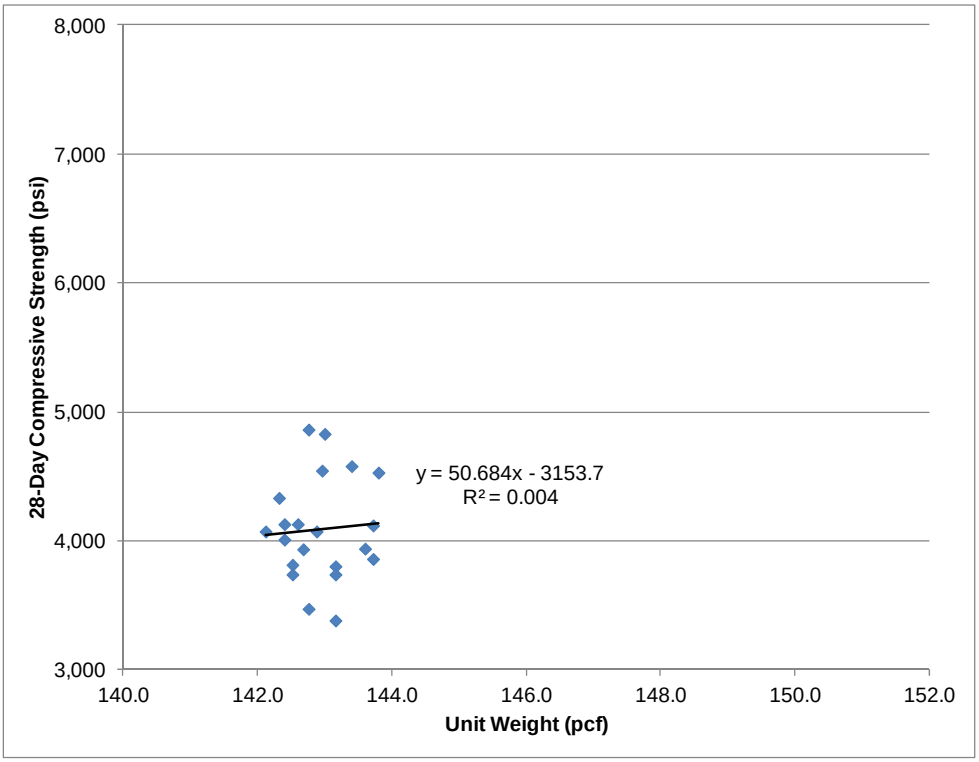

Figure 59 – 28-Day Compressive Strength vs Unit Weight: Gravel Aggregate, 75/25C

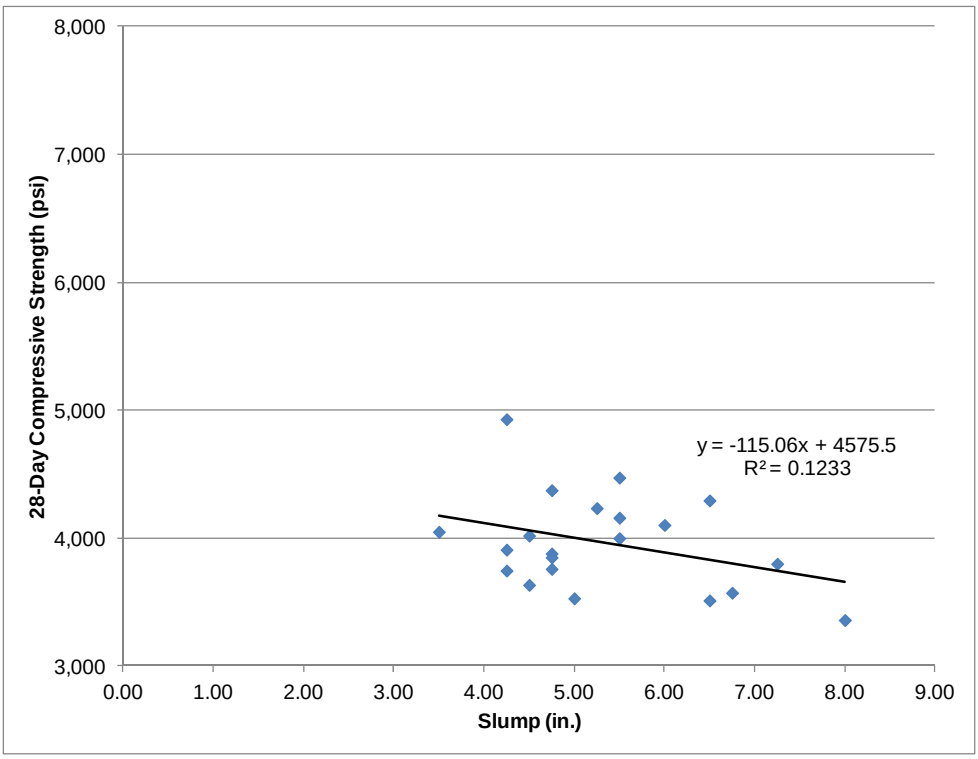

Figure 60 – 28-Day Compressive Strength vs Slump: Gravel Aggregate, 75/25F

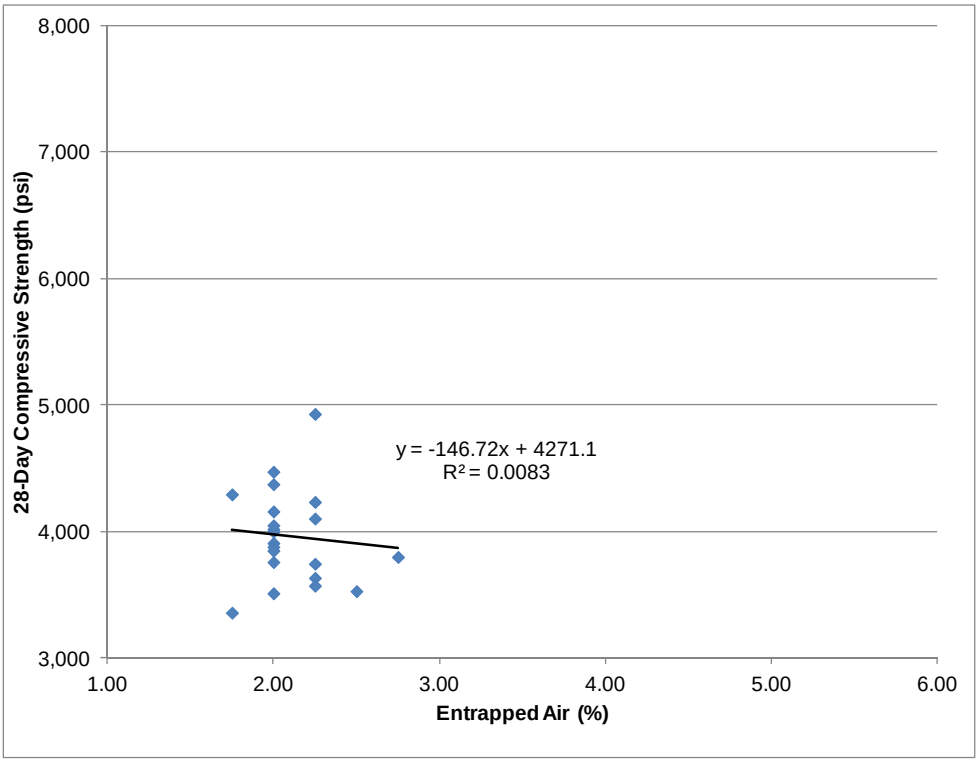

Figure 61 – 28-Day Compressive Strength vs Entrapped Air: Gravel Aggregate, 75/25F

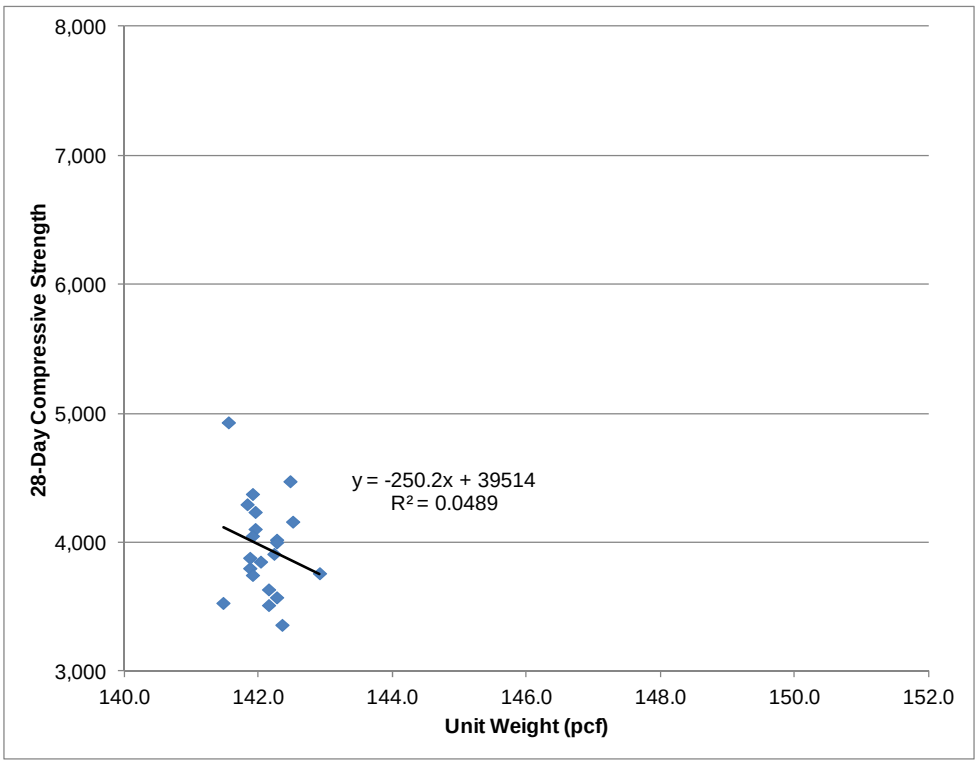

Figure 62 – 28-Day Compressive Strength vs Unit Weight: Gravel Aggregate 75/25F

Relationship Between 28-Day Mortar Cube Strength and 28-Day Concrete Strength

A linear regression analysis was performed and plotted for all of the gravel aggregate concrete mixes to determined correlations between 28-day mortar cube strength and the 28-day compressive strengths. These correlations for gravel aggregate concrete are presented in Figures 63 through 65. These data indicate that 28-day mortar cube strengths have little to no correlation with 28-day compressive strengths of gravel aggregate concrete.

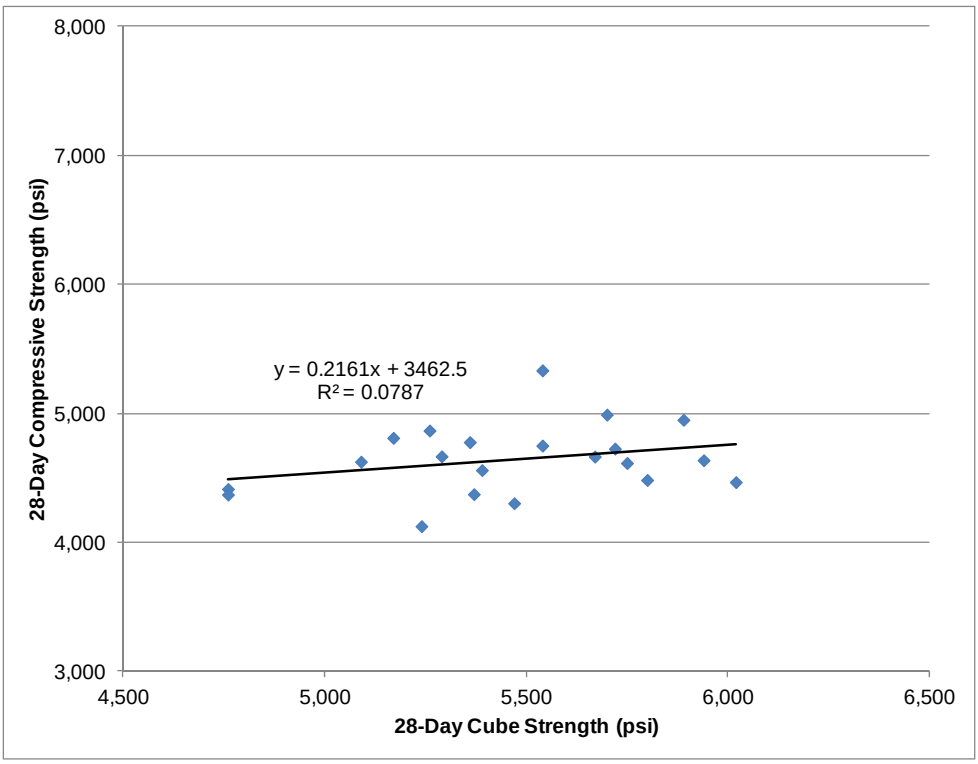

Figure 63 – 28-Day Compressive Strength vs 28-Day Cube Strength: Gravel Aggregate, 100

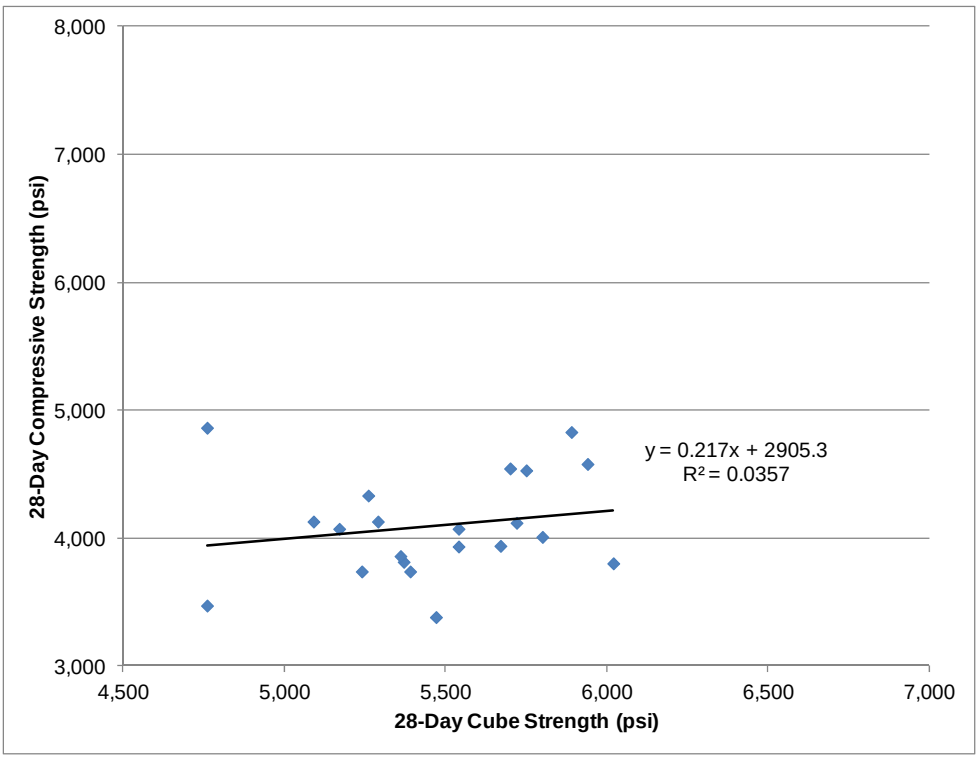

Figure 64 – 28-Day Compressive Strength vs 28-Day Cube Strength: Gravel Aggregate, 75/25C

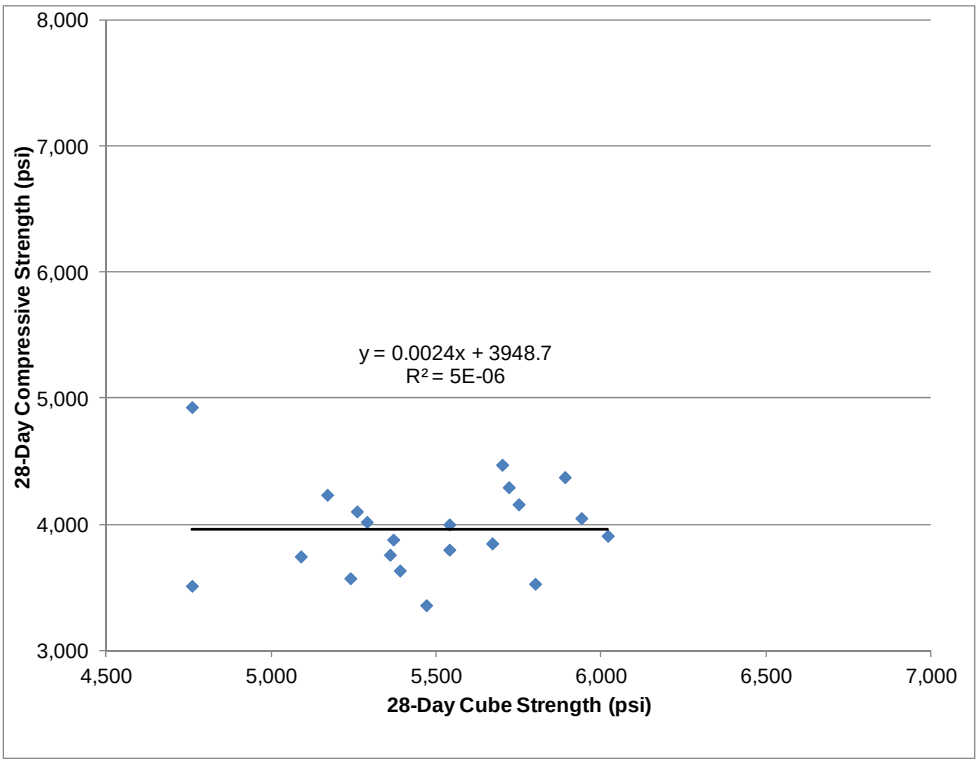

Figure 65 – 28-Day Compressive Strength vs Cube Strength: Gravel Aggregates, 75/25F

Relationship Between Chemical and Physical Properties of Cement and 28-Day Concrete Strength

Regression analysis was performed to determine the influence of cement chemical and physical properties on compressive strength of concrete. R squared values for gravel aggregate concrete are presented in Tables 39 through 41. R squared values for crushed limestone aggregate concrete are presented in Tables 42 through 44. These R squared values indicate that there is no strong correlation (It is the author's opinion that R squared values of 0.5 or greater indicate strong correlation) between cement chemical and physical properties and 28-day compressive strength of gravel aggregate concrete. The correlation between cement chemical and physical properties and 28-day compressive strength was stronger for crushed limestone aggregate concrete. In addition, there was good correlation with 28-day mortar cube strength and 28-day crushed limestone aggregate concrete with R squared values ranging from 0.3740 to 0.4549.

R squared values representing the correlation between cement chemical and physical properties and 28-day concrete compressive strengths of all mixes are ranked and presented in Table 45. A ranking of 1 means that this the chemical or physical property has the highest correlation of all of the cement chemical and physical properties evaluated in this study on 28-day concrete compressive strength. Likewise, a ranking of 26 associated with a particular cement chemical or physical property means that it has the least correlation of all of the cement chemical and physical properties on 28-day concrete compressive strength.

Table 39 - Influence of Cement Chemical and Physical Properties on Compressive Strength of Gravel Aggregate Concrete: 100

Cement Physical and Chemical Properties	R Squared Values				
	1 Day	7 Day	14 Day	28 Day	56 Day
Silicon Dioxide (SiO_2), %	0.3245	0.2195	0.0603	0.0029	0.0342
Aluminum Oxide (Al_2O_3), %	0.0763	0.0086	0.0130	0.0077	0.0320
Ferric Oxide (Fe_2O_3), %	0.0696	0.0448	0.0052	0.0276	0.2143
Calcium Oxide (CaO), %	0.1255	0.1766	0.1049	0.0148	0.0563
Magnesium Oxide (MgO), %	0.3602	0.0978	0.1175	0.0107	0.0352
Sulfur Trioxide (SO_3), %	0.5497	0.0507	0.1203	0.0497	0.0434
Loss of Ignition (LOI), %	0.0727	0.2452	0.0971	0.0189	0.2206
Insoluble Residue, %	0.0705	0.0438	0.0017	0.0112	0.0220
Free Lime, %	0.1355	0.0802	0.0799	0.1481	0.0190
Sodium Oxide (Na_2O)**, %**	0.0870	0.2100	0.3272	0.1422	0.3321
Na_2O Equivalent	0.0779	0.0470	0.0258	0.2747	0.1451
Potassium Oxide (K_2O)**, %**	0.1650	0.2312	0.2768	0.3921	0.4494
Tricalcium Silicate (C_3S), %	0.0578	0.0112	0.1280	0.0139	0.0425
Dicalcium Silicate (C_2S), %	0.0499	0.1820	0.0001	0.0011	0.0047
Tricalcium Aluminate (C_3A), %	0.0340	0.0284	0.0202	0.0009	0.0003
Tetracalcium Aluminoferrite (C_4AF), %	0.0642	0.0504	0.0061	0.0285	0.2195
Blaine Fineness, m^2/kg	0.2873	0.1315	0.1322	0.0610	0.2877
325 Mesh (% passing)	0.0734	0.0101	0.0261	0.2053	0.0901
Time of setting (Vicat) Initial Set, minutes	0.3459	0.3134	0.3207	0.2528	0.2130
Time of setting (Vicat) Final Set, minutes	0.4386	0.1936	0.1503	0.1944	0.1065
Air Content, %	0.4027	0.1069	0.1814	0.1399	0.1992
False Set, %	0.1132	0.0025	0.0036	0.0192	0.0000
Normal Consistency, %	0.2114	0.0296	0.0783	0.0881	0.0598
Autoclave Expansion, %	0.0833	0.0025	0.0768	0.0000	0.1917
Flow, %	0.0412	0.0444	0.0337	0.0704	0.0151
Mortar Cube 28 Day Strength	0.0051	0.0586	0.0131	0.0787	0.2501

Table 40 - Influence of Cement Chemical and Physical Properties on Compressive Strength of Gravel Aggregate Concrete: 75/25C

Cement Physical and Chemical Properties	R Squared Values				
	1 Day	7 Day	14 Day	28 Day	56 Day
Silicon Dioxide (SiO_2), %	0.4052	0.1272	0.4302	0.3523	0.4089
Aluminum Oxide (Al_2O_3), %	0.0381	0.0019	0.1025	0.0093	0.0197
Ferric Oxide (Fe_2O_3), %	0.1497	0.0884	0.0375	0.0292	0.0403
Calcium Oxide (CaO), %	0.0217	0.0723	0.1037	0.0000	0.0030
Magnesium Oxide (MgO), %	0.1380	0.0150	0.0810	0.0000	0.0000
Sulfur Trioxide (SO_3), %	0.5271	0.0163	0.0353	0.0596	0.0553
Loss of Ignition (LOI), %	0.0992	0.2015	0.2228	0.2525	0.5462
Insoluble Residue, %	0.0024	0.1272	0.4302	0.3523	0.4089
Free Lime, %	0.1418	0.0143	0.2275	0.0887	0.0059
Sodium Oxide (Na_2O), %	0.0711	0.0902	0.0340	0.0001	0.0001
Na_2O Equivalent	0.1737	0.0043	0.0381	0.2082	0.3151
Potassium Oxide (K_2O), %	0.2385	0.0674	0.0716	0.1012	0.1574
Tricalcium Silicate (C_3S), %	0.0017	0.0604	0.1873	0.0449	0.0160
Dicalcium Silicate (C_2S), %	0.1627	0.1967	0.4497	0.2515	0.2867
Tricalcium Aluminate (C_3A), %	0.0029	0.0226	0.1618	0.0261	0.0059
Tetracalcium Aluminoferrite (C_4AF), %	0.1435	0.0954	0.0402	0.0310	0.0449
Blaine Fineness, m^2/kg	0.2647	0.0491	0.1139	0.2016	0.4498
325 Mesh (% passing)	0.1968	0.0018	0.0056	0.0270	0.1708
Time of setting (Vicat) Initial Set, minutes	0.3093	0.0031	0.1440	0.1792	0.2269
Time of setting (Vicat) Final Set, minutes	0.5001	0.0001	0.0716	0.2055	0.3013
Air Content, %	0.3642	0.0001	0.0054	0.1381	0.2730
False Set, %	0.2707	0.0673	0.0071	0.0677	0.1293
Normal Consistency, %	0.1788	0.0005	0.0307	0.0334	0.1331
Autoclave Expansion, %	0.0180	0.0257	0.0008	0.0779	0.1528
Flow, %	0.0252	0.0500	0.1674	0.0273	0.0000
Mortar Cube 28 Day Strength	0.0118	0.1879	0.0050	0.0357	0.0491

Table 41 - Influence of Cement Chemical and Physical Properties on Compressive Strength of Gravel Aggregate Concrete: 75/25F

Cement Physical and Chemical Properties	R Squared Values				
	1 Day	7 Day	14 Day	28 Day	56 Day
Silicon Dioxide (SiO_2), %	0.1875	0.1523	0.1865	0.2846	0.3173
Aluminum Oxide (Al_2O_3), %	0.0051	0.0463	0.1568	0.0943	0.0003
Ferric Oxide (Fe_2O_3), %	0.1239	0.0869	0.0485	0.0084	0.0408
Calcium Oxide (CaO), %	0.0072	0.1104	0.1466	0.0008	0.1128
Magnesium Oxide (MgO), %	0.0487	0.0386	0.1270	0.0004	0.0856
Sulfur Trioxide (SO_3), %	0.1332	0.0048	0.0480	0.0590	0.1573
Loss of Ignition (LOI), %	0.0946	0.0881	0.0478	0.0683	0.3195
Insoluble Residue, %	0.0082	0.0227	0.0148	0.0005	0.0874
Free Lime, %	0.0125	0.1058	0.3393	0.3084	0.2390
Sodium Oxide (Na_2O), %	0.0797	0.0443	0.0582	0.0054	0.0978
Na_2O Equivalent	0.0526	0.0083	0.0008	0.1336	0.1064
Potassium Oxide (K_2O), %	0.1417	0.0068	0.0202	0.0371	0.1951
Tricalcium Silicate (C_3S), %	0.0060	0.1702	0.0776	0.0703	0.0522
Dicalcium Silicate (C_2S), %	0.0903	0.2655	0.1686	0.2013	0.2762
Tricalcium Aluminate (C_3A), %	0.0035	0.1099	0.2453	0.1251	0.0078
Tetracalcium Aluminoferrite (C_4AF), %	0.1225	0.0891	0.0473	0.0087	0.0435
Blaine Fineness, m^2/kg	0.2375	0.0142	0.0337	0.0701	0.2519
325 Mesh (% passing)	0.1418	0.0360	0.0593	0.0015	0.0652
Time of setting (Vicat) Initial Set, minutes	0.0780	0.0022	0.1415	0.1401	0.2159
Time of setting (Vicat) Final Set, minutes	0.1750	0.0035	0.0678	0.1335	0.2546
Air Content, %	0.1224	0.0416	0.0000	0.0369	0.1824
False Set, %	0.1462	0.1612	0.0568	0.0284	0.0024
Normal Consistency, %	0.0368	0.0612	0.0003	0.0239	0.2146
Autoclave Expansion, %	0.0798	0.0078	0.0327	0.0030	0.0713
Flow, %	0.0847	0.0748	0.3699	0.0578	0.1485
Mortar Cube 28 Day Strength	0.0072	0.0728	0.0079	0.0000	0.1192

Table 42 - Influence of Cement Chemical and Physical Properties on Compressive Strength of Crushed Limestone Aggregate Concrete: 100

Cement Physical and Chemical Properties	R Squared Values				
	1 Day	7 Day	14 Day	28 Day	56 Day
Silicon Dioxide (SiO_2), %	0.4293	0.0132	0.0004	0.0416	0.0053
Aluminum Oxide (Al_2O_3), %	0.4293	0.0640	0.0004	0.0416	0.0053
Ferric Oxide (Fe_2O_3), %	0.2560	0.2859	0.5687	0.3828	0.6185
Calcium Oxide (CaO), %	0.0440	0.1622	0.3009	0.4198	0.1990
Magnesium Oxide (MgO), %	0.4601	0.0016	0.0136	0.0238	0.0008
Sulfur Trioxide (SO_3), %	0.8363	0.3016	0.1838	0.3128	0.2800
Loss of Ignition (LOI), %	0.0740	0.2239	0.5268	0.3428	0.6090
Insoluble Residue, %	0.0011	0.1441	0.5180	0.3513	0.4900
Free Lime, %	0.1753	0.0048	0.0047	0.0923	0.0008
Sodium Oxide (Na_2O), %	0.1426	0.1862	0.2870	0.3034	0.2170
Na_2O Equivalent	0.0242	0.0347	0.0440	0.0036	0.0260
Potassium Oxide (K_2O), %	0.0418	0.0414	0.3108	0.1572	0.2131
Tricalcium Silicate (C_3S), %	0.2252	0.3651	0.2145	0.5440	0.1887
Dicalcium Silicate (C_2S), %	0.0306	0.1562	0.3943	0.3095	0.3773
Tricalcium Aluminate (C_3A), %	0.4676	0.0009	0.0813	0.2005	0.0117
Tetracalcium Aluminoferrite (C_4AF), %	0.2596	0.2903	0.5863	0.3949	0.6357
Blaine Fineness, m^2/kg	0.0209	0.1746	0.2958	0.1932	0.4100
325 Mesh (% passing)	0.0382	0.0131	0.0231	0.0159	0.0397
Time of setting (Vicat) Initial Set, minutes	0.4345	0.0056	0.0000	0.0818	0.0072
Time of setting (Vicat) Final Set, minutes	0.7454	0.0949	0.0234	0.1398	0.0321
Air Content, %	0.0037	0.3027	0.0353	0.0089	0.0024
False Set, %	0.2419	0.1707	0.4642	0.5773	0.2833
Normal Consistency, %	0.0179	0.0047	0.1256	0.0872	0.0809
Autoclave Expansion, %	0.0181	0.1942	0.3070	0.4390	0.2439
Flow, %	0.0050	0.1148	0.2228	0.0973	0.2610
Mortar Cube 28 Day Strength	0.3832	0.3586	0.4870	0.3740	0.5917

Table 43 - Influence of Cement Chemical and Physical Properties on Compressive Strength of Crushed Limestone Aggregate Concrete: 75/25C

Cement Physical and Chemical Properties	R Squared Values				
	1 Day	7 Day	14 Day	28 Day	56 Day
Silicon Dioxide (SiO_2), %	0.5941	0.0457	0.0290	0.0008	0.1519
Aluminum Oxide (Al_2O_3), %	0.6114	0.1668	0.0289	0.0292	0.0404
Ferric Oxide (Fe_2O_3), %	0.1989	0.7529	0.0126	0.5610	0.6341
Calcium Oxide (CaO), %	0.0072	0.0484	0.4843	0.0060	0.0731
Magnesium Oxide (MgO), %	0.3223	0.2642	0.4051	0.0146	0.2443
Sulfur Trioxide (SO_3), %	0.9415	0.1362	0.0934	0.0103	0.2515
Loss of Ignition (LOI), %	0.0205	0.1203	0.0157	0.0038	0.0049
Insoluble Residue, %	0.0053	0.0215	0.1335	0.0026	0.0072
Free Lime, %	0.2049	0.0830	0.0688	0.5957	0.1992
Sodium Oxide (Na_2O), %	0.0927	0.0050	0.5082	0.0488	0.1570
Na_2O Equivalent	0.0215	0.3445	0.0138	0.0076	0.0158
Potassium Oxide (K_2O), %	0.1226	0.1707	0.2635	0.0276	0.0768
Tricalcium Silicate (C_3S), %	0.4681	0.0039	0.0916	0.0334	0.0041
Dicalcium Silicate (C_2S), %	0.0454	0.0028	0.2530	0.0195	0.1023
Tricalcium Aluminate (C_3A), %	0.3775	0.0019	0.0548	0.2591	0.0211
Tetracalcium Aluminoferrite (C_4AF), %	0.1990	0.7504	0.0113	0.5527	0.6246
Blaine Fineness, m^2/kg	0.0029	0.0094	0.0087	0.0107	0.0123
325 Mesh (% passing)	0.0058	0.0002	0.0011	0.3462	0.1570
Time of setting (Vicat) Initial Set, minutes	0.5665	0.0318	0.0006	0.1796	0.0011
Time of setting (Vicat) Final Set, minutes	0.9183	0.0252	0.0685	0.0028	0.1439
Air Content, %	0.1710	0.0466	0.0390	0.0348	0.0000
False Set, %	0.2965	0.2542	0.0913	0.1838	0.2622
Normal Consistency, %	0.0013	0.0036	0.0969	0.2974	0.1979
Autoclave Expansion, %	0.0712	0.0056	0.1441	0.0678	0.0264
Flow, %	0.0042	0.2617	0.0000	0.6670	0.3443
Mortar Cube 28 Day Strength	0.3523	0.7886	0.0431	0.4392	0.6596

Table 44 - Influence of Cement Chemical and Physical Properties on Compressive Strength of Crushed Limestone Aggregate Concrete: 75/25F

Cement Physical and Chemical Properties	R Squared Values				
	1 Day	7 Day	14 Day	28 Day	56 Day
Silicon Dioxide (SiO_2), %	0.4242	0.0000	0.0117	0.1295	0.0583
Aluminum Oxide (Al_2O_3), %	0.5943	0.2683	0.0319	0.0987	0.1431
Ferric Oxide (Fe_2O_3), %	0.4928	0.0768	0.1476	0.4364	0.1398
Calcium Oxide (CaO), %	0.0132	0.2058	0.0412	0.0068	0.4637
Magnesium Oxide (MgO), %	0.3676	0.2350	0.0076	0.0825	0.6574
Sulfur Trioxide (SO_3), %	0.8231	0.0340	0.0536	0.0040	0.0468
Loss of Ignition (LOI), %	0.0798	0.0479	0.0003	0.0020	0.0106
Insoluble Residue, %	0.0031	0.0079	0.0004	0.0145	0.0376
Free Lime, %	0.0485	0.2613	0.0157	0.0632	0.0002
Sodium Oxide (Na_2O), %	0.0591	0.2725	0.4454	0.0851	0.0319
Na_2O Equivalent	0.0093	0.2927	0.1009	0.1610	0.6441
Potassium Oxide (K_2O), %	0.0226	0.0005	0.5351	0.2213	0.1431
Tricalcium Silicate (C_3S), %	0.2892	0.0990	0.0400	0.0308	0.0388
Dicalcium Silicate (C_2S), %	0.0215	0.0031	0.0033	0.0466	0.1261
Tricalcium Aluminate (C_3A), %	0.2418	0.4415	0.0003	0.0012	0.0512
Tetracalcium Aluminoferrite (C_4AF), %	0.4941	0.0706	0.1432	0.4247	0.1372
Blaine Fineness, m^2/kg	0.0137	0.0611	0.0476	0.0937	0.0033
325 Mesh (% passing)	0.0015	0.3454	0.0089	0.0492	0.1181
Time of setting (Vicat) Initial Set, minutes	0.2615	0.1372	0.0494	0.0168	0.0014
Time of setting (Vicat) Final Set, minutes	0.6487	0.0509	0.0564	0.0015	0.0213
Air Content, %	0.0318	0.4284	0.0156	0.0176	0.0659
False Set, %	0.4047	0.1176	0.2424	0.3956	0.0001
Normal Consistency, %	0.0002	0.3429	0.0110	0.0088	0.0738
Autoclave Expansion, %	0.0594	0.1665	0.0014	0.0054	0.4272
Flow, %	0.0323	0.3844	0.1077	0.2088	0.0021
Mortar Cube 28 Day Strength	0.6491	0.0693	0.1338	0.4549	0.2232

Table 45 - Influence of Cement Chemical and Physical Properties on 28-Day Compressive Strength – Ranked

Cement Physical and Chemical Properties	Gravel Aggregate Mixes			Crushed Limestone Mixes		
	100	**75/25C**	**75/25F**	**100**	**75/25C**	**75/25F**
Silicon Dioxide (SiO_2), %	23	1	2	21	26	8
Aluminum Oxide (Al_2O_3), %	22	23	8	22	15	9
Ferric Oxide (Fe_2O_3), %	15	19	19	6	3	2
Calcium Oxide (CaO), %	18	25	23	4	22	21
Magnesium Oxide (MgO), %	21	26	25	23	18	12
Sulfur Trioxide (SO_3), %	13	14	12	10	20	23
Loss of Ignition (LOI), %	17	3	11	9	23	24
Insoluble Residue, %	20	2	24	8	25	19
Free Lime, %	6	11	1	18	2	13
Sodium Oxide (Na_2O), %	7	24	20	12	12	11
Na_2O Equivalent	2	5	5	26	21	7
Potassium Oxide (K_2O), %	1	10	14	15	16	5
Tricalcium Silicate (C_3S), %	19	15	9	2	14	16
Dicalcium Silicate (C_2S), %	24	4	3	11	17	15
Tricalcium Aluminate (C_3A), %	25	22	7	13	8	26
Tetracalcium Aluminoferrite (C_4AF), %	14	18	18	5	4	3
Blaine Fineness, m^2/kg	12	7	10	14	19	10
325 Mesh (% passing)	4	21	22	24	6	14
Time of setting (Vicat) Initial Set, minutes	3	8	4	20	10	18
Time of setting (Vicat) Final Set, minutes	5	6	6	16	24	25
Air Content, %	8	9	15	25	13	17
False Set, %	16	13	16	1	9	4
Normal Consistency, %	9	17	17	19	7	20
Autoclave Expansion, %	26	12	21	3	11	22
Flow, %	11	20	13	17	1	6
Mortar Cube 28 Day Strength	10	16	26	7	5	1

Influence of Age on Concrete Compressive Strength

Concrete gains strength with age and continues to gain strength as long as there is favorable moisture conditions and temperatures, and there is cementitious materials and room for hydration products. Strength was measured at ages 1day, 7 days, 14 days, 28-days, and 56 days in this research. Figures 66 through 71 present scatter plots of percent of 28-day strengths verses age along with a regression line and the equation of the line. These natural log equations provide a method of estimating compressive strength at any age between 1 day and 56 days for mixes with similar proportions. When using these equations, the 7 day compressive strengths for all mixes in this research are within a range of 70 to 80 percent of the 28-day strengths.

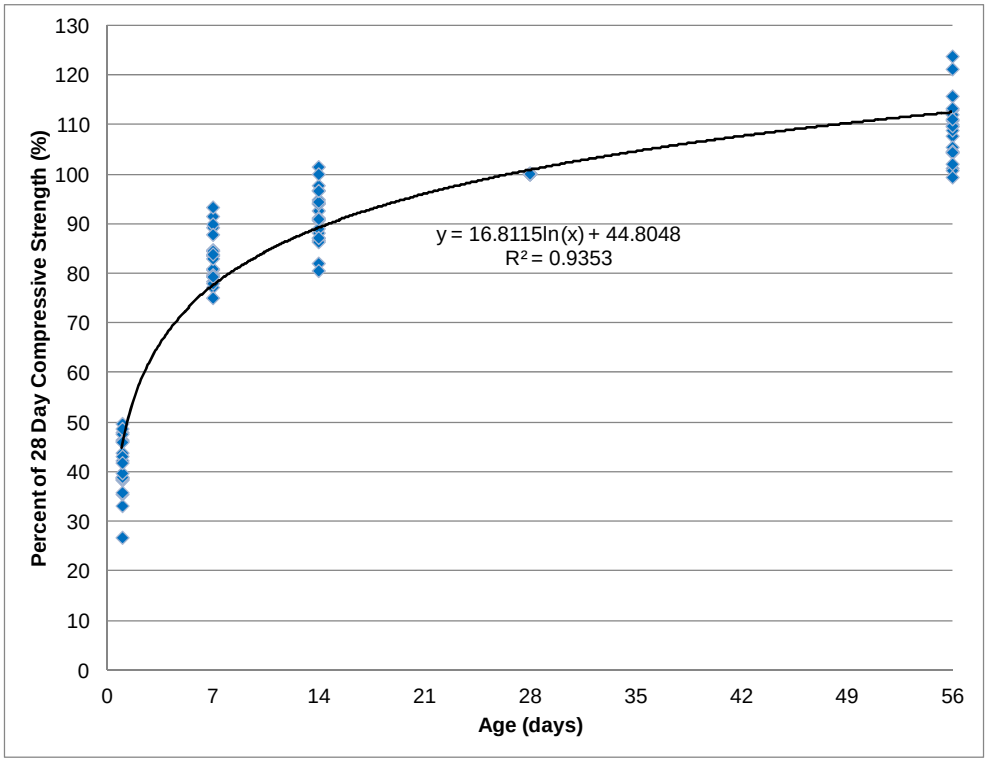

Figure 66 - Percent of 28-Day Compressive Strength vs Age of Gravel Aggregate Concrete: 100

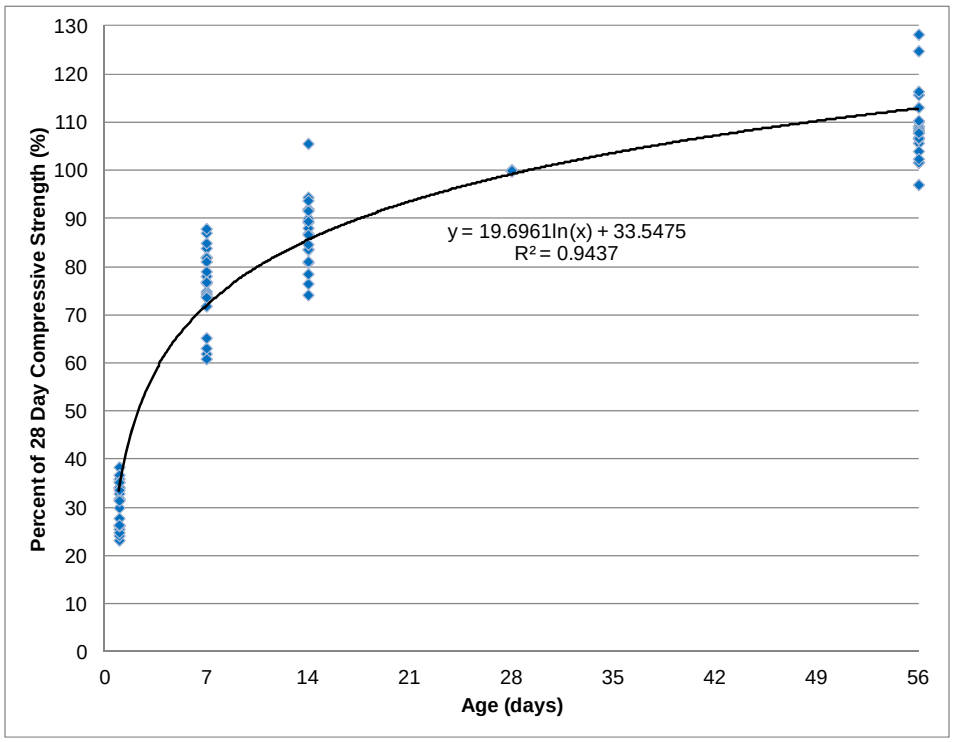

Figure 67 - Percent of 28-Day Compressive Strength vs Age of Gravel Aggregate Concrete: 75/25C

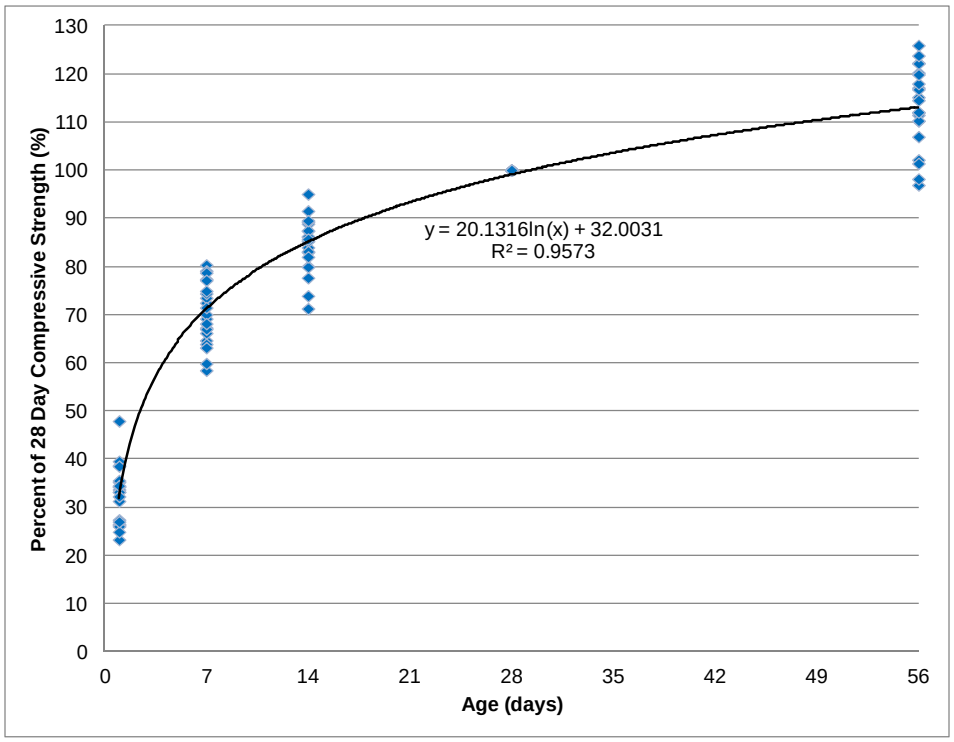

Figure 68 - Percent of 28-Day Compressive Strength vs Age of Gravel Aggregate Concrete: 75/25F

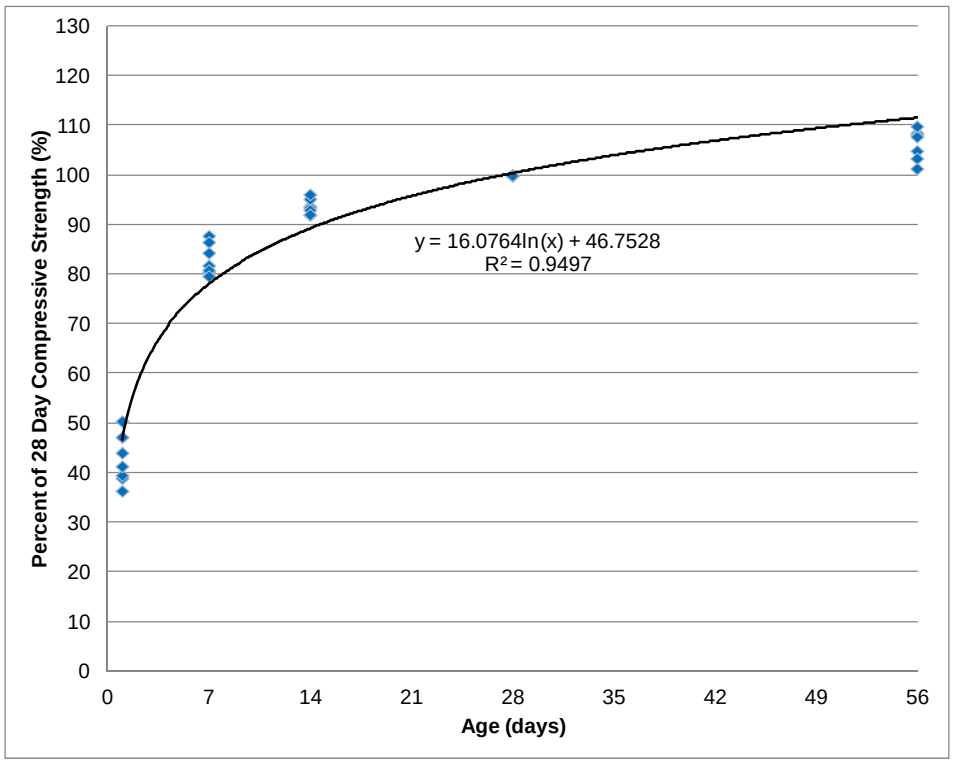

Figure 69 - Percent of 28-Day Compressive Strength vs Age of Crushed Limestone Aggregate Concrete: 100

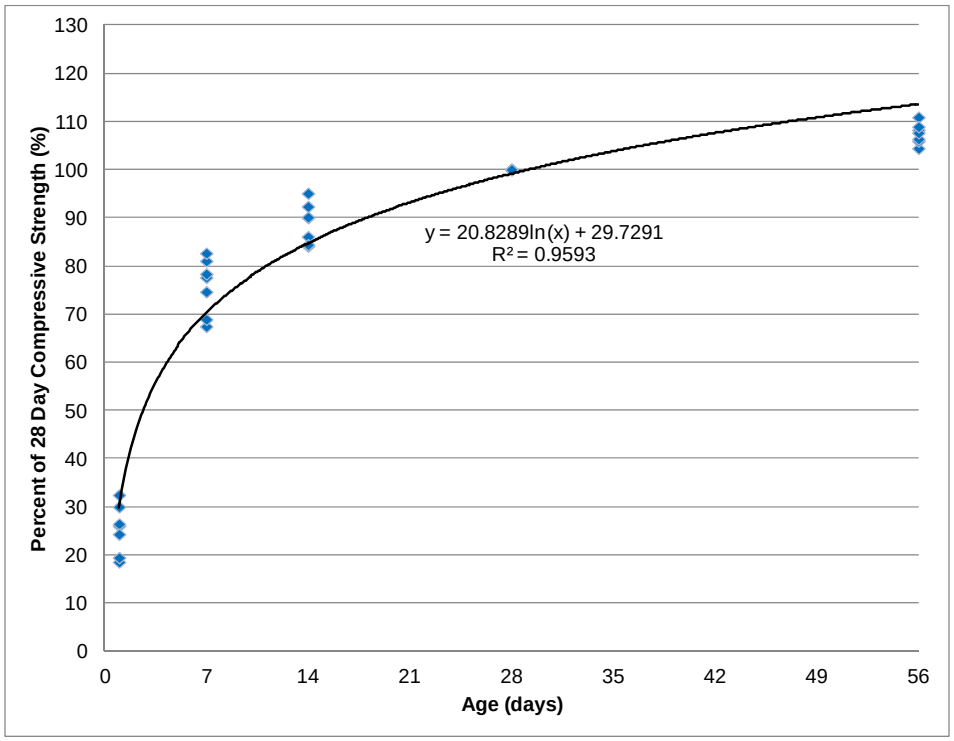

Figure 70 - Percent of 28-Day Compressive Strength vs Age of Crushed Limestone Aggregate Concrete: 75/25C

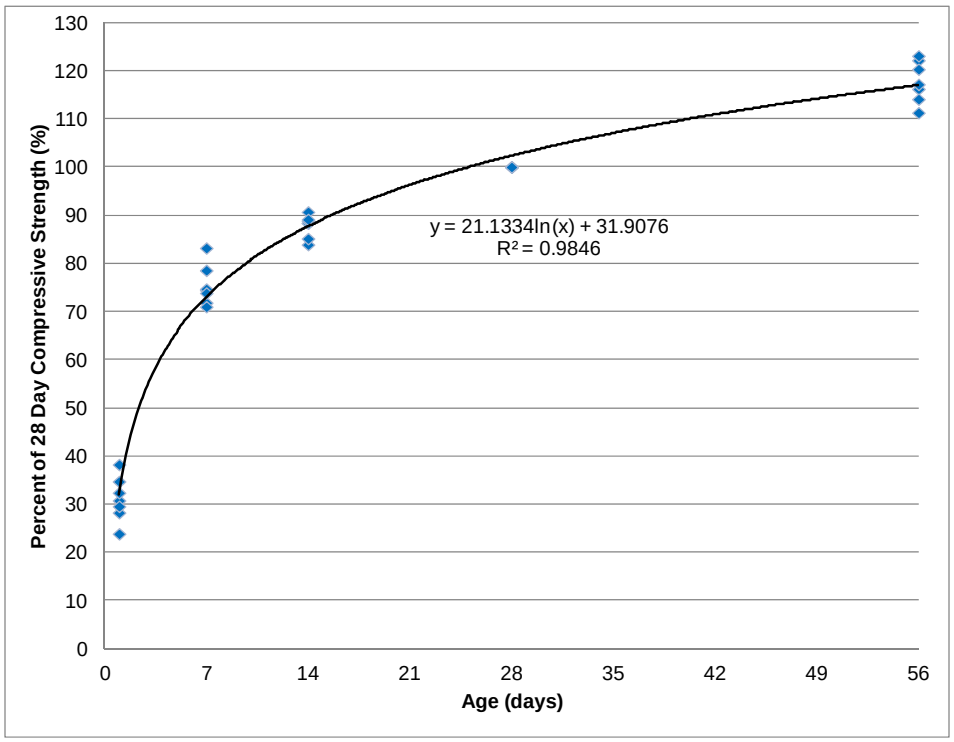

Figure 71 - Percent of 28-Day Compressive Strength vs Age of Crushed Limestone Aggregate Concrete: 75/25F

Chapter 8 - Conclusions and Recommendations

General

Conclusions and recommendations are based on data generated from mixture proportions and materials used in this research. These data represent results from mixtures that used six cement plant sources. One of these sources produced both a Type II and Type IL cement, one source produce a Type I cement, and all other sources produced Type II cement. Therefore, there were a total of seven cements used in this study. Both the Class C and Class F fly ash came from separate sources and only one sample was used from each source. The No. 67 gravel, No. 67 crushed limestone, and the sand came from different sources. Gravel aggregate mixtures were proportioned from three samples of each of the seven cements. Crushed limestone control mixtures were proportioned from the first sample from each of the seven cements. Each sample of cement was taken approximately one month apart. A Type A water reducing admixture was supplied by one manufacturer and it was the only chemical admixture used in the mixtures. A dosage rate of 3.05 ounces per 100 pounds of cementitious materials was used for all mixtures.

Mixtures were proportioned based on the water cementitious ratio required to produce a 3 in. slump as discussed in Chapter 3 "Concrete Mixtures." The conclusions and recommendations included herein do not consider the influence of adjusting water and/or chemical admixtures to produce similar slumps and the impact this would have on compressive strength.

Conclusions and recommendations may not be applicable for mixtures made with any other sources of materials or other mixture proportions than those used in this research.

Conclusions

A list of conclusions is provided below. Additional details are provided in the paragraphs that follow this list.

- A higher percentage of companion sets of cylinders made with gravel aggregate exceeded the acceptable range of individual cylinder strengths than specimens made with crushed limestone aggregate. The use of fly ash increased the number of companion cylinders exceeding the acceptable range.

- A change in cement sample from the same cement source can change the 28-day compressive strength by up to 21.6 percent. A change in cement source can change 28-day compressive strength by up to 31.8 percent when comparing all samples from each cement source. This percent change was reduced from 31.8 percent to 16.1 percent for 28-day compressive strength results when the results from the three samples were averaged and compared with results from other cement sources.
- Percent change in 28-day strengths due to changes in cement or cement sample increases when 25% fly ash is included in the mixture.
- Cement E (Type IL) produced the highest 56-day compressive strengths when results from all three cement samples were averaged.
- Gravel aggregate mixes proportioned with either 25% Class C or Class F fly ash produced less compressive strength than mixes proportioned with 100% cement.
- Compressive strengths of gravel aggregate mixtures are on average 63 percent of similar crushed limestone mixes.
- Crushed limestone mixtures proportioned with 25% Class C fly ash produced strengths that exceed mixtures proportioned with 100% cement. Mixtures proportioned with 25% Class F fly ash produced less strength than mixtures proportioned with 100% cement.
- Trends in mortar cube strengths do not always reflect trends in concrete strengths.
- The slump increased with the use of 25% fly ash. Class C fly ash had more influence on slump than Class F fly ash.
- Cement source and cement sample has influence on slump.
- The standard deviation of compressive strengths for gravel aggregate concrete increases when 25% fly ash is used in the mixture.
- When mixture proportions are held constant, fresh properties have little to no influence on 28-day compressive strengths of non-air entrained concrete.

Influence of Testing on Compressive Strength

The range of individual compressive strengths associated with companion cylinders of a set is influenced by the type of coarse aggregate and the type of cementitious materials used in the mix. The acceptable range of 10.6 percent is provided in AASHTO T 22 / ASTM C 39 for three 4 in. X 8 in. companion specimens that are made under laboratory conditions. Crushed

limestone aggregate concrete produced the least number of sets of companion cylinders outside this acceptable range. The percentage of cylinder sets of crushed limestone aggregate mixes that exceed the maximum range was only 2.4 percent.

Gravel aggregate mixes had 33.3 percent of the sets of companion cylinders that exceeded the acceptable range. 18.8 percent of the sets of companion cylinders of gravel aggregate concrete made with 100% cement exceeded the acceptable range. There were 32 out of 112 sets of companion cylinders made from mixtures with 75% cement and 25% Class C fly ash that exceeded the acceptable range or 28.6 percent. There were 33 out of 112 sets of companion cylinders made from mixtures with 75% cement and 25% Class F fly ash that exceeded the acceptable range or 29.5 percent. There were considerably more sets of companion cylinders that exceeded the acceptable range when using gravel aggregate when compared to crushed limestone aggregate and this trend increased with the use of fly ash to replace cement.

Influence of Aggregate Type on Compressive Strength

The compressive strength data of this research shows that gravel aggregate produces compressive strengths that are lower than mixtures with identical paste contents (by weight) and w/cm's made with crushed limestone aggregate. When comparing results of average 28-day compressive strengths from all cement samples, mixtures proportioned with 100% cement and gravel aggregate had compressive strengths of 67.2 percent of similar mixes made with crushed limestone. Mixtures proportioned with 75% cement and 25% Class C fly ash and gravel aggregate had compressive strengths of 54.6 percent of similar mixes with crushed limestone. Mixtures proportioned with 75% cement and 25% Class F fly ash and gravel aggregate had compressive strengths of 64.3 percent of similar mixes with crushed limestone.

Influence of Class C and Class F Fly Ash on Compressive Strength

Average test results for 28-day compressive strengths in this research show that mixtures proportioned with gravel aggregates and 25% Class C fly ash produce 88.1 percent of the compressive strength as similar mixtures with 100% cement. Average data generated in this research show that mixtures proportioned with gravel aggregates and 25% Class F fly ash produce 85.3 percent of the compressive as similar mixtures with 100% cement. The trend for

this research was that when either Class C or Class F fly ash was used to replace cement, compressive strengths were less than similar mixes proportioned with 100% cement. The only exception was when 25% Class C fly ash and 25% Class F fly ash with Cement C, sample 3 (CS-C-3). This cement sample produced 28-day compressive strengths that exceeded the 28-day compressive strengths of gravel aggregate concrete proportioned with 100% cement.

The trend was not consistent for mixes made with crushed limestone aggregate. When cement was replaced with 25% Class C fly ash, all of the mixtures made with crushed limestone produced compressive strengths that were greater than similar mixes with 100% cement. When cement was replaced with 25% Class F fly ash, all of the mixtures made with crushed limestone produced compressive strengths that were less than similar mixes with 100% cement.

Influence of Changing Cement Source and Sample of Cement Sources on 28-Day Compressive Strength

Making a change in the cement, whether changing source, sample, or type, has significant influence on 28-day compressive strength. The greatest change in 28-day compressive strength of gravel aggregate mixes proportioned with 100% cement occurred between using Cement D, sample 2 (CS-D-2) and Cement G, sample 1(CS-G-1). The 28-day compressive strengths for CS-D-2 and CS-G-1 were 5,333 psi and 4,125 psi, respectfully. This 1,208 psi difference in compressive strength represents a percent change of 22.7 based on the higher compressive strength. Cement D and Cement G are both Type II cements.

Changing cements has an ever greater influence on compressive strength when fly ash is included in the mixture. The greatest change in 28-day gravel aggregate concrete compressive strength proportioned with 75% cement and 25% Class C fly ash (75/25C) that was attributed to changing cement was between using Cement C, sample 3 (CS-C-3) and Cement A, sample 2 (CS-A-2). The 28-day compressive strengths for CS-C-3 and CS-A-2 were 4,863 psi and 3,383 psi, respectfully. This 1,480 psi difference in compressive strength represents a percent change of 30.4 percent based on the higher compressive strength. Cement C is a Type I cement and Cement A is a Type II cement.

The greatest change in 28-day gravel aggregate compressive strength that can be attribute to changing cements occurred with mixes proportioned with 75% cement and 25% Class F fly ash (75/25F). This changed occurred when using Cement C, sample 3 (CS-C-3) and Cement A, sample 2 (CS-A-2). The 28-day compressive strengths for CS-C-3 and CS-A-2 were 4,930 psi and 3,360 psi, respectfully. This 1,570 psi difference in compressive strength represents a percent change of 31.8 percent based on the higher compressive strength. Cement C is a Type I cement and Cement A is a Type II cement.

Changing cement for mixtures proportioned with crushed limestone did not have as much influence on 28-day compressive strength as mixtures proportioned with gravel aggregates. Changing cement can change the 28-day compressive strength of crushed limestone mixes by 9.9 percent for mixtures proportioned with 100% cement (100) or 75% cement and 25% Class C fly ash (75/25C). Mixtures made with crushed limestone aggregate and 75% cement and 25% Class F fly ash showed a percent change of 12.0 percent. Changing cements has a greater influence on 28-day compressive strengths of gravel aggregate concrete than crushed limestone aggregate concrete.

The Type IL cement used in this research performed similarly to the Type I and Type II cements. When evaluating average data of all samples for particular cement, Type IL cement was the best performer with respect to 28-day compressive strengths for mixes proportioned with 75% cement and 25% Class C fly ash (75/25C). Using these same average data, Type IL cement provided the highest 56 day compressive strengths for all categories of gravel aggregate concrete mixtures.

Influence of Cement Sample on Compressive Strength

Cement samples from the same source also have influence on 28-day compressive strength. The greatest change in 28-day compressive strength of gravel aggregate mixes with 100% cement (100) occurred when using Cement D, sample 2 (CS-D-2) and Cement D, sample 1 (CS-D-1). The 28-day compressive strengths for CS-D-2 and CS-D-1 were 5,333 psi and 4,560 psi, respectfully. This 773 psi represents a percent change of 14.5 percent based on the higher compressive strength. Cement D was Type II cement.

Using different cement samples from the same source has an ever greater influence on compressive strength when fly ash is added to the mixture. The greatest change in 28-day gravel aggregate compressive strength on mixes 75% cement and 25% Class C fly ash (75/25C) occurred when using Cement C, sample 3 (CS-C-3) and Cement C, sample 1 (CS-C-1). The 28-day compressive strengths for CS-C-3 and CS-C-1 were 4,863 psi and 3,815 psi, respectfully. This 1,048 psi represents a percent change of 21.6 percent based on the higher compressive strength. Cement C is a Type I cement.

The greatest change in 28-day gravel aggregate compressive strength on mixes 75% cement and 25% Class F fly ash (75/25F) occurred when using Cement C, sample 3 (CS-C-3) and Cement C, sample 1 (CS-C-1). The 28-day compressive strengths for CS-C-3 and CS-C-1 were 4,930 psi and 3,880 psi, respectfully. This 1,050 psi represents a percent change of 21.3 percent based on the higher compressive strength.

Recommendations

Number of 4 in. X 8 in. Companion Cylinders

We recommend that MDOT engineers increase the number of 28-day cylinders required for a compressive strength test from two to three when using gravel aggregate concrete. This increase in number of individual tests is needed because of high variability associated with testing gravel aggregate concrete. This high variability was demonstrated in this study by the number of companion cylinder sets that exceeded the recommended range of 10.6 provided in AASHTO T 22 / ASTM C 39. Three individual results per test would allow the Department to evaluate and discard an individual result that exceeded the recommend range. This recommendation applies only to 4 in. X 8 in. cylinders. No other specimen size was evaluated in this research.

Cement Source Change

We recommend that MDOT engineers require Contractors to provide compressive strength data using the proposed cement source before allowing a cement source change. Data in this study show potential strength loss or gain with cement source changes and the Contractor

should ensure that the new cement source will produce concrete with strengths that meet or exceed project requirements.

Cement Type

We recommend that MDOT engineers allow the use of Type IL cement in all classes of concrete. This recommendation is because of its performance with respect to compressive strength when used with Class C fly ash and 56 day compressive strengths.

Mixtures Based on Field Experience

Mixtures proportioned for MDOT projects on the basis of field experience currently use standard deviation that is calculated from 10 consecutive strength test results produced within the past 12 months. Since there are no other requirements for these 10 consecutive tests, standard deviation could potentially be calculated on strength test results from one sample of cement. Average compressive strength data from the seven cement sources of this research show that a 16.1 percent change in compressive strength can be expected when changing cement sources. We recommend that MDOT engineers modify requirements for proportioning mixtures based on field experience to include a minimum overdesign of 16 percent. Equation 3 should be added to section 804.02.10.1.1 with a requirement that the required average compressive strength has to be the greater of Equation 2 or 3.

$$f'_{cr} = f'_c + 1.43s \quad \textbf{(2)}$$

$$f'_{cr} = f'_c + 0.16 * f'_c \quad \textbf{(3)}$$

Research Opportunities

1. A research project should be conducted to validate data of this study on concrete mixtures that meet MDOT's criteria for chemical admixtures, strength, and fresh properties using various sources of gravel aggregate.
2. A research project should be conducted to determine the influence of source of fly ash on compressive strength of concrete.
3. A research project should be conducted to determine the influence of source of gravel aggregate on companion cylinder compressive strengths.

References

1. Mississippi Department of Transportation Concrete Field Manual. Jackson: Mississippi Department of Transportation, 2011.
2. Fulton, Frederick Sandrok, Concrete Technology – A South African Handbook (Portland Cement Institute, 1977) 309-316.
3. Kosmatka, Steven H., Beatrix Kerkhoff, and William C. Panarese. Design and Control of Concrete Mixtures. 15th ed. Skokie: Portland Cement Association, 2002.
4. Mindess, Sidney, and J. Francis Young. Concrete. (Englwood Cliffs: Prentice-Hall, Inc., 1981) 344-348.
5. Concrete in Practice: What, why & how? CIP 30 – Supplementary Cementitious Materials (National Ready Mixed Concrete Association, Silver Springs, MD, 2000)
6. Edson, Fowler, Juenger, Suh, and Moon Won. Effects of Supplementary Cementing Materials and Early Strength of Concrete. Center for Transportation Research at The University of Texas at Austin , 2007, Rev. 2008.
7. Air Entrainment and Concrete: (The Aberdeen Group, 1976)
8. Fowler, David W. and Pedro N. Quiroga. The Effects of Aggregates Characteristics on the Performance of Portland Cement Concrete. (Austin: The University of Texas at Austin, 2003) 17.
9. Shilstone, Jim, "Concrete Mixture Optimization" Concrete International, June 1990: 39
10. "ASTM C595 acknowledges 15% Limestone Threshold," Cement Americas, August 23, 2012.
11. National Cooperative Highway Research Program, Research Results Digest 324: Recommended Precision Statements for AASHTO Standard Methods of Test T 22, T 104, T 105, T 154, T 186, and T 242 (Transportation Research Board, 2010) 3.

Appendix A

Raw Data:

Concrete Mixtures

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 1** Name: **Gravel A1 100** Set #: 1

Date: **5/2/2011** Mix Code: 1 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-A-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:40 AM**	% Air	**3.50**
Sample Time	**8:49 AM**	Unit Weight (pcf)	**141.88**
Slump, in.	**2.50**	Yield	**1.27**
Mix Temp.	**70.2**	Initial set, min.	**NA**
Air Temp.	**73.0**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.29**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/03/11	1 day	1440	1477
	1 day	1440	
	1 day	1550	
05/09/11	7 day	3870	3730
	7 day	3770	
	7 day	3550	
05/16/11	14 day	3710	3867
	14 day	4040	
	14 day	3850	
5/30/2011	28 day	4400	4467
	28 day	4460	
	28 day	4540	
6/27/2011	56 day	4960	4807
	56 day	4740	
	56 day	4720	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 2** Name: **Gravel A1 75/25C** Set #: 1

Date: **5/2/2011** Mix Code: 2 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-A-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:22 AM**	% Air	**2.00**
Sample Time	**9:31 AM**	Unit Weight (pcf)	**143.16**
Slump, in.	**6.50**	Yield	**1.26**
Mix Temp.	**70.5**	Initial set, min.	**NA**
Air Temp.	**72.9**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.61**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/03/11	1 day	830	883
	1 day	910	
	1 day	910	
05/09/11	7 day	3000	3190
	7 day	3260	
	7 day	3310	
05/16/11	14 day	3380	3497
	14 day	3390	
	14 day	3720	
5/30/2011	28 day	3840	3803
	28 day	3640	
	28 day	3930	
6/27/2011	56 day	3940	3867
	56 day	3870	
	56 day	3790	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 3** Name: **Gravel A1 75/25F** Set #: 1

Date: **5/2/2011** Mix Code: 3 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-A-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:05 AM**	% Air	**2.00**
Sample Time	**10:14 AM**	Unit Weight (pcf)	**142.24**
Slump, in.	**4.25**	Yield	**1.26**
Mix Temp.	**69.1**	Initial set, min.	**NA**
Air Temp.	**72.9**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.38**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/03/11	1 day	940	910
	1 day	840	
	1 day	950	
05/09/11	7 day	"2850"	3140
	7 day	3080	
	7 day	3200	
05/16/11	14 day	3670	3715
	14 day	3760	
	14 day	"3360"	
5/30/2011	28 day	4090	3910
	28 day	3730	
	28 day	"3520"	
6/27/2011	56 day	4930	4700
	56 day	4560	
	56 day	4610	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 4** Name: **Gravel A2 100** Set #: 1

Date: **6/8/2011** Mix Code: 4 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-A-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:11 PM**	% Air	**3.25**
Sample Time	**1:20 PM**	Unit Weight (pcf)	**141.92**
Slump, in.	**5.50**	Yield	**1.27**
Mix Temp.	**71.1**	Initial set, min.	**NA**
Air Temp.	**77.4**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.31**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/09/11	1 day	1600	1647
	1 day	1720	
	1 day	1620	
06/15/11	7 day	3530	3470
	7 day	3500	
	7 day	3380	
06/22/11	14 day	4230	4160
	14 day	"3760"	
	14 day	4090	
7/6/2011	28 day	4250	4303
	28 day	4400	
	28 day	4260	
8/3/2011	56 day	4880	4977
	56 day	4850	
	56 day	5200	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 5** Name: **Gravel A2 75/25C** Set #: 1

Date: **6/8/2011** Mix Code: 5 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-A-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:43 PM**	% Air	**2.25**
Sample Time	**1:52 PM**	Unit Weight (pcf)	**143.16**
Slump, in.	**6.75**	Yield	**1.26**
Mix Temp.	**70.0**	Initial set, min.	**NA**
Air Temp.	**77.8**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.62**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/09/11	1 day	830	863
	1 day	870	
	1 day	890	
06/15/11	7 day	2840	2873
	7 day	2990	
	7 day	2790	
06/22/11	14 day	3100	3195
	14 day	"2850"	
	14 day	3290	
7/6/2011	28 day	3420	3383
	28 day	3520	
	28 day	3210	
8/3/2011	56 day	3510	3695
	56 day	"4340"	
	56 day	3880	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 6** Name: **Gravel A2 75/25F** Set #: 1

Date: **6/8/2011** Mix Code: 6 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-A-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**2:22 PM**	% Air	**1.75**
Sample Time	**2:31 PM**	Unit Weight (pcf)	**142.36**
Slump, in.	**8.00**	Yield	**1.25**
Mix Temp.	**68.3**	Initial set, min.	**NA**
Air Temp.	**78.5**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.42**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/09/11	1 day	880	890
	1 day	870	
	1 day	920	
06/15/11	7 day	2520	2657
	7 day	2710	
	7 day	2740	
06/22/11	14 day	"2640"	2985
	14 day	2950	
	14 day	3020	
7/6/2011	28 day	3420	3360
	28 day	3300	
	28 day	"3890"	
8/3/2011	56 day	4310	4107
	56 day	3930	
	56 day	4080	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 7** Name: **Gravel A3 100** Set #: 1

Date: **7/20/2011** Mix Code: 7 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-A-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:04 AM**	% Air	**3.75**
Sample Time	**9:13 AM**	Unit Weight (pcf)	**141.60**
Slump, in.	**2.75**	Yield	**1.28**
Mix Temp.	**71.0**	Initial set, min.	**NA**
Air Temp.	**72.7**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.26**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/21/11	1 day	1690	1720
	1 day	1780	
	1 day	1690	
07/27/11	7 day	3790	3743
	7 day	3870	
	7 day	3570	
08/03/11	14 day	3950	3900
	14 day	3780	
	14 day	3970	
8/17/2011	28 day	4300	4483
	28 day	4530	
	28 day	4620	
9/14/2011	56 day	"4780"	5430
	56 day	5300	
	56 day	5560	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 8** Name: **Gravel A3 75/25C** Set #: 1

Date: **7/20/2011** Mix Code: 8 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-A-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:44 AM**	% Air	**2.50**
Sample Time	**9:53 AM**	Unit Weight (pcf)	**142.40**
Slump, in.	**6.75**	Yield	**1.26**
Mix Temp.	**70.5**	Initial set, min.	**NA**
Air Temp.	**73.8**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.46**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/21/11	1 day	1000	970
	1 day	980	
	1 day	930	
07/27/11	7 day	3340	3130
	7 day	2810	
	7 day	3240	
08/03/11	14 day	3170	3243
	14 day	3370	
	14 day	3190	
8/17/2011	28 day	"3310"	4010
	28 day	3840	
	28 day	4180	
9/14/2011	56 day	"3620"	4415
	56 day	4350	
	56 day	4480	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 9** Name: **Gravel A3 75/25F** Set #: 1

Date: **7/20/2011** Mix Code: 9 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-A-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:20 AM**	% Air	**2.50**
Sample Time	**10:29 AM**	Unit Weight (pcf)	**141.48**
Slump, in.	**5.00**	Yield	**1.26**
Mix Temp.	**70.0**	Initial set, min.	**NA**
Air Temp.	**75.2**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.23**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/21/11	1 day	990	967
	1 day	1010	
	1 day	900	
07/27/11	7 day	2590	2557
	7 day	2590	
	7 day	2490	
08/03/11	14 day	"3450"	3040
	14 day	3030	
	14 day	3050	
8/17/2011	28 day	3600	3530
	28 day	3460	
	28 day	"3220"	
9/14/2011	56 day	4190	4133
	56 day	4090	
	56 day	4120	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 10** Name: **Stone A1 100** Set #: 1

Date: **5/3/2011** Mix Code: 10 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-A-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1264.55	**58.54**	**58.54**	58.54	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.01**	12.01	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4088.83	189.30	190.34					
UW w/o Air:		153.74	153.74	154.59					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:18 AM**	% Air	**3.75**
Sample Time	**8:27 AM**	Unit Weight (pcf)	**150.24**
Slump, in.	**2.50**	Yield	**1.27**
Mix Temp.	**68.9**	Initial set, min.	**NA**
Air Temp.	**72.0**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	151.44
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.38**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/04/11	1 day	2660	2637
	1 day	2580	
	1 day	2670	
05/10/11	7 day	6110	5833
	7 day	5580	
	7 day	5810	
05/17/11	14 day	6420	6787
	14 day	6880	
	14 day	7060	
5/31/2011	28 day	6920	7237
	28 day	7570	
	28 day	7220	
6/28/2011	56 day	7630	7593
	56 day	7510	
	56 day	7640	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 11** Name: **Stone A1 75/25C** Set #: 1

Date: **5/3/2011** Mix Code: 11 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-A-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.39	**57.47**	**57.47**	57.47	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4065.67	188.23	189.26					
UW w/o Air:		152.87	152.87	153.71					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:05 AM**	% Air	**2.50**
Sample Time	**9:14 AM**	Unit Weight (pcf)	**150.84**
Slump, in.	**4.25**	Yield	**1.25**
Mix Temp.	**68.3**	Initial set, min.	**NA**
Air Temp.	**71.1**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	150.58
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.53**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/04/11	1 day	1460	1467
	1 day	1460	
	1 day	1480	
05/10/11	7 day	5450	5340
	7 day	5220	
	7 day	5350	
05/17/11	14 day	6500	6660
	14 day	7030	
	14 day	6450	
5/31/2011	28 day	7850	7920
	28 day	7920	
	28 day	7990	
6/28/2011	56 day	8570	8570
	56 day	8520	
	56 day	8620	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 12** Name: **Stone A1 75/25F** Set #: 1

Date: **5/3/2011** Mix Code: 12 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-A-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.44	1217.27	**56.35**	**56.35**	56.35	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4041.55	187.11	188.14					
UW w/o Air:		151.97	151.97	152.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:47 AM**	% Air	**2.25**
Sample Time	**9:56 AM**	Unit Weight (pcf)	**150.88**
Slump, in.	**3.50**	Yield	**1.25**
Mix Temp.	**69.1**	Initial set, min.	**NA**
Air Temp.	**71.8**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	149.69
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.54**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/04/11	1 day	1560	1567
	1 day	1610	
	1 day	1530	
05/10/11	7 day	4560	4720
	7 day	4860	
	7 day	4740	
05/17/11	14 day	5520	5513
	14 day	5480	
	14 day	5540	
5/31/2011	28 day	6650	6573
	28 day	6470	
	28 day	6600	
6/28/2011	56 day	7640	7313
	56 day	7310	
	56 day	6990	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 13** Name: **Gravel B1 100** Set #: 1

Date: **5/4/2011** Mix Code: 13 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-B-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:14 AM**	% Air	**4.00**
Sample Time	**8:23 AM**	Unit Weight (pcf)	**140.72**
Slump, in.	**5.25**	Yield	**1.29**
Mix Temp.	**64.8**	Initial set, min.	**NA**
Air Temp.	**70.4**	Relative Yield	**1.030**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.00**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/05/11	1 day	1580	1673
	1 day	1640	
	1 day	1800	
05/11/11	7 day	3850	3747
	7 day	3740	
	7 day	3650	
05/18/11	14 day	4180	4163
	14 day	4060	
	14 day	4250	
6/1/2011	28 day	4730	4727
	28 day	4800	
	28 day	4650	
6/29/2011	56 day	4990	4927
	56 day	4790	
	56 day	5000	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 14** Name: **Gravel B1 75/25C** Set #: 1

Date: **5/4/2011** Mix Code: 14 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

Comments / Notes / Observations

Volumetric Air Meter leak - air not tested.
Calculated air content by unit weight

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-B-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:01 AM**	% Air	**1.60**
Sample Time	**9:10 AM**	Unit Weight (pcf)	**143.72**
Slump, in.	**8.25**	Yield	**1.25**
Mix Temp.	**66.2**	Initial set, min.	**NA**
Air Temp.	**72.0**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.75**

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/05/11	1 day	1040	1023
	1 day	990	
	1 day	1040	
05/11/11	7 day	3390	3380
	7 day	3470	
	7 day	3280	
05/18/11	14 day	3660	3677
	14 day	3730	
	14 day	3640	
6/1/2011	28 day	4040	4120
	28 day	4200	
	28 day	4120	
6/29/2011	56 day	"3930"	4355
	56 day	4300	
	56 day	4410	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 15** Name: **Gravel B1 75/25F** Set #: 1

Date: **5/4/2011** Mix Code: 15 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-B-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:15 AM**	% Air	**1.75**
Sample Time	**10:24 AM**	Unit Weight (pcf)	**141.84**
Slump, in.	**6.50**	Yield	**1.26**
Mix Temp.	**67.9**	Initial set, min.	**NA**
Air Temp.	**72.2**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.28**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/05/11	1 day	1130	1130
	1 day	1170	
	1 day	1090	
05/11/11	7 day	2870	2970
	7 day	3110	
	7 day	2930	
05/18/11	14 day	3500	3563
	14 day	3610	
	14 day	3580	
6/1/2011	28 day	"3860"	4295
	28 day	4370	
	28 day	4220	
6/29/2011	56 day	4350	4387
	56 day	4160	
	56 day	4650	

Technician who conducted tests:

State Study No. 239 - Influences oo Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 16** Name: **Gravel B2 100** Set #: 1

Date: **6/9/2011** Mix Code: 16 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-B-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:06 AM**	% Air	**4.00**
Sample Time	**9:15 AM**	Unit Weight (pcf)	**141.48**
Slump, in.	**4.50**	Yield	**1.28**
Mix Temp.	**70.2**	Initial set, min.	**NA**
Air Temp.	**72.9**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.20**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/10/11	1 day	1870	1883
	1 day	1950	
	1 day	1830	
06/16/11	7 day	"3720"	4340
	7 day	4410	
	7 day	4270	
06/23/11	14 day	"3950"	4505
	14 day	4330	
	14 day	4680	
7/7/2011	28 day	4790	4867
	28 day	4860	
	28 day	4950	
8/4/2011	56 day	5480	5493
	56 day	5410	
	56 day	5590	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 17** Name: **Gravel B2 75/25C** Set #: 1

Date: **6/9/2011** Mix Code: 17 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-B-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:42 AM**	% Air	**2.75**
Sample Time	**9:51 AM**	Unit Weight (pcf)	**142.32**
Slump, in.	**7.50**	Yield	**1.26**
Mix Temp.	**68.0**	Initial set, min.	**NA**
Air Temp.	**74.0**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.41**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/10/11	1 day	1100	1137
	1 day	1090	
	1 day	1220	
06/16/11	7 day	3440	3320
	7 day	3150	
	7 day	3370	
06/23/11	14 day	3580	3625
	14 day	3670	
	14 day	"3120"	
7/7/2011	28 day	4380	4333
	28 day	4260	
	28 day	4360	
8/4/2011	56 day	4400	4407
	56 day	4330	
	56 day	4490	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 18** Name: **Gravel B2 75/25F** Set #: 1

Date: **6/9/2011** Mix Code: 18 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-B-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:17 AM**	% Air	**2.25**
Sample Time	**10:26 AM**	Unit Weight (pcf)	**141.96**
Slump, in.	**6.00**	Yield	**1.26**
Mix Temp.	**67.3**	Initial set, min.	**NA**
Air Temp.	**74.3**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.32**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/10/11	1 day	1260	1283
	1 day	1290	
	1 day	1300	
06/16/11	7 day	3090	3015
	7 day	"3280"	
	7 day	2940	
06/23/11	14 day	3680	3503
	14 day	3390	
	14 day	3440	
7/7/2011	28 day	4170	4103
	28 day	4050	
	28 day	4090	
8/4/2011	56 day	"3690"	4160
	56 day	4360	
	56 day	3960	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 19** Name: **Gravel B3 100** Set #: 1

Date: **7/21/2011** Mix Code: 19 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-B-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:19 AM**	% Air	**4.75**
Sample Time	**8:28 AM**	Unit Weight (pcf)	**140.56**
Slump, in.	**5.50**	Yield	**1.29**
Mix Temp.	**68.7**	Initial set, min.	**NA**
Air Temp.	**72.0**	Relative Yield	**1.030**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.00**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/22/11	1 day	1220	1267
	1 day	1300	
	1 day	1280	
07/28/11	7 day	3850	3840
	7 day	3890	
	7 day	3780	
08/04/11	14 day	"3670"	4305
	14 day	4120	
	14 day	4490	
8/18/2011	28 day	4570	4750
	28 day	5000	
	28 day	4680	
9/15/2011	56 day	4800	4803
	56 day	4800	
	56 day	4810	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 20** Name: **Gravel B3 75/25C** Set #: 1

Date: **7/21/2011** Mix Code: 20 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-B-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:57 AM**	% Air	**2.75**
Sample Time	**9:06 AM**	Unit Weight (pcf)	**142.12**
Slump, in.	**7.50**	Yield	**1.26**
Mix Temp.	**67.1**	Initial set, min.	**NA**
Air Temp.	**72.4**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.39**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/22/11	1 day	1310	1287
	1 day	1340	
	1 day	1210	
07/28/11	7 day	3330	3335
	7 day	"2970"	
	7 day	3340	
08/04/11	14 day	3530	3540
	14 day	3550	
	14 day	"3140"	
8/18/2011	28 day	4200	4073
	28 day	3960	
	28 day	4060	
9/15/2011	56 day	4320	4340
	56 day	"3720"	
	56 day	4360	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 21** Name: **Gravel B3 75/25F** Set #: 1

Date: **7/21/2011** Mix Code: 21 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-B-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:35 AM**	% Air	**2.75**
Sample Time	**9:44 AM**	Unit Weight (pcf)	**141.88**
Slump, in.	**7.25**	Yield	**1.26**
Mix Temp.	**66.0**	Initial set, min.	**NA**
Air Temp.	**72.0**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.33**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/22/11	1 day	1760	1820
	1 day	1670	
	1 day	2030	
07/28/11	7 day	2940	2940
	7 day	3050	
	7 day	2830	
08/04/11	14 day	3060	3190
	14 day	3380	
	14 day	3130	
8/18/2011	28 day	4020	3800
	28 day	3680	
	28 day	3700	
9/15/2011	56 day	4570	4375
	56 day	"3720"	
	56 day	4180	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER Mix 22 Name: **Stone B1 100** Set #: 1

Date: **5/5/2011** Mix Code: 22 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-B-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1264.55	**58.54**	**58.54**	58.54	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.01**	12.01	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4088.83	189.30	190.34					
UW w/o Air:		153.74	153.74	154.59					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:02 PM**	% Air	**3.75**
Sample Time	**1:11 PM**	Unit Weight (pcf)	**150.20**
Slump, in.	**3.00**	Yield	**1.27**
Mix Temp.	**68.4**	Initial set, min.	**NA**
Air Temp.	**73.4**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	151.44
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.37**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/06/11	1 day	2780	2740
	1 day	2630	
	1 day	2810	
05/12/11	7 day	6510	6170
	7 day	6010	
	7 day	5990	
05/19/11	14 day	6570	6463
	14 day	6390	
	14 day	6430	
6/2/2011	28 day	7110	7023
	28 day	7080	
	28 day	6880	
6/30/2011	56 day	7660	7623
	56 day	7670	
	56 day	7540	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER Mix 23 Name: **Stone B1 75/25C** Set #: 1

Date: **5/5/2011** Mix Code: 23 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-B-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.39	**57.47**	**57.47**	57.47	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4065.67	188.23	189.26					
UW w/o Air:		152.87	152.87	153.71					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:46 PM**	% Air	**2.75**
Sample Time	**1:54 PM**	Unit Weight (pcf)	**150.72**
Slump, in.	**5.50**	Yield	**1.26**
Mix Temp.	**67.8**	Initial set, min.	**NA**
Air Temp.	**73.3**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	150.58
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.50**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/06/11	1 day	1430	1413
	1 day	1400	
	1 day	1410	
05/12/11	7 day	5410	5647
	7 day	5810	
	7 day	5720	
05/19/11	14 day	6690	6550
	14 day	6410	
	14 day	6550	
6/2/2011	28 day	7320	7277
	28 day	7280	
	28 day	7230	
6/30/2011	56 day	7760	8067
	56 day	8070	
	56 day	8370	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 24** Name: **Stone B1 75/25F** Set #: 1

Date: **5/5/2011** Mix Code: 24 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-B-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.44	1217.27	**56.35**	**56.35**	56.35	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4041.55	187.11	188.14					
UW w/o Air:		151.97	151.97	152.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**2:23 PM**	% Air	**2.25**
Sample Time	**2:32 PM**	Unit Weight (pcf)	**151.32**
Slump, in.	**4.00**	Yield	**1.24**
Mix Temp.	**68.6**	Initial set, min.	**NA**
Air Temp.	**73.6**	Relative Yield	**0.990**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	149.69
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.65**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/06/11	1 day	1700	1700
	1 day	1700	
	1 day	1700	
05/12/11	7 day	4750	4730
	7 day	4690	
	7 day	4750	
05/19/11	14 day	5270	5323
	14 day	5390	
	14 day	5310	
6/2/2011	28 day	5950	6023
	28 day	6050	
	28 day	6070	
6/30/2011	56 day	7290	7357
	56 day	7210	
	56 day	7570	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 25** Name: **Gravel C1 100** Set #: 1

Date: **5/9/2011** Mix Code: 25 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-C-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:13 AM**	% Air	**3.75**
Sample Time	**9:22 AM**	Unit Weight (pcf)	**141.60**
Slump, in.	**3.00**	Yield	**1.28**
Mix Temp.	**70.8**	Initial set, min.	**NA**
Air Temp.	**73.1**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.23**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/10/11	1 day	2070	2170
	1 day	2310	
	1 day	2130	
05/16/11	7 day	3610	3693
	7 day	3720	
	7 day	3750	
05/23/11	14 day	4030	4113
	14 day	4260	
	14 day	4050	
6/6/2011	28 day	4450	4373
	28 day	4470	
	28 day	4200	
7/4/2011	56 day	4520	4790
	56 day	4990	
	56 day	4860	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 26** Name: **Gravel C1 75/25C** Set #: 1

Date: **5/9/2011** Mix Code: 26 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-C-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:54 AM**	% Air	**2.50**
Sample Time	**10:03 AM**	Unit Weight (pcf)	**142.52**
Slump, in.	**5.75**	Yield	**1.26**
Mix Temp.	**68.2**	Initial set, min.	**NA**
Air Temp.	**73.8**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.46**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/10/11	1 day	1410	1373
	1 day	1370	
	1 day	1340	
05/16/11	7 day	3010	3093
	7 day	3210	
	7 day	3060	
05/23/11	14 day	3570	3510
	14 day	"3190"	
	14 day	3450	
6/6/2011	28 day	3830	3815
	28 day	"4380"	
	28 day	3800	
7/4/2011	56 day	4020	4150
	56 day	"3630"	
	56 day	4280	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER Mix 27 Name: **Gravel C1 75/25F** Set #: 1

Date: **5/9/2011** Mix Code: 27 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-C-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:41 AM**	% Air	**2.00**
Sample Time	**10:50 AM**	Unit Weight (pcf)	**141.88**
Slump, in.	**4.75**	Yield	**1.26**
Mix Temp.	**71.9**	Initial set, min.	**NA**
Air Temp.	**74.1**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.30**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/10/11	1 day	1330	1330
	1 day	1320	
	1 day	1340	
05/16/11	7 day	2980	3053
	7 day	3150	
	7 day	3030	
05/23/11	14 day	3400	3390
	14 day	3550	
	14 day	3220	
6/6/2011	28 day	"3400"	3880
	28 day	4000	
	28 day	3760	
7/4/2011	56 day	4400	4323
	56 day	4250	
	56 day	4320	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 28** Name: **Gravel C2 100** Set #: 1

Date: **6/13/2011** Mix Code: 28 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-C-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:37 PM**	% Air	**3.00**
Sample Time	**1:46 PM**	Unit Weight (pcf)	**141.84**
Slump, in.	**3.50**	Yield	**1.28**
Mix Temp.	**75.7**	Initial set, min.	**NA**
Air Temp.	**81.7**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.29**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/14/11	1 day	2360	2233
	1 day	2280	
	1 day	2060	
06/20/11	7 day	4290	4267
	7 day	4290	
	7 day	4220	
06/27/11	14 day	4560	4557
	14 day	4530	
	14 day	4580	
7/11/2011	28 day	4490	4667
	28 day	4630	
	28 day	4880	
8/8/2011	56 day	4670	4917
	56 day	4970	
	56 day	5110	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 29** Name: **Gravel C2 75/25C** Set #: 1

Date: **6/13/2011** Mix Code: 29 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-C-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**2:11 AM**	% Air	**2.50**
Sample Time	**2:20 AM**	Unit Weight (pcf)	**142.60**
Slump, in.	**5.75**	Yield	**1.26**
Mix Temp.	**72.2**	Initial set, min.	**NA**
Air Temp.	**81.0**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.48**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/14/11	1 day	1240	1360
	1 day	1420	
	1 day	1420	
06/20/11	7 day	3570	3595
	7 day	3620	
	7 day	"3170"	
06/27/11	14 day	3540	3720
	14 day	3760	
	14 day	3860	
7/11/2011	28 day	4040	4130
	28 day	4210	
	28 day	4140	
8/8/2011	56 day	4210	4453
	56 day	4640	
	56 day	4510	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 30** Name: **Gravel C2 75/25F** Set #: 1

Date: **6/13/2011** Mix Code: 30 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-C-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**2:48 AM**	% Air	**2.00**
Sample Time	**2:57 AM**	Unit Weight (pcf)	**142.28**
Slump, in.	**4.50**	Yield	**1.26**
Mix Temp.	**72.2**	Initial set, min.	**NA**
Air Temp.	**80.6**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.40**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/14/11	1 day	1360	1353
	1 day	1310	
	1 day	1390	
06/20/11	7 day	3020	3100
	7 day	3300	
	7 day	2980	
06/27/11	14 day	3460	3427
	14 day	3420	
	14 day	3400	
7/11/2011	28 day	3900	4020
	28 day	3950	
	28 day	4210	
8/8/2011	56 day	4200	4430
	56 day	4580	
	56 day	4510	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 31** Name: **Gravel C3 100** Set #: 1

Date: **7/25/2011** Mix Code: 31 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-C-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**12:21 PM**	% Air	**3.50**
Sample Time	**12:30 PM**	Unit Weight (pcf)	**141.36**
Slump, in.	**3.00**	Yield	**1.28**
Mix Temp.	**74.8**	Initial set, min.	**NA**
Air Temp.	**75.1**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.20**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/26/11	1 day	1900	1930
	1 day	1920	
	1 day	1970	
08/01/11	7 day	"3530"	3965
	7 day	4010	
	7 day	3920	
08/08/11	14 day	4190	4183
	14 day	4230	
	14 day	4130	
8/22/2011	28 day	4470	4413
	28 day	4480	
	28 day	4290	
9/19/2011	56 day	4930	4940
	56 day	4830	
	56 day	5060	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 32** Name: **Gravel C3 75/25C** Set #: 1

Date: **7/25/2011** Mix Code: 32 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-C-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:04 PM**	% Air	**2.50**
Sample Time	**1:13 PM**	Unit Weight (pcf)	**142.76**
Slump, in.	**4.50**	Yield	**1.26**
Mix Temp.	**70.7**	Initial set, min.	**NA**
Air Temp.	**75.6**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.55**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/26/11	1 day	1320	1280
	1 day	1250	
	1 day	1270	
08/01/11	7 day	3000	3013
	7 day	3110	
	7 day	2930	
08/08/11	14 day	4410	4457
	14 day	4530	
	14 day	4430	
8/22/2011	28 day	4860	4863
	28 day	4870	
	28 day	4860	
9/19/2011	56 day	4380	4720
	56 day	5060	
	56 day	"4150"	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 33** Name: **Gravel C3 75/25F** Set #: 1

Date: **7/25/2011** Mix Code: 33 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-C-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:46 PM**	% Air	**2.25**
Sample Time	**1:55 PM**	Unit Weight (pcf)	**141.56**
Slump, in.	**4.25**	Yield	**1.26**
Mix Temp.	**69.8**	Initial set, min.	**NA**
Air Temp.	**75.2**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.25**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/26/11	1 day	1230	1283
	1 day	1310	
	1 day	1310	
08/01/11	7 day	2930	2880
	7 day	2900	
	7 day	2810	
08/08/11	14 day	4320	4400
	14 day	4440	
	14 day	4440	
8/22/2011	28 day	4860	4930
	28 day	4920	
	28 day	5010	
9/19/2011	56 day	4800	4777
	56 day	4710	
	56 day	4820	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 34** Name: **Stone C1 100** Set #: 1

Date: **5/10/2011** Mix Code: 34 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-C-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1264.55	**58.54**	**58.54**	58.54	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.01**	12.01	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4088.83	189.30	190.34					
UW w/o Air:		153.74	153.74	154.59					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**2:09 PM**	% Air	**3.50**
Sample Time	**2:18 PM**	Unit Weight (pcf)	**150.24**
Slump, in.	**1.75**	Yield	**1.27**
Mix Temp.	**72.5**	Initial set, min.	**NA**
Air Temp.	**76.0**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	151.44
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**45.39**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/11/11	1 day	3360	3320
	1 day	3280	
	1 day	3320	
05/17/11	7 day	5590	5693
	7 day	5660	
	7 day	5830	
05/24/11	14 day	6050	6153
	14 day	6260	
	14 day	6150	
6/7/2011	28 day	6610	6577
	28 day	6570	
	28 day	6550	
7/5/2011	56 day	7040	7110
	56 day	7260	
	56 day	7030	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 35** Name: **Stone C1 75/25C** Set #: 1

Date: **5/10/2011** Mix Code: 35 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-C-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.39	**57.47**	**57.47**	57.47	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4065.67	188.23	189.26					
UW w/o Air:		152.87	152.87	153.71					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**2:46 PM**	% Air	**2.25**
Sample Time	**2:55 PM**	Unit Weight (pcf)	**151.56**
Slump, in.	**3.00**	Yield	**1.25**
Mix Temp.	**71.5**	Initial set, min.	**NA**
Air Temp.	**75.6**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	150.58
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**45.72**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/11/11	1 day	2320	2295
	1 day	2270	
	1 day		
05/17/11	7 day	5950	5997
	7 day	5900	
	7 day	6140	
05/24/11	14 day	6570	6590
	14 day	6520	
	14 day	6680	
6/7/2011	28 day	7640	7657
	28 day	7840	
	28 day	7490	
7/5/2011	56 day	7980	7993
	56 day	7940	
	56 day	8060	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 36** Name: **Stone C1 75/25F** Set #: 1

Date: **5/10/2011** Mix Code: 36 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-C-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.44	1217.27	**56.35**	**56.35**	56.35	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4041.55	187.11	188.14					
UW w/o Air:		151.97	151.97	152.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**3:19 PM**	% Air	**2.25**
Sample Time	**3:28 PM**	Unit Weight (pcf)	**150.68**
Slump, in.	**3.25**	Yield	**1.25**
Mix Temp.	**70.8**	Initial set, min.	**NA**
Air Temp.	**75.8**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	149.69
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**45.50**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/11/11	1 day	2300	2210
	1 day	2190	
	1 day	2140	
05/17/11	7 day	4670	4810
	7 day	4950	
	7 day	"4400"	
05/24/11	14 day	5370	5243
	14 day	5270	
	14 day	5090	
6/7/2011	28 day	5660	5783
	28 day	5930	
	28 day	5760	
7/5/2011	56 day	6680	6720
	56 day	6650	
	56 day	6830	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 37** Name: **Gravel D1 100** Set #: 1

Date: **4/18/2011** Mix Code: 37 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Source	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-D-1**	3.15		
Cement 2:	0.00		**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00		**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00		**0.00**	**0.00**					
Coarse Aggregate 3:	0.00		**0.00**	**0.00**					
Coarse Aggregate 4:	0.00		**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04		1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:45 PM**	% Air	**2.75**	Des. w/c	0.450
Sample Time	**1:54 PM**	Unit Weight (pcf)	**142.44**	Act. w/c	0.450
Slump, in.	**3.00**	Yield	**1.27**	Des.Un.Wt.	141.42
Mix Temp.	**75.6**	Initial set, min.	**NA**	Fine/Coarse by Vol	0.624
Air Temp.	**72.4**	Relative Yield	**1.016**	Bag Factor	5.6

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.43**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/19/11	1 day	1960	1923
	1 day	1930	
	1 day	1880	
04/25/11	7 day	3740	3780
	7 day	3860	
	7 day	3740	
05/02/11	14 day	4260	4283
	14 day	4520	
	14 day	4070	
5/16/2011	28 day	4690	4560
	28 day	"4960"	
	28 day	4430	
6/13/2011	56 day	5020	4960
	56 day	4820	
	56 day	5040	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 38** Name: **Gravel D1 75/25C** Set #: 1

Date: **4/25/2011** Mix Code: 38 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-D-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:00 AM**	% Air	**2.25**
Sample Time	**9:09 AM**	Unit Weight (pcf)	**143.16**
Slump, in.	**6.00**	Yield	**1.26**
Mix Temp.	**72.5**	Initial set, min.	**NA**
Air Temp.	**72.5**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.61**

Comments / Notes / Observations

Opened new bucket of cement

Opened new bucket of C Ash

Volumetric Air - 2.25 (First roll)

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/26/11	1 day	1430	1437
	1 day	1490	
	1 day	1390	
05/02/11	7 day	2810	2877
	7 day	2870	
	7 day	2950	
05/09/11	14 day	3380	3507
	14 day	3540	
	14 day	3600	
5/23/2011	28 day	3760	3740
	28 day	3700	
	28 day	3760	
6/20/2011	56 day	3930	3890
	56 day	3920	
	56 day	3820	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 39** Name: **Gravel D1 75/25F** Set #: 1

Date: **4/25/2011** Mix Code: 39 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-D-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:10 AM**	% Air	**2.25**	Des. w/c	0.450
Sample Time	**10:19 AM**	Unit Weight (pcf)	**142.16**	Act. w/c	0.450
Slump, in.	**4.50**	Yield	**1.26**	Des.Un.Wt.	139.67
Mix Temp.	**70.8**	Initial set, min.	**NA**	Fine/Coarse by Vol	0.601
Air Temp.	**72.7**	Relative Yield	**1.010**	Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.36**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/26/11	1 day	1460	1407
	1 day	1410	
	1 day	1350	
05/02/11	7 day	2740	2703
	7 day	2630	
	7 day	2740	
05/09/11	14 day	3410	3327
	14 day	3350	
	14 day	3220	
5/23/2011	28 day	"4080"	3635
	28 day	3530	
	28 day	3740	
6/20/2011	56 day	"3870"	4440
	56 day	4260	
	56 day	4620	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 40** Name: **Gravel D2 100** Set #: 1

Date: **6/6/2011** Mix Code: 40 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-D-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**12:47 PM**	% Air	**3.00**
Sample Time	**12:56 PM**	Unit Weight (pcf)	**142.08**
Slump, in.	**3.50**	Yield	**1.27**
Mix Temp.	**73.4**	Initial set, min.	**NA**
Air Temp.	**78.8**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.35**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/07/11	1 day	2080	2063
	1 day	2030	
	1 day	2080	
06/13/11	7 day	4050	4113
	7 day	4080	
	7 day	4210	
06/20/11	14 day	4780	4743
	14 day	4920	
	14 day	4530	
7/4/2011	28 day	5090	5333
	28 day	5580	
	28 day	5330	
8/1/2011	56 day	5130	5370
	56 day	5370	
	56 day	5610	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 41** Name: **Gravel D2 75/25C** Set #: 1

Date: **6/6/2011** Mix Code: 41 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-D-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:19 PM**	% Air	**2.00**
Sample Time	**1:28 PM**	Unit Weight (pcf)	**142.68**
Slump, in.	**4.75**	Yield	**1.26**
Mix Temp.	**72.7**	Initial set, min.	**NA**
Air Temp.	**79.0**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.50**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/07/11	1 day	1270	1343
	1 day	1350	
	1 day	1410	
06/13/11	7 day	3040	2947
	7 day	2900	
	7 day	2900	
06/20/11	14 day	3570	3465
	14 day	3360	
	14 day	"3050"	
7/4/2011	28 day	3740	3935
	28 day	"4840"	
	28 day	4130	
8/1/2011	56 day	"4750"	4205
	56 day	4260	
	56 day	4150	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 42** Name: **Gravel D2 75/25F** Set #: 1

Date: **6/6/2011** Mix Code: 42 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-D-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:53 PM**	% Air	**2.00**
Sample Time	**2:02 PM**	Unit Weight (pcf)	**142.28**
Slump, in.	**5.50**	Yield	**1.26**
Mix Temp.	**71.5**	Initial set, min.	**NA**
Air Temp.	**79.6**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.40**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/07/11	1 day	1350	1327
	1 day	1330	
	1 day	1300	
06/13/11	7 day	2820	2690
	7 day	2560	
	7 day	"2300"	
06/20/11	14 day	3380	3450
	14 day	3440	
	14 day	3530	
7/4/2011	28 day	4050	4000
	28 day	3970	
	28 day	3980	
8/1/2011	56 day	"5090"	4580
	56 day	4690	
	56 day	4470	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 43** Name: **Gravel D3 100** Set #: 1

Date: **7/6/2011** Mix Code: 43 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-D-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:44 AM**	% Air	**3.50**
Sample Time	**9:53 AM**	Unit Weight (pcf)	**142.36**
Slump, in.	**2.75**	Yield	**1.27**
Mix Temp.	**70.7**	Initial set, min.	**NA**
Air Temp.	**72.5**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.85**
Bucket Volume	**0.25**
Bucket Full	**43.44**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/07/11	1 day	2140	2213
	1 day	2140	
	1 day	2360	
07/13/11	7 day	3790	3803
	7 day	3750	
	7 day	3870	
07/20/11	14 day	4690	4507
	14 day	4400	
	14 day	4430	
8/3/2011	28 day	4780	4777
	28 day	4790	
	28 day	4760	
8/31/2011	56 day	5090	5253
	56 day	5200	
	56 day	5470	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 44** Name: **Gravel D3 75/25C** Set #: 1

Date: **7/6/2011** Mix Code: 44 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-D-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:09 AM**	% Air	**2.50**
Sample Time	**10:18 AM**	Unit Weight (pcf)	**143.72**
Slump, in.	**4.50**	Yield	**1.25**
Mix Temp.	**71.2**	Initial set, min.	**NA**
Air Temp.	**73.1**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.85**
Bucket Volume	**0.25**
Bucket Full	**43.78**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/07/11	1 day	1370	1420
	1 day	1440	
	1 day	1450	
07/13/11	7 day	"2630"	2965
	7 day	2870	
	7 day	3060	
07/20/11	14 day	3200	3227
	14 day	3280	
	14 day	3200	
8/3/2011	28 day	"3460"	3860
	28 day	3980	
	28 day	3740	
8/31/2011	56 day	4230	4180
	56 day	"4910"	
	56 day	4130	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 45** Name: **Gravel D3 75/25F** Set #: 1

Date: **7/6/2011** Mix Code: 45 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-D-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:38 AM**	% Air	**2.00**
Sample Time	**10:46 AM**	Unit Weight (pcf)	**142.92**
Slump, in.	**4.75**	Yield	**1.25**
Mix Temp.	**71.9**	Initial set, min.	**NA**
Air Temp.	**74.0**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.85**
Bucket Volume	**0.25**
Bucket Full	**43.58**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/07/11	1 day	1560	1487
	1 day	1450	
	1 day	1450	
07/13/11	7 day	"2770"	2430
	7 day	2380	
	7 day	2480	
07/20/11	14 day	3130	3125
	14 day	3120	
	14 day	"2750"	
8/3/2011	28 day	3600	3760
	28 day	3710	
	28 day	3970	
8/31/2011	56 day	4240	4390
	56 day	4540	
	56 day	"3790"	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 46** Name: **Stone D1 100** Set #: 1

Date: **4/26/2011** Mix Code: 46 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-D-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1264.55	**58.54**	**58.54**	58.54	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.01**	12.01	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4088.83	189.30	190.34					
UW w/o Air:		153.74	153.74	154.59					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:30 AM**	% Air	**3.50**	Des. w/c	0.450
Sample Time	**8:39 AM**	Unit Weight (pcf)	**151.00**	Act. w/c	0.450
Slump, in.	**2.50**	Yield	**1.26**	Des.Un.Wt.	151.44
Mix Temp.	**70.5**	Initial set, min.	**NA**	Fine/Coarse by Vol	0.624
Air Temp.	**72.5**	Relative Yield	**1.010**	Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.57**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/27/11	1 day	3120	3267
	1 day	3390	
	1 day	3290	
05/03/11	7 day	5350	5657
	7 day	5710	
	7 day	5910	
05/10/11	14 day	6520	6430
	14 day	6560	
	14 day	6210	
5/24/2011	28 day	6910	6910
	28 day	6850	
	28 day	6970	
6/21/2011	56 day	7060	7147
	56 day	7230	
	56 day	7150	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 47** Name: **Stone D1 75/25C** Set #: 1

Date: **4/26/2011** Mix Code: 47 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-D-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.39	**57.47**	**57.47**	57.47	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4065.67	188.23	189.26					
UW w/o Air:		152.87	152.87	153.71					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:17 AM**	% Air	**3.50**	Des. w/c	0.450
Sample Time	**9:26 AM**	Unit Weight (pcf)	**151.28**	Act. w/c	0.450
Slump, in.	**4.25**	Yield	**1.25**	Des.Un.Wt.	150.58
Mix Temp.	**70.5**	Initial set, min.	**NA**	Fine/Coarse by Vol	0.613
Air Temp.	**72.4**	Relative Yield	**1.000**	Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.64**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/27/11	1 day	2310	2313
	1 day	2330	
	1 day	2300	
05/03/11	7 day	5780	5780
	7 day	5720	
	7 day	5840	
05/10/11	14 day	6670	6780
	14 day	7010	
	14 day	6660	
5/24/2011	28 day	7020	7133
	28 day	7190	
	28 day	7190	
6/21/2011	56 day	7350	7553
	56 day	7360	
	56 day	7950	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 48** Name: **Stone D1 75/25F** Set #: 1

Date: **4/26/2011** Mix Code: 48 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-D-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.44	1217.27	**56.35**	**56.35**	56.35	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4041.55	187.11	188.14					
UW w/o Air:		151.97	151.97	152.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:06 AM**	% Air	**3.25**	Des. w/c	0.450
Sample Time	**10:15 AM**	Unit Weight (pcf)	**150.64**	Act. w/c	0.450
Slump, in.	**3.00**	Yield	**1.25**	Des.Un.Wt.	149.69
Mix Temp.	**71.5**	Initial set, min.	**NA**	Fine/Coarse by Vol	0.601
Air Temp.	**73.1**	Relative Yield	**1.000**	Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.48**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/27/11	1 day	2170	2203
	1 day	2220	
	1 day	2220	
05/03/11	7 day	4890	4727
	7 day	4550	
	7 day	4740	
05/10/11	14 day	5310	5610
	14 day	5630	
	14 day	5890	
5/24/2011	28 day	6380	6350
	28 day	6320	
	28 day	"7250"	
6/21/2011	56 day	7200	7243
	56 day	7080	
	56 day	7450	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 49** Name: **Gravel F1 100** Set #: 1

Date: **5/18/2011** Mix Code: 49 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-F-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**7:56 AM**	% Air	**3.50**
Sample Time	**8:05 AM**	Unit Weight (pcf)	**141.96**
Slump, in.	**3.00**	Yield	**1.27**
Mix Temp.	**66.8**	Initial set, min.	**NA**
Air Temp.	**70.9**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.32**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/19/11	1 day	1710	1783
	1 day	1790	
	1 day	1850	
05/25/11	7 day	3790	3907
	7 day	3810	
	7 day	4120	
06/01/11	14 day	4300	4347
	14 day	4260	
	14 day	4480	
6/15/2011	28 day	4880	4990
	28 day	5000	
	28 day	5090	
7/13/2011	56 day	5060	5217
	56 day	5110	
	56 day	5480	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 50** Name: **Gravel F1 75/25C** Set #: 1

Date: **5/18/2011** Mix Code: 50 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-F-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:43 AM**	% Air	**2.00**
Sample Time	**8:52 AM**	Unit Weight (pcf)	**142.96**
Slump, in.	**6.50**	Yield	**1.26**
Mix Temp.	**66.8**	Initial set, min.	**NA**
Air Temp.	**70.7**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.57**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/19/11	1 day	1260	1263
	1 day	1280	
	1 day	1250	
05/25/11	7 day	"2690"	2965
	7 day	3080	
	7 day	2850	
06/01/11	14 day	3840	4067
	14 day	4130	
	14 day	4230	
6/15/2011	28 day	4600	4545
	28 day	"4040"	
	28 day	4490	
7/13/2011	56 day	4790	4850
	56 day	4760	
	56 day	5000	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 51** Name: **Gravel F1 75/25F** Set #: 1

Date: **5/18/2011** Mix Code: 51 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-F-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:26 AM**	% Air	**2.00**
Sample Time	**9:35 AM**	Unit Weight (pcf)	**142.48**
Slump, in.	**5.50**	Yield	**1.25**
Mix Temp.	**68.4**	Initial set, min.	**NA**
Air Temp.	**71.6**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.45**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/19/11	1 day	1070	1113
	1 day	1130	
	1 day	1140	
05/25/11	7 day	2540	2677
	7 day	2820	
	7 day	2670	
06/01/11	14 day	"3970"	3580
	14 day	3570	
	14 day	3590	
6/15/2011	28 day	4450	4473
	28 day	4490	
	28 day	4480	
7/13/2011	56 day	4870	4783
	56 day	4650	
	56 day	4830	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 52** Name: **Gravel F2 100** Set #: 1

Date: **6/2/2011** Mix Code: 52 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-F-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:59 AM**	% Air	**3.50**
Sample Time	**9:08 AM**	Unit Weight (pcf)	**142.08**
Slump, in.	**3.25**	Yield	**1.27**
Mix Temp.	**69.8**	Initial set, min.	**NA**
Air Temp.	**73.8**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.35**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/03/11	1 day	1840	1793
	1 day	1700	
	1 day	1840	
06/09/11	7 day	4010	3897
	7 day	3870	
	7 day	3810	
06/16/11	14 day	"4850"	4205
	14 day	4490	
	14 day	3920	
6/30/2011	28 day	"5110"	4615
	28 day	4500	
	28 day	4730	
7/28/2011	56 day	5400	5060
	56 day	4880	
	56 day	4900	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 53** Name: **Gravel F2 75/25C** Set #: 1

Date: **6/2/2011** Mix Code: 53 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-F-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:30 AM**	% Air	**2.00**
Sample Time	**9:39 AM**	Unit Weight (pcf)	**143.80**
Slump, in.	**5.75**	Yield	**1.25**
Mix Temp.	**68.5**	Initial set, min.	**NA**
Air Temp.	**74.2**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.78**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/03/11	1 day	1200	1197
	1 day	1250	
	1 day	1140	
06/09/11	7 day	3220	3255
	7 day	3290	
	7 day	"2940"	
06/16/11	14 day	3370	3360
	14 day	3350	
	14 day	"3860"	
6/30/2011	28 day	4770	4530
	28 day	4360	
	28 day	4460	
7/28/2011	56 day	"4370"	4885
	56 day	5170	
	56 day	4600	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 54** Name: **Gravel F2 75/25F** Set #: 1

Date: **6/2/2011** Mix Code: 54 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-F-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:02 AM**	% Air	**2.00**
Sample Time	**10:11 AM**	Unit Weight (pcf)	**142.52**
Slump, in.	**5.50**	Yield	**1.25**
Mix Temp.	**68.4**	Initial set, min.	**NA**
Air Temp.	**74.7**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.46**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/03/11	1 day	1080	1123
	1 day	1170	
	1 day	1120	
06/09/11	7 day	2600	2657
	7 day	2660	
	7 day	2710	
06/16/11	14 day	3270	3323
	14 day	3250	
	14 day	3450	
6/30/2011	28 day	4170	4160
	28 day	4300	
	28 day	4010	
7/28/2011	56 day	4780	4587
	56 day	4570	
	56 day	4410	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 55** Name: **Gravel F3 100** Set #: 1

Date: **7/14/2011** Mix Code: 55 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	23.37	**CS-F-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:41 AM**	% Air	**3.50**
Sample Time	**9:50 AM**	Unit Weight (pcf)	**141.72**
Slump, in.	**3.00**	Yield	**1.27**
Mix Temp.	**69.6**	Initial set, min.	**NA**
Air Temp.	**73.3**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.469
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.88**
Bucket Volume	**0.25**
Bucket Full	**43.31**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/15/11	1 day	2040	1990
	1 day	1960	
	1 day	1970	
07/21/11	7 day	4040	3875
	7 day	"3360"	
	7 day	3710	
07/28/11	14 day	4180	4203
	14 day	4160	
	14 day	4270	
8/11/2011	28 day	"5340"	4625
	28 day	4610	
	28 day	4640	
9/8/2011	56 day	5040	5135
	56 day	5230	
	56 day	"6110"	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 56** Name: **Gravel F3 75/25C** Set #: 1

Date: **7/14/2011** Mix Code: 56 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-F-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:04 AM**	% Air	**2.50**
Sample Time	**10:15 AM**	Unit Weight (pcf)	**142.40**
Slump, in.	**6.00**	Yield	**1.26**
Mix Temp.	**69.6**	Initial set, min.	**NA**
Air Temp.	**73.6**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.88**
Bucket Volume	**0.25**
Bucket Full	**43.48**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/15/11	1 day	1380	1317
	1 day	1320	
	1 day	1250	
07/21/11	7 day	"2890"	2515
	7 day	2570	
	7 day	2460	
07/28/11	14 day	3430	3453
	14 day	3570	
	14 day	3360	
8/11/2011	28 day	4330	4130
	28 day	4050	
	28 day	4010	
9/8/2011	56 day	5150	5155
	56 day	"4630"	
	56 day	5160	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 57** Name: **Gravel F3 75/25F** Set #: 1

Date: **7/14/2011** Mix Code: 57 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-F-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:33 AM**	% Air	**2.25**
Sample Time	**10:42 AM**	Unit Weight (pcf)	**141.92**
Slump, in.	**4.25**	Yield	**1.26**
Mix Temp.	**69.9**	Initial set, min.	**NA**
Air Temp.	**74.0**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.88**
Bucket Volume	**0.25**
Bucket Full	**43.36**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/15/11	1 day	1250	1243
	1 day	1240	
	1 day	1240	
07/21/11	7 day	"2660"	2365
	7 day	2350	
	7 day	2380	
07/28/11	14 day	3120	3210
	14 day	3300	
	14 day	3210	
8/11/2011	28 day	3660	3747
	28 day	3870	
	28 day	3710	
9/8/2011	56 day	4710	4717
	56 day	4660	
	56 day	4780	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 58** Name: **Stone F1 100** Set #: 1

Date: **5/19/2011** Mix Code: 58 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-F-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1264.55	**58.54**	**58.54**	58.54	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.01**	12.01	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4088.83	189.30	190.34					
UW w/o Air:		153.74	153.74	154.59					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**11:58 AM**	% Air	**3.00**
Sample Time	**12:07 PM**	Unit Weight (pcf)	**150.52**
Slump, in.	**1.75**	Yield	**1.26**
Mix Temp.	**72.2**	Initial set, min.	**NA**
Air Temp.	**77.6**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	151.44
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**45.46**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/20/11	1 day	2800	2913
	1 day	2880	
	1 day	3060	
05/26/11	7 day	5750	5573
	7 day	5360	
	7 day	5610	
06/02/11	14 day	6360	6350
	14 day	6640	
	14 day	6050	
6/16/2011	28 day	6310	6603
	28 day	6630	
	28 day	6870	
7/14/2011	56 day	7080	7257
	56 day	7280	
	56 day	7410	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 59** Name: **Stone F1 75/25C** Set #: 1

Date: **5/19/2011** Mix Code: 59 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-F-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.39	**57.47**	**57.47**	57.47	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4065.67	188.23	189.26					
UW w/o Air:		152.87	152.87	153.71					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**12:40 PM**	% Air	**2.25**
Sample Time	**12:49 PM**	Unit Weight (pcf)	**151.20**
Slump, in.	**3.00**	Yield	**1.25**
Mix Temp.	**72.1**	Initial set, min.	**NA**
Air Temp.	**76.5**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	150.58
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**45.63**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/20/11	1 day	2030	2043
	1 day	2090	
	1 day	2010	
05/26/11	7 day	5480	5330
	7 day	5440	
	7 day	5070	
06/02/11	14 day	6580	6530
	14 day	6530	
	14 day	6480	
6/16/2011	28 day	7790	7737
	28 day	7710	
	28 day	7710	
7/14/2011	56 day	8540	8327
	56 day	8220	
	56 day	8220	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 60** Name: **Stone F1 75/25F** Set #: 1

Date: **5/19/2011** Mix Code: 60 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-F-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.44	1217.27	**56.35**	**56.35**	56.35	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4041.55	187.11	188.14					
UW w/o Air:		151.97	151.97	152.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:14 PM**	% Air	**2.00**
Sample Time	**1:24 PM**	Unit Weight (pcf)	**150.76**
Slump, in.	**2.50**	Yield	**1.25**
Mix Temp.	**72.4**	Initial set, min.	**NA**
Air Temp.	**79.6**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	149.69
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**45.52**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/20/11	1 day	1890	1887
	1 day	1920	
	1 day	1850	
05/26/11	7 day	4490	4533
	7 day	4580	
	7 day	4530	
06/02/11	14 day	5430	5437
	14 day	5510	
	14 day	5370	
6/16/2011	28 day	6300	6387
	28 day	6560	
	28 day	6300	
7/14/2011	56 day	7730	7860
	56 day	8060	
	56 day	7790	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 61** Name: **Gravel G1 100** Set #: 1

Date: **5/11/2011** Mix Code: 61 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-G-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:33 AM**	% Air	**3.75**
Sample Time	**10:42 AM**	Unit Weight (pcf)	**141.12**
Slump, in.	**4.50**	Yield	**1.28**
Mix Temp.	**68.8**	Initial set, min.	**NA**
Air Temp.	**72.4**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.11**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/12/11	1 day	1960	1893
	1 day	1850	
	1 day	1870	
05/18/11	7 day	3050	3213
	7 day	3320	
	7 day	3270	
05/25/11	14 day	3520	3380
	14 day	3450	
	14 day	3170	
6/8/2011	28 day	"4570"	4125
	28 day	4160	
	28 day	4090	
7/6/2011	56 day	4320	4303
	56 day	4430	
	56 day	4160	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 62** Name: **Gravel G1 75/25C** Set #: 1

Date: **5/11/2011** Mix Code: 62 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-G-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:23 AM**	% Air	**2.50**
Sample Time	**8:32 AM**	Unit Weight (pcf)	**142.52**
Slump, in.	**7.50**	Yield	**1.26**
Mix Temp.	**68.1**	Initial set, min.	**NA**
Air Temp.	**72.7**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.46**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/12/11	1 day	1130	1177
	1 day	1220	
	1 day	1180	
05/18/11	7 day	2760	2765
	7 day	2770	
	7 day	"3490"	
05/25/11	14 day	3050	2937
	14 day	2960	
	14 day	2800	
6/8/2011	28 day	3710	3740
	28 day	3750	
	28 day	3760	
7/6/2011	56 day	3840	3830
	56 day	3820	
	56 day	3830	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 63** Name: **Gravel G1 75/25F** Set #: 1

Date: **5/11/2011** Mix Code: 63 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-G-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:10 AM**	% Air	**2.25**
Sample Time	**9:19 AM**	Unit Weight (pcf)	**142.28**
Slump, in.	**6.75**	Yield	**1.26**
Mix Temp.	**71.1**	Initial set, min.	**NA**
Air Temp.	**73.1**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.40**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/12/11	1 day	1230	1270
	1 day	1270	
	1 day	1310	
05/18/11	7 day	2420	2393
	7 day	2480	
	7 day	2280	
05/25/11	14 day	2570	2640
	14 day	2620	
	14 day	2730	
6/8/2011	28 day	3580	3573
	28 day	3490	
	28 day	3650	
7/6/2011	56 day	3910	4003
	56 day	4100	
	56 day	4000	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 64** Name: **Gravel G2 100** Set #: 1

Date: **6/1/2011** Mix Code: 64 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-G-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:11 PM**	% Air	**3.00**
Sample Time	**1:20 PM**	Unit Weight (pcf)	**141.96**
Slump, in.	**4.25**	Yield	**1.27**
Mix Temp.	**72.5**	Initial set, min.	**NA**
Air Temp.	**78.3**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.32**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/02/11	1 day	1660	1733
	1 day	1730	
	1 day	1810	
06/08/11	7 day	3390	3463
	7 day	3480	
	7 day	3520	
06/15/11	14 day	"3800"	4220
	14 day	4310	
	14 day	4130	
6/29/2011	28 day	4510	4370
	28 day	4700	
	28 day	3900	
7/27/2011	56 day	4400	4457
	56 day	4610	
	56 day	4360	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 65** Name: **Gravel G2 75/25C** Set #: 1

Date: **6/1/2011** Mix Code: 65 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-G-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:54 PM**	% Air	**2.00**
Sample Time	**2:03 PM**	Unit Weight (pcf)	**142.76**
Slump, in.	**7.50**	Yield	**1.26**
Mix Temp.	**70.7**	Initial set, min.	**NA**
Air Temp.	**78.5**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.52**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/02/11	1 day	1140	1170
	1 day	1210	
	1 day	1160	
06/08/11	7 day	2740	2745
	7 day	2750	
	7 day	"3200"	
06/15/11	14 day	2820	2940
	14 day	"3480"	
	14 day	3060	
6/29/2011	28 day	3500	3473
	28 day	3490	
	28 day	3430	
7/27/2011	56 day	4010	4043
	56 day	4090	
	56 day	4030	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 66** Name: **Gravel G2 75/25F** Set #: 1

Date: **6/1/2011** Mix Code: 66 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-G-2**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**2:35 PM**	% Air	**2.00**
Sample Time	**2:44 PM**	Unit Weight (pcf)	**142.16**
Slump, in.	**6.50**	Yield	**1.26**
Mix Temp.	**69.8**	Initial set, min.	**NA**
Air Temp.	**78.0**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.37**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/02/11	1 day	1130	1133
	1 day	1090	
	1 day	1180	
06/08/11	7 day	2580	2510
	7 day	2450	
	7 day	2500	
06/15/11	14 day	2970	2880
	14 day	2890	
	14 day	2780	
6/29/2011	28 day	3480	3513
	28 day	3540	
	28 day	3520	
7/27/2011	56 day	"3870"	4210
	56 day	4060	
	56 day	4360	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 67** Name: **Gravel G3 100** Set #: 1

Date: **7/5/2011** Mix Code: 67 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-G-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1265.03	**58.57**	**58.57**	58.57	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.04**	15.04	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3818.31	176.77	180.84					
UW w/o Air:		143.57	143.57	146.88					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:51 AM**	% Air	**3.25**
Sample Time	**9:59 AM**	Unit Weight (pcf)	**143.32**
Slump, in.	**3.50**	Yield	**1.26**
Mix Temp.	**72.7**	Initial set, min.	**NA**
Air Temp.	**72.4**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.42
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.66**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/06/11	1 day	2000	2007
	1 day	2040	
	1 day	1980	
07/12/11	7 day	3540	3607
	7 day	3680	
	7 day	3600	
07/19/11	14 day	3930	3870
	14 day	"4240"	
	14 day	3810	
8/2/2011	28 day	4760	4810
	28 day	4700	
	28 day	4970	
8/30/2011	56 day	4920	4777
	56 day	4630	
	56 day	4780	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 68** Name: **Gravel G3 75/25C** Set #: 1

Date: **7/5/2011** Mix Code: 68 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-G-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.87	**57.49**	**57.49**	57.49	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3795.15	175.70	179.77					
UW w/o Air:		142.70	142.70	146.00					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:12 AM**	% Air	**2.75**
Sample Time	**10:20 AM**	Unit Weight (pcf)	**142.88**
Slump, in.	**6.25**	Yield	**1.26**
Mix Temp.	**72.3**	Initial set, min.	**NA**
Air Temp.	**72.7**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.56
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.55**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/06/11	1 day	1530	1437
	1 day	1440	
	1 day	1340	
07/12/11	7 day	3000	3000
	7 day	"3410"	
	7 day	3000	
07/19/11	14 day	3400	3530
	14 day	3450	
	14 day	3740	
8/2/2011	28 day	4010	4073
	28 day	4280	
	28 day	3930	
8/30/2011	56 day	4490	4607
	56 day	4520	
	56 day	4810	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 69** Name: **Gravel G3 75/25F** Set #: 1

Date: **7/5/2011** Mix Code: 69 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-G-3**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.45	1217.75	**56.38**	**56.38**	56.38	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3771.03	174.58	178.65					
UW w/o Air:		141.79	141.79	145.09					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:34 AM**	% Air	**2.25**
Sample Time	**10:42 AM**	Unit Weight (pcf)	**141.96**
Slump, in.	**5.25**	Yield	**1.26**
Mix Temp.	**74.1**	Initial set, min.	**NA**
Air Temp.	**73.1**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.67
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.32**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/06/11	1 day	1490	1460
	1 day	1430	
	1 day	1460	
07/12/11	7 day	2840	2885
	7 day	"2620"	
	7 day	2930	
07/19/11	14 day	3290	3017
	14 day	2940	
	14 day	2820	
8/2/2011	28 day	"3750"	4235
	28 day	4310	
	28 day	4160	
8/30/2011	56 day	4040	4157
	56 day	4080	
	56 day	4350	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 70** Name: **Stone G1 100** Set #: 1

Date: **5/16/2011** Mix Code: 70 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-G-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1264.55	**58.54**	**58.54**	58.54	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.01**	12.01	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4088.83	189.30	190.34					
UW w/o Air:		153.74	153.74	154.59					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:52 PM**	% Air	**3.50**
Sample Time	**1:40 PM**	Unit Weight (pcf)	**150.44**
Slump, in.	**2.25**	Yield	**1.27**
Mix Temp.	**68.4**	Initial set, min.	**NA**
Air Temp.	**70.2**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	151.44
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**45.44**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/17/11	1 day	2740	2790
	1 day	2810	
	1 day	2820	
05/23/11	7 day	5330	5373
	7 day	5440	
	7 day	5350	
05/30/11	14 day	6030	6210
	14 day	6330	
	14 day	6270	
6/13/2011	28 day	6870	6740
	28 day	6740	
	28 day	6610	
7/11/2011	56 day	6830	6833
	56 day	6740	
	56 day	6930	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 71** Name: **Stone G1 75/25C** Set #: 1

Date: **5/16/2011** Mix Code: 71 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-G-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.39	**57.47**	**57.47**	57.47	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4065.67	188.23	189.26					
UW w/o Air:		152.87	152.87	153.71					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**2:28 PM**	% Air	**2.50**
Sample Time	**2:37 PM**	Unit Weight (pcf)	**150.92**
Slump, in.	**3.50**	Yield	**1.25**
Mix Temp.	**68.0**	Initial set, min.	**NA**
Air Temp.	**70.0**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	150.58
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**45.56**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/17/11	1 day	1710	1750
	1 day	1790	
	1 day	1750	
05/23/11	7 day	5840	5957
	7 day	6120	
	7 day	5910	
05/30/11	14 day	6860	6657
	14 day	6600	
	14 day	6510	
6/13/2011	28 day	7470	7210
	28 day	6970	
	28 day	7190	
7/11/2011	56 day	7770	7850
	56 day	7850	
	56 day	7930	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 72** Name: **Stone G1 75/25F** Set #: 1

Date: **5/16/2011** Mix Code: 72 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-G-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.44	1217.27	**56.35**	**56.35**	56.35	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4041.55	187.11	188.14					
UW w/o Air:		151.97	151.97	152.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**3:07 PM**	% Air	**2.50**
Sample Time	**3:16 PM**	Unit Weight (pcf)	**150.28**
Slump, in.	**3.50**	Yield	**1.25**
Mix Temp.	**67.1**	Initial set, min.	**NA**
Air Temp.	**70.0**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	149.69
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**45.40**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
05/17/11	1 day	1830	1920
	1 day	1900	
	1 day	2030	
05/23/11	7 day	4350	4380
	7 day	4280	
	7 day	4510	
05/30/11	14 day	5270	5287
	14 day	5250	
	14 day	5340	
6/13/2011	28 day	5930	5933
	28 day	6050	
	28 day	5820	
7/11/2011	56 day	7190	7137
	56 day	7180	
	56 day	7040	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 73** Name: **Gravel E1 100** Set #: 1

Date: **4/27/2011** Mix Code: 73 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.72	526.40	**24.37**	**24.37**	24.37	**CS-E-1**	3.10		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.69	1257.97	**58.24**	**58.24**	58.24	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3811.25	176.45	180.51					
UW w/o Air:		143.31	143.31	146.61					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:50 AM**	% Air	**3.75**
Sample Time	**9:59 AM**	Unit Weight (pcf)	**141.64**
Slump, in.	**3.25**	Yield	**1.27**
Mix Temp.	**70.1**	Initial set, min.	**NA**
Air Temp.	**72.7**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.16
Fine/Coarse by Vol	0.621
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.23**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/28/11	1 day	2230	2217
	1 day	2220	
	1 day	2200	
05/04/11	7 day	"3720"	4350
	7 day	4380	
	7 day	4320	
05/11/11	14 day	4810	4730
	14 day	4620	
	14 day	4760	
5/25/2011	28 day	4420	4665
	28 day	"4360"	
	28 day	4910	
6/22/2011	56 day	5230	5167
	56 day	5270	
	56 day	5000	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 74** Name: **Gravel E1 75/25C** Set #: 1

Date: **4/27/2011** Mix Code: 74 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.04	394.80	**18.28**	**18.28**	18.28	**CS-E-1**	3.10		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.56	1236.57	**57.25**	**57.25**	57.25	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3789.85	175.46	179.52					
UW w/o Air:		142.50	142.50	145.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:28 AM**	% Air	**2.50**	Des. w/c	0.450
Sample Time	**10:35 AM**	Unit Weight (pcf)	**143.60**	Act. w/c	0.450
Slump, in.	**5.25**	Yield	**1.25**	Des.Un.Wt.	140.36
Mix Temp.	**70.2**	Initial set, min.	**NA**	Fine/Coarse by Vol	0.610
Air Temp.	**73.3**	Relative Yield	**1.000**	Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.72**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/28/11	1 day	1320	1350
	1 day	1340	
	1 day	1390	
05/04/11	7 day	3330	3463
	7 day	3570	
	7 day	3490	
05/11/11	14 day	4150	4160
	14 day	3930	
	14 day	4400	
5/25/2011	28 day	4020	3940
	28 day	3890	
	28 day	3910	
6/22/2011	56 day	5220	5053
	56 day	5050	
	56 day	4890	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 75** Name: **Gravel E1 75/25F** Set #: 1

Date: **4/27/2011** Mix Code: 75 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.04	394.80	**18.28**	**18.28**	18.28	**CS-E-1**	3.10		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.41	1212.45	**56.13**	**56.13**	56.13	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3765.73	174.34	178.40					
UW w/o Air:		141.60	141.60	144.89					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**11:01 AM**	% Air	**2.00**
Sample Time	**11:10 AM**	Unit Weight (pcf)	**142.04**
Slump, in.	**4.75**	Yield	**1.26**
Mix Temp.	**73.2**	Initial set, min.	**NA**
Air Temp.	**74.2**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.47
Fine/Coarse by Vol	0.599
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**43.33**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/28/11	1 day	1350	1357
	1 day	1390	
	1 day	1330	
05/04/11	7 day	2800	2883
	7 day	2800	
	7 day	3050	
05/11/11	14 day	3220	3367
	14 day	3360	
	14 day	3520	
5/25/2011	28 day	3810	3850
	28 day	"4250"	
	28 day	3890	
6/22/2011	56 day	4750	4765
	56 day	"4280"	
	56 day	4780	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 76** Name: **Gravel E2 100** Set #: 1

Date: **6/7/2011** Mix Code: 76 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.72	526.40	**24.37**	**24.37**	24.37	**CS-E-2**	3.10		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.69	1257.97	**58.24**	**58.24**	58.24	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3811.25	176.45	180.51					
UW w/o Air:		143.31	143.31	146.61					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**7:54 AM**	% Air	**3.00**
Sample Time	**8:03 AM**	Unit Weight (pcf)	**142.28**
Slump, in.	**3.00**	Yield	**1.27**
Mix Temp.	**69.3**	Initial set, min.	**NA**
Air Temp.	**73.1**	Relative Yield	**1.020**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.16
Fine/Coarse by Vol	0.621
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.40**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/08/11	1 day	2290	2280
	1 day	2380	
	1 day	2170	
06/14/11	7 day	4530	4343
	7 day	4220	
	7 day	4280	
06/21/11	14 day	4160	4270
	14 day	4250	
	14 day	4400	
7/5/2011	28 day	4910	4950
	28 day	5200	
	28 day	4740	
8/2/2011	56 day	5520	5603
	56 day	5500	
	56 day	5790	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 77** Name: **Gravel E2 75/25C** Set #: 1

Date: **6/7/2011** Mix Code: 77 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.04	394.80	**18.28**	**18.28**	18.28	**CS-E-2**	3.10		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.56	1236.57	**57.25**	**57.25**	57.25	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3789.85	175.46	179.52					
UW w/o Air:		142.50	142.50	145.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**8:31 AM**	% Air	**2.00**
Sample Time	**8:40 AM**	Unit Weight (pcf)	**143.00**
Slump, in.	**6.25**	Yield	**1.26**
Mix Temp.	**69.0**	Initial set, min.	**NA**
Air Temp.	**73.8**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.36
Fine/Coarse by Vol	0.610
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.58**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/08/11	1 day	1610	1707
	1 day	1760	
	1 day	1750	
06/14/11	7 day	3590	3593
	7 day	3590	
	7 day	3600	
06/21/11	14 day	3890	3917
	14 day	3860	
	14 day	4000	
7/5/2011	28 day	4900	4830
	28 day	4790	
	28 day	4800	
8/2/2011	56 day	5190	5330
	56 day	5200	
	56 day	5600	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 78** Name: **Gravel E2 75/25F** Set #: 1

Date: **6/7/2011** Mix Code: 78 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.04	394.80	**18.28**	**18.28**	18.28	**CS-E-2**	3.10		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.41	1212.45	**56.13**	**56.13**	56.13	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3765.73	174.34	178.40					
UW w/o Air:		141.60	141.60	144.89					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**9:05 AM**	% Air	**2.00**
Sample Time	**9:20 AM**	Unit Weight (pcf)	**141.92**
Slump, in.	**4.75**	Yield	**1.26**
Mix Temp.	**68.5**	Initial set, min.	**NA**
Air Temp.	**75.2**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.47
Fine/Coarse by Vol	0.599
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.83**
Bucket Volume	**0.25**
Bucket Full	**43.31**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/08/11	1 day	1500	1500
	1 day	1480	
	1 day	1520	
06/14/11	7 day	3040	3063
	7 day	2980	
	7 day	3170	
06/21/11	14 day	3190	3397
	14 day	3540	
	14 day	3460	
7/5/2011	28 day	4460	4375
	28 day	4290	
	28 day	"3920"	
8/2/2011	56 day	5080	4897
	56 day	4890	
	56 day	4720	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 79** Name: **Gravel E3 100** Set #: 1

Date: **7/11/2011** Mix Code: 79 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.72	526.40	**24.37**	**24.37**	24.37	**CS-E-3**	3.10		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.69	1257.97	**58.24**	**58.24**	58.24	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3811.25	176.45	180.51					
UW w/o Air:		143.31	143.31	146.61					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:14 AM**	% Air	**2.75**
Sample Time	**10:23 AM**	Unit Weight (pcf)	**143.16**
Slump, in.	**2.75**	Yield	**1.26**
Mix Temp.	**73.3**	Initial set, min.	**NA**
Air Temp.	**75.4**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	141.16
Fine/Coarse by Vol	0.621
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.65**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/12/11	1 day	2200	2253
	1 day	2240	
	1 day	2320	
07/18/11	7 day	3860	3925
	7 day	"3520"	
	7 day	3990	
07/25/11	14 day	4350	4633
	14 day	4670	
	14 day	4880	
8/8/2011	28 day	4680	4637
	28 day	4670	
	28 day	4560	
9/5/2011	56 day	5700	5735
	56 day	"4970"	
	56 day	5770	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 80** Name: **Gravel E3 75/25C** Set #: 1

Date: **7/11/2011** Mix Code: 80 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.04	394.80	**18.28**	**18.28**	18.28	**CS-E-3**	3.10		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.56	1236.57	**57.25**	**57.25**	53.13	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3789.85	175.46	179.52					
UW w/o Air:		142.50	142.50	145.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**10:43 AM**	% Air	**2.50**
Sample Time	**10:52 AM**	Unit Weight (pcf)	**143.40**
Slump, in.	**3.75**	Yield	**1.22**
Mix Temp.	**69.2**	Initial set, min.	**NA**
Air Temp.	**76.0**	Relative Yield	**0.980**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	140.36
Fine/Coarse by Vol	0.610
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.71**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/12/11	1 day	1450	1373
	1 day	1250	
	1 day	1420	
07/18/11	7 day	2860	2890
	7 day	3020	
	7 day	2790	
07/25/11	14 day	3740	3503
	14 day	3390	
	14 day	3380	
8/8/2011	28 day	4340	4580
	28 day	4730	
	28 day	4670	
9/5/2011	56 day	5180	5300
	56 day	5520	
	56 day	5200	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 81** Name: **Gravel E3 75/25F** Set #: 1

Date: **7/11/2011** Mix Code: 81 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.04	394.80	**18.28**	**18.28**	18.28	**CS-E-3**	3.10		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.41	1212.45	**56.13**	**56.13**	56.13	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	1790.00	**82.87**	**82.87**	82.87	**CA-1**	2.316	4.67%	6.51
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**15.03**	15.03	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	3765.73	174.34	178.40					
UW w/o Air:		141.60	141.60	144.89					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**11:10 AM**	% Air	**2.00**
Sample Time	**11:18 AM**	Unit Weight (pcf)	**141.92**
Slump, in.	**3.50**	Yield	**1.26**
Mix Temp.	**70.8**	Initial set, min.	**NA**
Air Temp.	**76.1**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	139.47
Fine/Coarse by Vol	0.599
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-4.67%	-3.87
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.86**
Bucket Volume	**0.25**
Bucket Full	**43.34**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/12/11	1 day	1600	1560
	1 day	1520	
	1 day	1560	
07/18/11	7 day	2640	2680
	7 day	"2950"	
	7 day	2720	
07/25/11	14 day	3550	3625
	14 day	"3310"	
	14 day	3700	
8/8/2011	28 day	4030	4050
	28 day	4010	
	28 day	4110	
9/5/2011	56 day	4560	4777
	56 day	4890	
	56 day	4880	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 82** Name: **Stone E1 100** Set #: 1

Date: **4/28/2011** Mix Code: 82 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.68	526.40	**24.37**	**24.37**	24.37	**CS-E-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.00	0.00	**0.00**	**0.00**			1.00		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.73	1264.55	**58.54**	**58.54**	58.54	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.01**	12.01	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4088.83	189.30	190.34					
UW w/o Air:		153.74	153.74	154.59					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**11:56 AM**	% Air	**3.50**
Sample Time	**12:05 PM**	Unit Weight (pcf)	**150.60**
Slump, in.	**1.75**	Yield	**1.26**
Mix Temp.	**70.7**	Initial set, min.	**NA**
Air Temp.	**72.5**	Relative Yield	**1.010**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	151.44
Fine/Coarse by Vol	0.624
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.47**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/29/11	1 day	2840	2890
	1 day	2900	
	1 day	2930	
05/05/11	7 day	5660	5907
	7 day	5960	
	7 day	6100	
05/12/11	14 day	7130	6953
	14 day	6820	
	14 day	6910	
5/26/2011	28 day	7330	7300
	28 day	7340	
	28 day	7230	
6/23/2011	56 day	7650	7870
	56 day	8100	
	56 day	7860	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 83** Name: **Stone E1 75/25C** Set #: 1

Date: **4/28/2011** Mix Code: 83 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-E-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.81	131.60	**6.09**	**6.09**	6.09	**SCM-1 (Class C Fly Ash)**	2.60		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.59	1241.39	**57.47**	**57.47**	57.47	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4065.67	188.23	189.26					
UW w/o Air:		152.87	152.87	153.71					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**12:41 PM**	% Air	**2.25**
Sample Time	**12:50 PM**	Unit Weight (pcf)	**151.20**
Slump, in.	**3.50**	Yield	**1.25**
Mix Temp.	**69.8**	Initial set, min.	**NA**
Air Temp.	**72.5**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	150.58
Fine/Coarse by Vol	0.613
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.20
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.62**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/29/11	1 day	1890	1943
	1 day	1990	
	1 day	1950	
05/05/11	7 day	5550	5573
	7 day	5750	
	7 day	5420	
05/12/11	14 day	6510	6730
	14 day	6750	
	14 day	6930	
5/26/2011	28 day	7550	7470
	28 day	7390	
	28 day	7470	
6/23/2011	56 day	7700	7943
	56 day	7720	
	56 day	8410	

Technician who conducted tests:

State Study No. 239 - Influences on Strength Variability of Gravel Aggregate Concrete

Customer: **MDOT** Project: Lab #: **BCD**

MIX NUMBER **Mix 84** Name: **Stone E1 75/25F** Set #: 1

Date: **4/28/2011** Mix Code: 84 f'c: **4,000 psi** Size(c.f.): **1.25** Factor: **0.05**

MIX DESIGN INFO

Material	Vol. (c.f.)	Dry mix 1 cu. yd. Wt. (lbs.)	Dry mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)	Material Code	Dry Specific Gravity	Agg. absorption	Agg. FM
Cement 1:	2.01	394.80	**18.28**	**18.28**	18.28	**CS-E-1**	3.15		
Cement 2:	0.00	0.00	**0.00**	**0.00**			1.00		
Fly Ash:	0.96	131.60	**6.09**	**6.09**	6.09	**SCM-2 (Class F Fly Ash)**	2.20		
GGBFS:	0.00	0.00	**0.00**	**0.00**			1.00		
Sand 1:	7.44	1217.27	**56.35**	**56.35**	56.35	**FA-1**	2.621	0.34%	2.21
Coarse Aggregate 1:	12.39	2061.00	**95.42**	**95.42**	95.42	**CA-2**	2.666	0.88%	6.45
Coarse Aggregate 2:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 3:	0.00	0.00	**0.00**	**0.00**					
Coarse Aggregate 4:	0.00	0.00	**0.00**	**0.00**					
Air: **1.50%**	0.41	0.00	**0.00**	**0.00**					
Water:	3.80	236.88	**10.97**	**12.00**	12.00	**Water**	1.00		
"+-Air: **1.00%**									
Total:	27.00	4041.55	187.11	188.14					
UW w/o Air:		151.97	151.97	152.80					

ADMIX INFORMATION

Type	oz /cwt	oz /cy	ml /cy	batch ml	actual ml	Brand / Name
WR Type A	3.05	16.1	474.8	22.0	22.0	**Water Reducer**

PLASTIC TEST RESULTS

Batch Time	**1:37 PM**	% Air	**1.75**
Sample Time	**1:46 PM**	Unit Weight (pcf)	**150.76**
Slump, in.	**2.50**	Yield	**1.25**
Mix Temp.	**69.7**	Initial set, min.	**NA**
Air Temp.	**73.1**	Relative Yield	**1.000**

OTHER INFO

Des. w/c	0.450
Act. w/c	0.450
Des.Un.Wt.	149.69
Fine/Coarse by Vol	0.601
Bag Factor	5.60

Aggregate Moistures

	Free H_2O Content	Batch free H_2O (lbs.)
Sand:	-0.34%	-0.19
CA 1	-0.88%	-0.84
CA 2	0.00%	0.00
CA 3	0.00%	0.00
CA 4	0.00%	0.00

Water Added/Withheld

+/- h2o	Added	W/held

Unit Weight

Bucket Weight	**7.82**
Bucket Volume	**0.25**
Bucket Full	**45.51**

Comments / Notes / Observations

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
04/29/11	1 day	1890	1877
	1 day	1880	
	1 day	1860	
05/05/11	7 day	4610	4557
	7 day	4450	
	7 day	4610	
05/12/11	14 day	5380	5420
	14 day	5360	
	14 day	5520	
5/26/2011	28 day	6020	6103
	28 day	5980	
	28 day	6310	
6/23/2011	56 day	7030	7150
	56 day	7330	
	56 day	7090	

Technician who conducted tests: