UNIVERSITY OF NORTH DAKOTA
Grand Forks

Effects of Water Reducer Admixtures on Concrete Strength and Durability

Final Report

September 2004

SCHOOL OF ENGINEERING AND MINES

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT	EXPERIMENTAL PROJECT NO. 1 — STATE: UND; YEAR: 02 - NUMBER: 02; SURF: — / CONSTRUCTION PROJ NO 8 / LOCATION 28
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EVALUATION	CONSTRUCTION PROBLEMS 318: 1 NONE; 2 SLIGHT; 3 MODERATE; 4 SIGNIFICANT; 5 SEVERE / PERFORMANCE 319: 1 EXCELLENT; 2 GOOD; 3 SATISFACTORY; 4 MARGINAL; 5 UNSATISFACTORY
APPLICATION	320: 1 ADOPTED AS PRIMARY STD.; 2 PERMITTED ALTERNATIVE; 3 ADOPTED CONDITIONALLY; 4 PENDING; 5 REJECTED; 6 NOT CONSTRUCTED *(Explain in remarks if 3, 4, 5, or 6 is checked)*
REMARKS	321 The objective of this research was to determine the effects of water – reducing admixtures on the strength and durability of concrete. Four brands of water reducer were used to reduce water from 5% to 12% for a total of 16 mixes. Compressive and flexural strengths were higher than the control mix. Freeze-thaw durability was lower than the control mix. Deicer scaling tests were in the moderate to severe range. Rapid chloride ion permeability tests were in the moderate range for both the control and water reducing mixes.

University of North Dakota
Department of Civil Engineering

Effects of Water Reducer Admixtures on Concrete Strength and Durability

Final Report

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Disclaimer

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Acknowledgements

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Chapter 1

Introduction and Literature Review

1.1 Introduction

Durability of concrete materials is one of the major concerns of material engineers throughout the country, particularly in cold regions such as the State of North Dakota. Previous research projects sponsored by the North Dakota Department of Transportation (NDDOT) have investigated the effects of fly ash and dense graded aggregates on the durability characteristics of concrete pavements and bridge decks. This research is intended to build on previous research and study the effects of different water reducing-admixtures on the strength and durability of concrete used for pavements.

Water-reducing admixtures for Portland cement concrete have been used since the 1950's. Early types of admixtures were used to achieve water reductions of at most 10%. In the 1970's, new types of admixtures sometimes referred to as "super water reducers" were introduced. These products were capable of achieving substantially higher water reduction in concrete. According to the Portland Cement Association, water-reducing admixtures are used for the following reasons (Ref. 1, pp. 107 - 109):

- To reduce the amount of mixing water needed to produce a given slump
- To reduce the water to cement ratio for a mix

(Ref. 1) Kosmatka, S., Kerkhoff, B., and W. Panarese, "Design and Control of Concrete Mixtures," 14th Ed., Portland Cement Association, Skokie, Ill., 2002.

- To reduce the cement content of a mix, or
- To increase the slump of a mix.

The objective of this research is to identify the effects of water-reducing admixtures on the strength and durability characteristics of concrete designed using the current NDDOT standards and specifications. Four brands of water reducers that are commonly used in the State of North Dakota were selected for study. Brett, GRT, Grace, and Master Builders supplied the admixtures for this research. Each company sent two different water reducers and an air-entraining product. Batches of concrete were then prepared using each water reducer. The characteristics of the concretes produced were evaluated by performing the following tests on appropriately prepared specimens:

- Compressive strength (AASHTO T-22)
- Flexural strength (AASHTO T-97)
- Resistance of concrete to rapid freezing and thawing (ASTM C 666)
- Rapid chloride ion permeability (ASTM C 1202)
- Air-void analysis on hardened concrete (ASTM C 457), and
- Resistance of concrete surface to deicing chemicals (ASTM C 672)

1.2 Background Information on Water Reducing Admixtures

Type A water-reducing admixtures conforming to ASTM C 494 and AASHTO M194 can typically reduce the water content of concrete by 5% to 10%. Type F (high range) water reducing-admixtures can typically reduce the water content by 12% to 30%.

Water reducing admixtures generally produce an increase in the strength of concrete when the water-cement (w/c) ratio is decreased. For concretes with equivalent cement content, air content, and slump, the 28-day strength may be increased by 10% to 25% with the addition of Type A admixtures. Type F admixtures can produce concretes with ultimate compressive strengths greater than 10,000 psi, increased early strength gain, reduced chloride ion penetration, and other beneficial characteristics caused by a lower w/c ratio in concrete (Ref. 1, p.108).

Water reducing admixtures have other effects on concrete mixes. For example, they can increase the rate of slump loss in freshly mixed concrete. Water reducers can also increase the drying shrinkage of concrete. Type F admixtures can significantly retard the time of set of concrete (Ref.1, p.110). .

Whiting and Dziedzic (Ref. 2) studied the effects of Type A and Type F water reducers on concrete properties. They used a control concrete mix prepared with 545 lb/yd^3 of cement, w/c ratio of 0.5, air content of 6% and a slump of 3 to 5 inches. Test mixes were prepared with Type A water reducers to achieve about an 8% water reduction compared to the control mix, and with Type F water reducers to achieve about a 16% water reduction compared to the control mix. These test mixes targeted the same w/c ratio and slump as the control mix. Several additional test mixes were prepared with increased additions of Type F water reducers to produce a flowing concrete with a slump of 7 to 9 inches.

The various concrete mixes were tested for slump, air loss, setting time, bleeding, resistance to freezing and thawing, resistance to deicer scaling, air-void analysis, chloride permeability, drying shrinkage, and compressive strength. This research produced the following conclusions:

- Initial workabilities of the mixes were adequate, but there was rapid slump loss with time observed for both types of water reducers.
- Concrete durability with respect to deicing chemicals may be adversely affected by the use of Type F water reducers when used to produce flowing concretes and there is a short curing period prior to application of deicing chemicals.
- Non-flowing concretes produced with water reducers appear to be durable under freezing conditions, but the flowing concretes exhibited problems with respect to freeze-thaw durability.
- Water reducers appeared to contribute to an increase in drying shrinkage, particularly in the early stages of curing and with cement containing a moderate tricalcium aluminate content.
- Compressive strength did not appear to be affected in any consistent way by addition of water reducers.
- Water reducers had little or no effect on the chloride ion permeability of the concrete.

(Ref . 2) Whiting, D., and W. Dziedzic, "Effects of Conventional and High-Range Water Reducers on Concrete Properties," Portland Cement Association., Research and Development Bulletin RD107T, Skokie, Ill., 1992.

Whiting (Ref. 3) evaluated the use of super-water reducers (sometimes called high-range water reducers) for highway applications. Chapter 10 of Reference 3 is a guide to the use of super-water reducers (SWR) for highway applications. The following information is contained in Reference 3:

- "No major changes in concrete mix designs (other than reduction in water-cement ratio) need be made when using SWR. A small increase in sand content (approximately 5%) may be useful to avoid a rocky mix. If desired, the total paste content may be increased to compensate for the volume of water removed from the batch. This may be done by the use of additional cement, fly ash or other finely ground materials. The water cement ratio should be maintained, however."
- "In mixes typical of those used for full-depth pavement and bridge deck construction having cement contents of 560-660 lb/yd^3, SWR can be used to reduce the water/cement ratios to less than 0.35."
- The design slump for pavement mixes containing SWR should be in the range of 5-6 inches to maintain workability over the time needed for transport and placement. If necessary, this slump should be produced by using more SWR rather than increasing the water content.
- The total dosage of SWR (on a dry solids basis) added to a concrete mix should not exceed 1.0% by weight of the cement contained in the mix.

(Ref. 3) D. Whiting, "Evaluation of Super-Water Reducers for Highway Applications," Portland Cement Association., Research and Development Bulletin RD078.01T, Skokie, Ill., 1981.

- When the SWR dosage is between 0.6% and 1.0% (dry solids of admixture to weight of cement), lab tests should be done to check the effects on setting time and early strength development.
- Air contents in fresh mixed concrete should be in the range of 7-8%. Lab tests should be done to check the tendency of SWR to cause rapid air loss in fresh concrete.

1.3 Scope of the Research

Sixteen different concrete mixes were prepared for this research using eight different water-reducing admixtures. Each supplier provided two water reducers. One was used to produce two concrete mixes with targeted water-reduction percentages of 5% and 8%, and the other was used to produce two concrete mixes with targeted water-reduction percentages of 8% and 12%. In addition, a control mix was prepared without water reducer for comparison purposes. The control mix was designed based on the *NDDOT's Standards and Specifications for Road and Bridge Construction, 1997, Volumes 1 and 2.*

The performance of each concrete mix was evaluated based on the results of standard tests conducted on prepared specimens. The methods used for the various tests are described in Chapter 2, the test results are presented in Chapter 3, the test results are discussed in Chapter 4, summary and conclusions are included in Chapter 5, and recommendations are given in Chapter 6.

Chapter 2

Materials and Methods

2.1 Chemical Admixtures

The suppliers of the water reducers used for this project were chosen because of their reputations within the concrete construction industry and because they have an established work history with the NDDOT. Products were obtained from the following suppliers:

1. Master Builders
2. Brett Admixtures
3. Grace Construction Products
4. GRT Admixtures

Each supplier was asked to send two water reducing admixtures. In addition, they were asked to send a suitable air-entraining product along with the water reducers. This was done so that compatible water reducer and air-entraining products would be used for all mixes. All suppliers graciously donated their products for this study.

Master Builders is one of the nation's oldest suppliers of chemical additives for construction purposes. With headquarters in Cleveland, OH and regional offices all over the U.S., they are able to supply most parts of the country with admixtures. Master Builders' local representative sent their Pozzolith 322N, Polyheed 997, and PAVE-AIR products. Pozzolith 322N is a ASTM C 494 Type A admixture suitable for 5 to 10% water reduction. Polyheed 997 is a ASTM C 494 Type A and F admixture suitable for 5 to 15% water reduction. PAVE-AIR is an air-entraining admixture. (See Section 1.2 for a discussion of the typical properties of Type A and Type F admixtures.)

Brett Admixtures is located in Eden Prairie, MN. They supply various chemical admixtures for concrete construction. Brett supplied Eucon WR 91, Eucon 37, and AEA-92 products for this study. The Euclid Chemical Company manufactures the Eucon WR 91 and Eucon 37 admixtures. Eucon WR 91 is a Type A and D water-reducing and set-retarding admixture. Eucon 37 is water-reducing admixture conforming to ASTM C 494, Types A and F. AEA-92 is an air-entraining admixture. Specific water reduction ranges for these admixtures were not stated in the technical literature.

Grace Construction Products is located in Cambridge MA. Grace sent their WRDA-82, ADVA 140, and Daravair 1400 products for this study. WRDA-82 is a Type A water reducer. It is suitable for producing a maximum 15% water reduction. ADVA 140 is a Type A and F water reducer. It is suitable for producing a maximum 40% water reduction. Daravair 1400 is an air-entraining agent.

GRT Admixtures is located in Eagan, MN. GRT supplied their Polychem 400NC, Melchem, and Polychem VR admixtures for this research. Polychem 400NC is a Type A water reducer. The GRT product catalog indicates that Melchem is a Type A and F water reducer. Polychem VR is an air-entraining admixture. Specific water reduction ranges for the GRT additives were not stated in the technical literature.

2.2 Aggregates

The aggregate source for this research project was the Sheyenne pit. This aggregate is produced from glacial deposits laid down during the ice age. The pit is located a few miles north of the town of Sheyenne in north central North Dakota. The pit is owned and operated by Aggregate Industries, a national supplier of construction materials. The coarse aggregate obtained from the Sheyenne pit was classified as NDDOT size number 3, with a maximum particle size of 1 inch. The fine aggregate, or sand, from the Sheyenne pit meets NDDOT standards. Tables 2.1 and 2.2 contain the gradations and physical properties of the Sheyenne aggregates along with NDDOT requirements for aggregates. The moisture contents of the aggregates were measured on a daily basis whenever a batch of concrete was mixed to determine mix moisture requirements.

2.3 Cement and Fly Ash

The local Grand Forks, ND plant of Lafarge Dakota donated the Type I Portland cement and the fly ash for this project. The cement was produced at the Alberta, Canada plant. The cement conforms to ASTM C 150-02a standards. A Class C fly ash was used for this study. This fly ash, which met ASTM C 618 standards, was produced at the Coal Creek Station in North Dakota. Physical and chemical properties of the Portland cement and fly ash are contained in Appendix A.

Table 2.1 Properties of Fine Aggregate From the Sheyenne Pit

Fine Aggregate Sieve Analysis		
Sieve Size	Cumulative % Passing	NDDOT Specifications
1.5”	100	100
1”	100	100
3/4”	100	100
1/2'”	100	100
3/8”	100	100
#4	100	90-100
#8	90	
#16	60	45-80
#30	33	
#50	14	10-30
#100	3.8	0-10
#200	2.4	0-3
Fine Aggregate	Bulk Specific Gravity (SSD)	2.625
	Absorption Capacity	1.70%
	Fineness Modulus	2.99

Table 2.2 Properties of Coarse Aggregate From the Sheyenne Pit

Coarse Aggregate Sieve Analysis		
Sieve Size	Cumulative % Passing	NDDOT Specifications
1.5”	100	100
1”	100	100
3/4”	93	95-100
1/2'”	55	25-65
3/8”	21	15-55
#4	0.6	0-10
#8	0.3	0-5
#16	0	
#30	0	
#50	0	
#100	0	
#200	0	
Fine Aggregate	Bulk Specific Gravity (SSD)	2.673
	Absorption Capacity	1.8%

2.4 Mix Design Methodology

All concrete mixes used for this research were designed to have a 1 to 1.5-inch slump and an air content of approximately 6%. Calculations for the various mix designs were done with an Excel spreadsheet program developed by Midwest Testing, Inc. This spreadsheet uses concrete proportioning calculations to generate a volumetric mix design.

The control mix was designed in accordance with current NDDOT standards found in the NDDOT's *Standard Specifications for Road and Bridge Construction, 1997, Volumes 1 and 2.* The control mix had a w/c ratio of 0.35 and a slump of 1.5 inches. An air-entraining admixture was used for the control mix, but no water reducer was added. The w/c ratio used for the 5% water-reduced mixes was 0.34. The w/c ratio used for the 8% water-reduced mixes was 0.33. And the w/c ratio used for the 12% water-reduced mixes was 0.31. An example of a design spreadsheet for a mix is contained in Appendix A.

2.5 Concrete Mixing Procedure

A 9 ft^3 capacity concrete mixer was used for this study. The aggregates, cement, fly ash, and water, required for each batch of concrete were weighed out using buckets and a scale accurate to 0.01 pound. The air-entraining and water-reducing admixtures were measured with graduated cylinders.

The procedure followed for mixing concrete batches was ASTM C 192-97. The mixing process was done as follows:

1. Place all of the coarse aggregate in the mixer along with half of the water and the water reducer.
2. Turn mixer on for approximately 10 seconds to allow rock and water to mix.

3. Stop mixer and place half of the fine aggregate and the air-entraining admixture in mixer.
4. Start mixer and slowly add all of the cement and fly ash.
5. Place remaining sand in mixer and use the remaining water to wash constituents from the inside edges of mixer.
6. Mix materials for 3 minutes.
7. After the 3 minutes of mixing; shut off mixer, cover with a damp cloth, and allow the concrete to sit for three minutes.
8. After the 3-minute rest, turn mixer back on for 2 minutes.

Once the concrete was completely mixed, it was tested for slump, unit weight, temperature, and air content. Next, the concrete was cast into cylinders, beams, freeze-thaw specimens, and slabs for the durability tests.

2.6 Test Methods

The following test methods were used for this research:

Concrete Slump Test - ASTM C 143-00/AASHTO T 119-99

Unit Weight and Yield of Concrete - ASTM C 138-01, AASHTO T 121-97

Air Content of Freshly Mixed Concrete - ASTM C 231-97/AASHTO T 152-01

Concrete Temperature – ASTM C 1064-01

Flexural Strength Testing - ASTM C 78-94, AASHTO T 97-97

Flexural tests on the cured concrete were performed on 1, 7, 14, 28, 56, and 90 days after the batching day. The dimensions of the beam specimen used for the test were 21”x 6”x 6”. Test specimens were cured in accordance with ASTM C 192-98. The following equation was used to calculate the flexural strength:

Modulus of Rupture (psi) = Pl/bd^2

Where: P is the maximum load (lbs.)

l is the span length (inches)

b is the ave. width (inches)

d is the ave. depth (inches)

Multiple specimens were broken for each test. The average strength of the specimens was reported as the flexural strength of that mix.

Compressive Strength Testing - ASTM C 39-01, AASHTO T 22-97

Compressive tests on the cured concrete were performed on 1, 3, 7, 14, 28, 56, and 90 days after the batching day. The dimensions of the cylinders were 6" in diameter by 12" in height. The test specimens were cured in accordance with ASTM C 192-98. Two steel caps with neoprene inserts were used to support the specimens. The caps conform to ASTM C 1231-00. The following equation was used to calculate the compressive strength:

Compressive Strength of Concrete (psi) =

Max. Applied Load (lbs)/Cross-sectional Area (in^2*)*

Multiple specimens were broken for each test. The average strength of the specimens was reported as the compressive strength of that mix.

Rapid Chloride Ion Permeability Test - ASTM C 1202-97

The equipment used for testing was the <u>PROOVE IT</u> system, version 1.3, manufactured by Germann Instruments, In-Situ Test Systems. The slabs for the test specimens were cured for a 24-hour period with plastic covering. After this 24-hour period, the slab was separated from the wood forms and cured for a period of 56 days in the laboratory environment. A 4-inch diameter diamond core drill was used to obtain cores. Three individual cores from each slab were evaluated to determine a mean permeability for each mix design. Each core was cut into four slices of 2-in. (+/- 0.125”) thickness using a wet-cut masonry saw. These four slices were individually tested to obtain permeability data at 2-inch intervals through the depth of the slab.

Resistance of Concrete to Rapid Freezing and Thawing - ASTM C 666-97

For each design mix, two or three 4”x 3”x 16” specimens were cast in the laboratory with embedded gauge studs at each end in accordance with ASTM C 192. After 24 hours of curing, the specimens were removed from their molds and placed in a temperature controlled curing room. After 14 days of curing, the specimens were either placed directly in the testing apparatus for immediate testing, or placed in a freezer to keep the hydration process dormant until the test apparatus was available for the next group of specimens.

There was one difference between the ASTM C 666 procedure and the procedure used for this research. ASTM C 666 specifies that the specimens should be removed from the freeze-thaw apparatus and tested for fundamental transverse frequency and length change (at most) every 36 freeze-thaw cycles. For this research, the samples were removed and tested after about every 50 freeze-thaw cycles. However the full freeze-thaw procedure was run for a total of 300 cycles in accordance with ASTM C 666.

Air-Void Analysis - ASTM C 457-98, procedure B ”modified point count method.”

A concrete specimen was prepared for each concrete mix for microscopic determination of the air-void system parameters in hardened concrete. One half inch thick specimens were cut axially from cores obtained in the same manner as the cores used for rapid chloride ion permeability test.

Resistance of Concrete Surface to Deicing Chemicals - ASTM C 672

Two test specimens were prepared for each concrete mix for the deicer test. The specimens were 13”x 13”x 3” concrete slabs. The specimens were first cured for 14 days and then they were either subjected to the test right away or placed in a freezer. The specimens were fitted with a latex caulk rim around their edges. This caulk was approximately 0.5” high. Next, a 4% sodium chloride solution was placed on the top of the specimen to a depth of approximately 0.25”. Sodium chloride was used for the test at the request of NDDOT because this chemical is commonly used in North Dakota. The specimens were then put through 50 freeze-thaw cycles. This was accomplished by moving the specimens in and out of a freezer room on specially designed carts. The freeze-thaw cycle usually occurred once per day.

Chapter 3

Experimental Test Results

3.1 Introduction

Experimental results from tests conducted on seventeen different concrete mixes are presented in this chapter. Sixteen of the mixes were prepared using eight different commercially available water-reducing admixtures at two dosage levels each. The results obtained for each mix include, plastic properties, flexural strength, compressive strength, air-void characteristics, freeze-thaw resistance, resistance of concrete to deicing chemicals, and concrete permeability.

The various types of water reducer admixtures used for this research are listed in Table 3.1. The table lists four different admixture suppliers, the names of their admixtures, identification codes for the mixes, water reduction targets for the mixes, suggested dosages for the admixtures, dosages used for this research, and general water reducer range classification for each admixture. The mix identification code contains the name of the supplier, a product identifier, and the water reduction target for each mix. For example, MB-322N-5 stands for Master Builders- Pozzolith 322N-5% water reduction.

3.2 Mix Design Proportions

Approximately 18.4 ft^3 of concrete was produced in four 4.6 ft^3 batches for each mix. This amount of concrete was needed to prepare all of the specimens required for the durability tests. The component proportions for each mix are listed in Tables 3.2 through 3.5. Table 3.2 also contains the plastic properties for the control mix. Detailed mix design spreadsheets for each mix are contained in the Appendix G

Mix Identifier	Admixture Supplier for Mix	Product Name	ASTM C 494 Admixture Type	Suggested Dosage (fl.oz./100 lbs.cement)	Dosage Used for Research (fl.oz./100 lb. cement.)	Water Reduction Target for Research (%)
MB-332N-5	Master Builders	Pozzolith 322N	Type A	3 to 7	1.82	5
MB-332N-8	Master Builders	Pozzolith 322N	Type A	3 to 7	2.96	8
MB-997-8	Master Builders	Polyheed 997	Type A and F	3 to 15	2.72	8
MB-997-12	Master Builders	Polyheed 997	Type A and F	3 to 15	4.10	12
Brett-WR91-5	Brett	Eucon WR 91	Types A and D*	2 to 10	2.0	5
Brett-WR91-8	Brett	Eucon WR 91	Types A and D	2 to 10	2.58	8
Brett-37-8	Brett	Eucon 37	Type A and F	6 to 20	2.22	8
Brett-37-12	Brett	Eucon 37	Type A and F	6 to 20	4.45	12
Grace-82-5	Grace	WRDA-82	Type A	3 to 6	1.82	5
Grace-82-8	Grace	WRDA-82	Type A	3 to 6	3.12	8
Grace-140-8	Grace	ADVA 140	Type A and F	6 to 16	2.73	8
Grace-140-12	Grace	ADVA 140	Type A and F	6 to 16	4.32	12
GRT-400NC-5	GRT	Polychem 400NC	Type A	3 to 5	1.82	5
GRT-400NC-8	GRT	Polychem 400NC	Type A	3 to 5	2.73	8
GRT-Melchem-8	GRT	Melchem	Type A and F	6 to 18	2.73	8
GRT-Melchem-12	GRT	Melchem	Type A and F	6 to 18	4.32	12

* D indicates that admixture has the effect of retarding set in addition to reducing water

Table 3.1 Water-Reducing Admixtures Used for This Research Project

Table 3.2 Master Builders and Control Mix Proportions

Mix Identification	Control	MB-322N-5	MB-322N-8	MB-997-8	MB-997-12
Batch Date	25-Nov-02	9-Oct-02	10-Oct-02	14-Oct-02	23-Oct-02
Cement (lbs.)	67.26	68.72	67.26	67.26	67.26
Fly Ash (lbs.)	28.83	29.45	28.83	28.83	28.83
Fine Aggregate (lbs.)	216.98	223.06	224.13	223.48	226.65
Coarse Aggregate (lbs.)	321.59	328.58	320.63	320.79	320.79
Expected Air Content (%)	6%	6%	6%	6%	6%
Expected Slump (in.)	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5
Air-Entraining Admixture (ml)	61.4	43.8	38.6	50	46.9
Water-Reducing Admixture (ml)	0	116.1	184.7	169.9	255.8
Water (lbs.)	34.46	36.67	32.88	33.37	32.27
Water/Cement Ratio	0.35	0.34	0.33	0.33	0.31

Table 3.3 Brett Mix Proportions

Mix Identification	Brett-WR91-5	Brett-WR91-8	Brett-37-8	Brett-37-12
Batch Date	28-Oct-02	1-Nov-02	11-Feb-03	13-Feb-03
Cement (lbs.)	67.26	67.26	67.26	67.26
Fly Ash (lbs.)	28.83	28.83	28.83	28.83
Fine Aggregate (lbs.)	219.39	226.73	221.31	225.77
Coarse Aggregate (lbs.)	320.79	320.79	320.47	320.47
Expected Air Content (%)	6%	6%	6%	6%
Expected Slump (in.)	1-1.5	1-1.5	1-1.5	1-1.5
Air-Entraining Admixture (ml)	28.4	38.4	56.8	56.8
Water-Reducing Admixture (ml)	127.9	161.1	137.8	278.5
Water (lbs.)	35.62	30.12	35.86	33.47
Water/Cement Ratio	0.34	0.33	0.33	0.31

Table 3.4 Grace Mix Proportions

Mix Identification	Grace-82-5	Grace-82-8	Grace-140-8	Grace-140-12
Batch Date	20-Feb-03	21-Feb-03	25-Feb-03	27-Feb-03
Cement (lbs.)	67.26	67.26	67.26	67.26
Fly Ash (lbs.)	28.83	28.83	28.83	28.83
Fine Aggregate (lbs.)	224.74	227.82	224.78	230.84
Coarse Aggregate (lbs.)	320.47	320.47	320.47	320.47
Expected Air Content (%)	6%	6%	6%	6%
Expected Slump (in.)	1-1.5	1-1.5	1-1.5	1-1.5
Air-Entraining Admixture (ml)	38.4	39.8	44.0	46.9
Water-Reducing Admixture (ml)	113.7	194.7	170.5	270.0
Water (lbs.)	30.59	29.35	32.39	28.41
Water/Cement Ratio	0.34	0.33	0.33	0.31

Table 3.5 GRT Mix Proportions

Mix Identification	GRT-400NC-5	GRT-400NC-8	GRT-Melchem-8	GRT-Melchem-12
Batch Date	2-Apr-03	4-Apr-03	29-Apr-03	6-May-03
Cement (lbs.)	67.26	67.26	67.26	67.26
Fly Ash (lbs.)	28.83	28.83	28.83	28.83
Fine Aggregate (lbs.)	225.81	227.82	232.38	230.84
Coarse Aggregate (lbs.)	323.19	321.91	323.51	321.59
Expected Air Content (%)	6%	6%	6%	6%
Expected Slump (in.)	1-1.5	1-1.5	1-1.5	1-1.5
Air-Entraining Admixture (ml)	48.3	48.3	71.0	49.7
Water-Reducing Admixture (ml)	113.7	170.5	170.5	270.0
Water (lbs.)	26.8	27.91	23.83	27.29
Water/Cement Ratio	0.34	0.33	0.33	0.31

3.3 Plastic Properties of Mixes

The plastic properties measured for the design mixes include slump, air content, unit weight, and w/c ratio. The two control variables used for the mixes were slump and air content. The slump was controlled at 1 to 1.5 inches because this is in the range typically used for slipform paving. The air content was controlled at approximately 6%. The plastic properties of the control and water-reducer design mixes are summarized in Table 3.6. Additional detailed batch data including batch temperatures for the mixes can be found in the Appendix G.

3.4 Flexural Strength Test Results

Flexural strength is an important indicator of concrete quality. The average flexural strengths measured for the water reducer mixes after curing times of 1, 28, and 90 days are summarized in Table 3.7. A complete set of flexural strength data, including 1, 7, 14, 28, 56, and 90 day results is contained in the Appendix B-F.

3.5 Compressive Strength Test Results

Compressive strength is also an important indicator of concrete quality. The average compressive strengths measured for the water reducer mixes after curing times of 1, 28, and 90 days are summarized in Table 3.8. A complete set of compressive strength data, including 1, 3, 7, 14, 28, 56, and 90 day results is contained in the Appendix B-F.

Table 3.6 Summary of Plastic Properties of the Concrete Mixes

Mix Identifier	Product	Water/Cement Ratio	Slump (inches)	Air Content (%)	Unit Weight (lb/ft^3)
Control	N/A	0.35	1.25	6.0	146.6
MB-332N-5	Pozzolith 322N	0.34	1 .5	6.2	146.8
MB-332N-8	Pozzolith 322N	0.33	1.25	6.3	146.6
MB-997-8	Polyheed 997	0.33	1.25	6.0	147.3
MB-997-12	Polyheed 997	0.31	1.25	5.5	148.5
Brett-WR91-5	Eucon WR 91	0.34	1.75	6.4	145.3
Brett-WR91-8	Eucon WR 91	0.33	1.5	6.2	145.5
Brett-37-8	Eucon 37	0.33	1.0	5.7	148.1
Brett-37-12	Eucon 37	0.31	1.0	5.7	148.7
Grace-82-5	WRDA-82	0.34	1.0	6.1	146.6
Grace-82-8	WRDA-82	0.33	1.25	6.5	147.0
Grace-140-8	ADVA 140	0.33	1.5	5.9	147.0
Grace-140-12	ADVA 140	0.31	1.25	5.8	148.0
GRT-400NC-5	Polychem 400NC	0.34	1.25	5.6	146.5
GRT-400NC-8	Polychem 400NC	0.33	1.25	5.9	146.8
GRT-Melchem-8	Melchem	0.33	1.75	5.7	146.9
GRT-Melchem-12	Melchem	0.31	1.5	5.4	148.0

Table 3.7 Summary of Flexural Strengths for the Concrete Mixes

Mix Identifier	Product	1 Day (psi)	28 Day (psi)	90 Day (psi)
Control	N/A	288	496	571
MB-332N-5	Pozzolith 322N	325	580	675
MB-332N-8	Pozzolith 322N	490	620	715
MB-997-8	Polyheed 997	385	635	685
MB-997-12	Polyheed 997	330	665	760
Brett-WR91-5	Eucon WR 91	255	525	645
Brett-WR91-8	Eucon WR 91	285	600	675
Brett-37-8	Eucon 37	380	585	630
Brett-37-12	Eucon 37	310	540	615
Grace-82-5	WRDA-82	355	610	625
Grace-82-8	WRDA-82	480	685	730
Grace-140-8	ADVA 140	265	575	625
Grace-140-12	ADVA 140	285	635	700
GRT-400NC-5	Polychem 400NC	325	575	655
GRT-400NC-8	Polychem 400NC	360	575	675
GRT-Melchem-8	Melchem	385	630	735
GRT-Melchem-12	Melchem	390	635	740

Table 3.8 Summary of Compressive Strengths for the Concrete Mixes

Mix Identifier	Product	1 Day (psi)	28 Day (psi)	90 Day (psi)
Control	N/A	1335	3425	4140
MB-332N-5	Pozzolith 322N	1255	3910	4750
MB-332N-8	Pozzolith 322N	1835	5080	5860
MB-997-8	Polyheed 997	1845	5150	5725
MB-997-12	Polyheed 997	1590	5570	6310
Brett-WR91-5	Eucon WR 91	1025	3510	4630
Brett-WR91-8	Eucon WR 91	1240	4525	4965
Brett-37-8	Eucon 37	1850	3325	4105
Brett-37-12	Eucon 37	1710	3530	4325
Grace-82-5	WRDA-82	1360	3990	4420
Grace-82-8	WRDA-82	1375	4310	5475
Grace-140-8	ADVA 140	1105	3075	4080
Grace-140-12	ADVA 140	1295	3575	4560
GRT-400NC-5	Polychem 400NC	1370	4000	4955
GRT-400NC-8	Polychem 400NC	1515	4060	5230
GRT-Melchem-8	Melchem	2070	4355	5745
GRT-Melchem-12	Melchem	2310	4935	5795

3.6 Air-Void Analysis Test Results

Air content in concrete is an important factor relating to durability. Air-void analysis is done to characterize the arrangement of air-voids in the hardened concrete matrix. The test involves making a microscopic examination of the surface of a concrete section. Important parameters determined with the air-void analysis include the total hardened air content, the specific surface of the voids, and the spacing factor for the voids. Values for these parameters measured for the control and water-reduced mixes can be found in Table 3.9.

3.7 Freeze-Thaw Test Results

Concrete specimens are subjected to 300 cycles of freezing and thawing for the freeze-thaw test. Freeze-thaw results are an important indicator of the durability of concrete. Important results from freeze-thaw tests include the durability factor, the weight loss of specimen, and the length change of specimen. The averaged values for these parameters measured for the control and water-reduced mixes are contained in Table 3.10. The complete data set for the freeze-thaw tests is contained in the Appendix J.

3.8 Resistance of Concrete to Deicing Chemicals Test Results

This test is designed to evaluate the surface durability of cured concrete to common deicing chemicals. For the test, concrete specimens were covered with a 4% sodium chloride solution and subjected to 50 cycles of freezing and thawing. Sodium chloride was used at the request of NDDOT for the test because it is the type of deicing chemical used on highways in North Dakota. A numerical rating system used for evaluating the surface appearance of each concrete specimen is explained in Table 3.11.

Table 3.9 Summary of Air-Void Analyses for the Concrete Mixes

Mix Identifier	Product	Air Content Fresh Concrete (%)	Air Content Hardened Concrete (%)	Specific Surface (in.)	Spacing Factor (sq.in./cu.in)
Control	N/A	6.0	5.8	748	0.0062
MB-332N-5	Pozzolith 322N	6.2	3.6	1008	0.0051
MB-332N-8	Pozzolith 322N	6.3	4.5	687	0.0060
MB-997-8	Polyheed 997	6.0	5.6	826	0.0061
MB-997-12	Polyheed 997	5.5	3.9	696	0.0072
Brett-WR91-5	Eucon WR 91	6.4	5.0	1094	0.0044
Brett-WR91-8	Eucon WR 91	6.2	7.3	1062	0.0041
Brett-37-8	Eucon 37	5.7	5.4	861	0.0057
Brett-37-12	Eucon 37	5.7	5.3	1200	0.0040
Grace-82-5	WRDA-82	6.1	7.9	603	0.0048
Grace-82-8	WRDA-82	6.5	9.1	958	0.0051
Grace-140-8	ADVA 140	5.9	6.6	796	0.0042
Grace-140-12	ADVA 140	5.8	8.3	972	0.0048
GRT-400NC-5	Polychem 400NC	5.6	5.1	778	0.0060
GRT-400NC-8	Polychem 400NC	5.9	4.4	756	0.0061
GRT-Melchem-8	Melchem	5.7	4.6	998	0.0046
GRT-Melchem-12	Melchem	5.4	3.7	689	0.0067

Table 3.10 Summary of Freeze-Thaw Test Results for the Concrete Mixes

Mix Designation	Product	Durability Factor (%)	Specimen Weight Loss (%)	Specimen Length Change (%)
Control	N/A	88.7	-0.244	0.0070
MB-332N-5	Pozzolith 322N	78.5	-1.520	0.0907
MB-332N-8	Pozzolith 322N	76.9	-0.712	0.0983
MB-997-8	Polyheed 997	73.7	0.188	0.0090
MB-997-12	Polyheed 997	72.9	0.227	0.0090
Brett-WR91-5	Eucon WR 91	76.7	-0.134	0.0763
Brett-WR91-8	Eucon WR 91	77.4	0.299	0.0010
Brett-37-8	Eucon 37	73.8	-0.421	0.0260
Brett-37-12	Eucon 37	76.6	-0.540	0.0457
Grace-82-5	WRDA-82	81.7	-0.897	0.0157
Grace-82-8	WRDA-82	78.7	-0.765	0.0485
Grace-140-8	ADVA 140	72.9	0.030	0.0125
Grace-140-12	ADVA 140	75.5	-0.491	0.0250
GRT-400NC-5	Polychem 400NC	76.7	0.091	0.0360
GRT-400NC-8	Polychem 400NC	73.7	-0.605	0.0265
GRT-Melchem-8	Melchem	73.0	-0.490	0.0295
GRT-Melchem-12	Melchem	80.4	-0.332	0.0595

Table 3.11 Numerical Rating System for Deicing Chemical Test Specimens

Rating	Condition of Surface
0	No scaling
1	Very slight scaling (1/8” depth max, no coarse aggregate visible)
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

Deicing chemical test results are listed in Table 3.12 for each of the water-reduced mixes at 5, 10, 15, 25, and 50 freeze-thaw cycles. The results in Table 3.12 correspond to the surface descriptions contained in Table 3.11. Two concrete specimens were tested for each concrete mix. The ratings in Table 3.12 are averaged values. The complete data set for the deicer test including pictures of the test slabs is contained in Appendix I.

Table 3.12 Summary of Averaged Deicing Chemical Test Results for the Concrete Mixes

Mix Designation	Product	5 Cycles	10 Cycles	15 Cycles	25 Cycles	50 Cycles
Control	N/A	1	1	2	2.5	3
MB-332N-5	Pozzolith 322N	2	3	3	3	3
MB-332N-8	Pozzolith 322N	1	1.5	2	2	2
MB-997-8	Polyheed 997	1.5	2.5	2.5	2.5	3
MB-997-12	Polyheed 997	1.5	2.5	3	3.5	3.5
Brett-WR91-5	Eucon WR 91	1.5	2.25	2.5	3	3.25
Brett-WR91-8	Eucon WR 91	1	1.5	2	3	3
Brett-37-8	Eucon 37	2.5	3.5	3.5	3.5	3.75
Brett-37-12	Eucon 37	2.5	3.5	3.5	3.5	3.5
Grace-82-5	WRDA-82	1	1.5	1.75	2.5	3
Grace-82-8	WRDA-82	1.5	2	2.5	2.75	3
Grace-140-8	ADVA 140	1.5	3	3.5	3.5	3.5
Grace-140-12	ADVA 140	1.5	1.5	2.5	2.5	2.5
GRT-400NC-5	Polychem 400NC	1	2.5	2.5	3	3.25
GRT-400NC-8	Polychem 400NC	1	2	2	2	2
GRT-Melchem-8	Melchem	2	3	3	3	3
GRT-Melchem-12	Melchem	1	2	2	2	2.25

3.9 Permeability Test Results

Permeability of concrete as measured by the rapid chloride ion permeability test is based on the amount of electrical charge passed through a specially prepared concrete specimen during the testing period. The permeability of the concrete is then classified as high, moderate, low, very low, or negligible based on the rating system shown in Table 3.13.

Table 3.13 Permeability Rating Chart

Rating	Number of Coulombs Passed
High (H)	> 4,000
Moderate (M)	2,000-4,000
Low (L)	1,000-2,000
Very Low (VL)	100-1,000
Negligible (N)	< 100

The permeability test results for the water reducer mixes are contained in Table 3.14. The table lists the coulombs of current passed and the permeability classification for 2-inch thick sections cut at depths of 0-2", 2-4", 4-6", and 6-8" from an 8-inch concrete core from a test slab. The 0-2" section came from the top (finished) portion of the slab. The permeability values reported in the table are averaged from three test specimens, the complete set of test results are contained in the Appendix H.

Table 3.14 Average Rapid Chloride Ion Permeability Data for the Concrete Mixes

Mix Identifier	Product	0-2 Inches (Coul.)	2-4 Inches (Coul.)	4-6 Inches (Coul.)	6-8 Inches (Coul.)
Control	N/A	2723-M*	1222-L	601-VL	233-VL
MB-332N-5	Pozzolith 322N	3697-M	1144-L	1078-L	1215-L
MB-332N-8	Pozzolith 322N	2347-M	1112-L	1026-L	1292-L
MB-997-8	Polyheed 997	3094-M	1133-L	801-VL	749-VL
MB-997-12	Polyheed 997	3042-M	1052-L	839-VL	1013-L
Brett-WR91-5	Eucon WR 91	2677-M	1129-L	836-VL	789-VL
Brett-WR91-8	Eucon WR 91	3406-M	1375-L	852-VL	629-VL
Brett-37-8	Eucon 37	2958-M	909-VL	785-VL	518-VL
Brett-37-12	Eucon 37	2364-M	838-VL	640-VL	826-VL
Grace-82-5	WRDA-82	2462-M	1409-L	445-VL	834-VL
Grace-82-8	WRDA-82	2218-M	941-VL	732-VL	618-VL
Grace-140-8	ADVA 140	3589-H	2054-M	1002-L	623-VL
Grace-140-12	ADVA 140	4149-H	1949-L	478-VL	850-VL
GRT-400NC-5	Polychem 400NC	2422-M	2847-M	495-VL	1010-L
GRT-400NC-8	Polychem 400NC	3679-M	2236-M	1115-L	274-VL
GRT-Melchem-8	Melchem	2804-M	1779-L	943-VL	471-VL
GRT-Melchem-12	Melchem	3025-M	1603-L	610-VL	772-VL

* The letter indicates the permeability rating as described in Table 3.13.

Chapter 4

Discussion and Analysis of Results

4.1 Compressive and Flexural Strength Test Results

Water-reducing admixtures generally produce an increase in the strength of concrete as the w/c ratio is reduced. For concretes of equal cement content, air content, and slump; the 28-day strength of a water-reduced concrete can be 10% to 25% greater than concrete without water reducing admixture (Ref. 1).

The 28-day unconfined compressive strengths and 28-day flexural strengths of the concrete mixes prepared for this study are shown in Figure 4.1 and Figure 4.2 respectively. The figures show that strengths measured for the water-reduced mixes were generally higher than the control. A specific identifier for each mix is written below the x-axis in the figures. For each mix, the identifier indicates the admixture supplier, the type of admixture used, and the percentage water reduction achieved. See Table 3.1 for more information about the various admixtures.

It appears that the mixes generally followed the expected trend of increasing strength with decreasing w/c ratio. The averaged 28-day compressive and 28-day flexural strengths of the 5%, 8%, and 12% water-reduced mixes are plotted versus w/c ratio in Figure 4.3 and Figure 4.4 respectively. Both figures show a consistent increase in average concrete strength as the w/c ratio of the mixes decrease. (The w/c ratio for the control mix was 0.35, the w/c ratio for the 5% water-reduced mixes was 0.34, the w/c ratio for the 8% water-reduced mixes was 0.33, and the w/c ratio for the 12% water-reduced mixes was 0.31).

Figure 4.1 28-Day Compressive Strengths

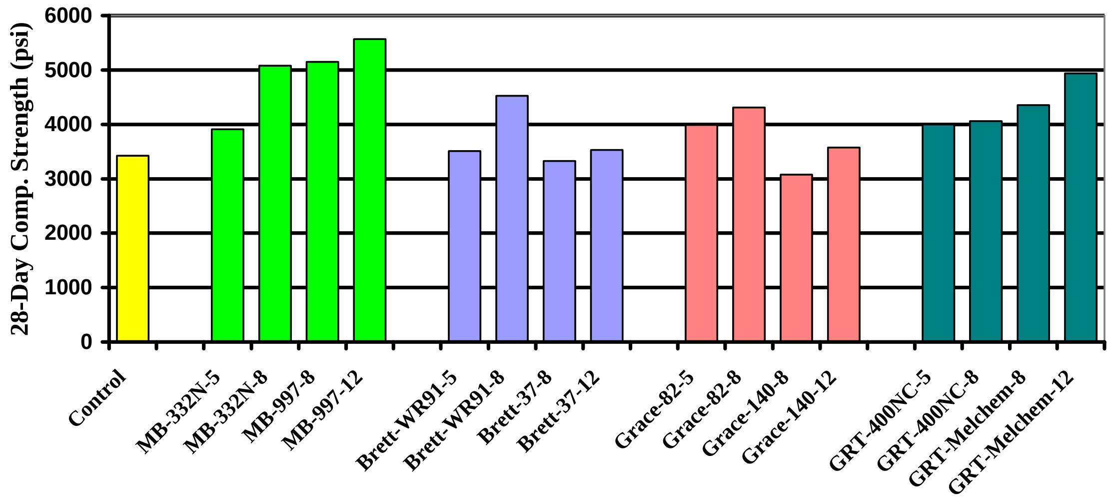


Figure 4.2 28-Day Flexural Strengths

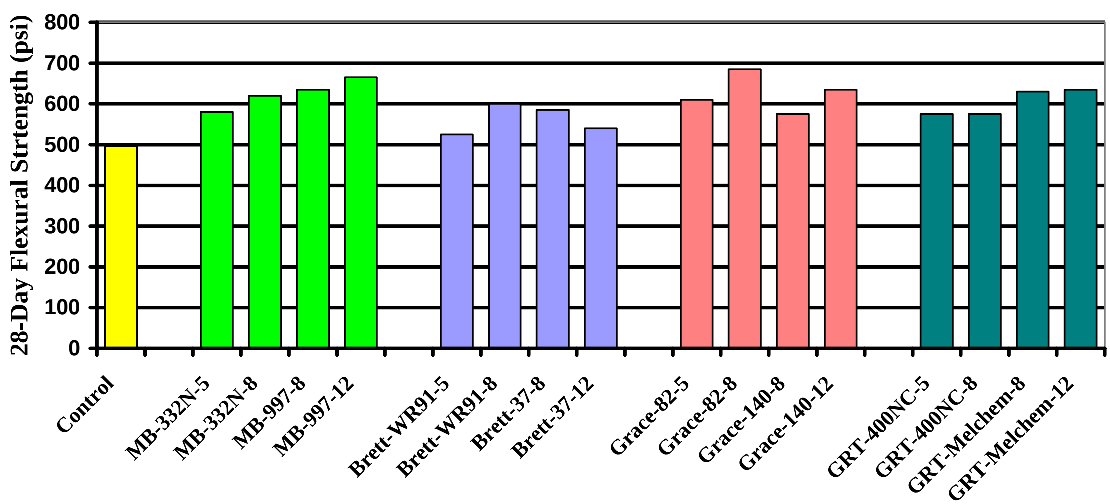


Figure 4.3 Average 28-Day Compressive Strength VS. Water-Cement Ratio

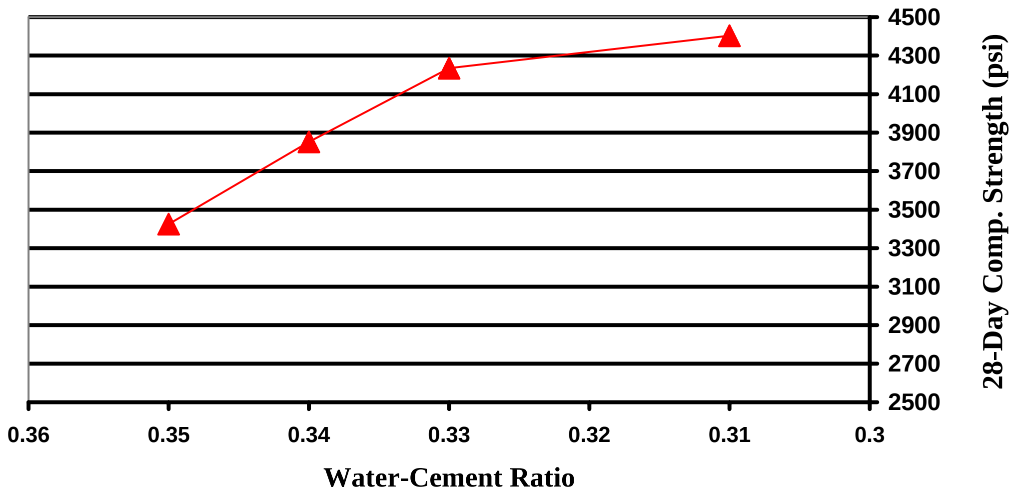
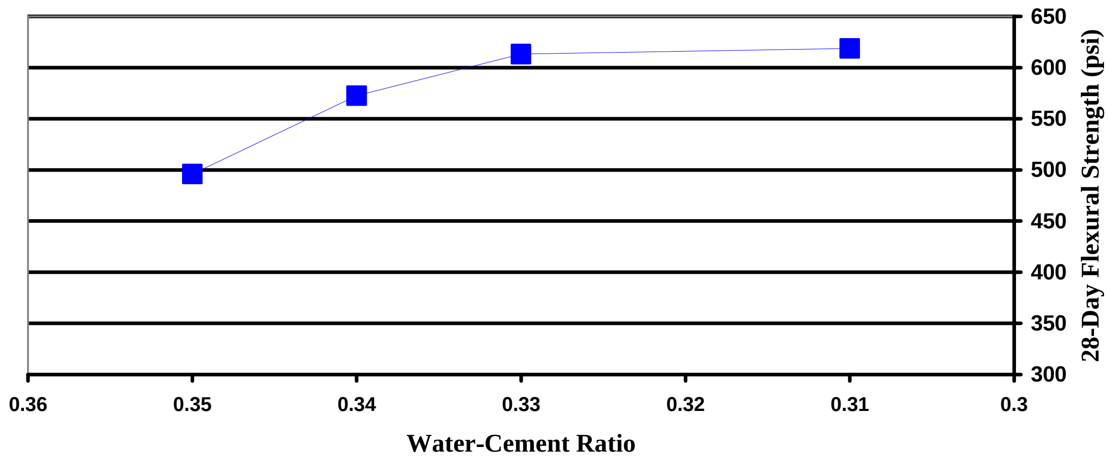


Figure 4.4 Average 28-Day Flexural Strength VS. Water-Cement Ratio



4.2 Freeze-Thaw Durability Test Results

Freeze-thaw durability of concrete prepared with Type F water reducers was studied in a previous research project (Ref. 3). For that research, a control concrete mix was prepared with a cement content of 658 lb/yd^3, maximum aggregate size of 0.75 inches, slump of 2 to 3 inches, w/c ratio of 0.4, and air content of 6% +/- 1%. Water-reduced concrete mixes were also prepared using two different admixtures in a similar manner except that the slump was 5 to 6 inches, w/c ratio was 0.34, and the air content of fresh concrete was 7% to 8%. Results of freeze-thaw tests (ASTM C 666) performed on these concretes indicated that the freeze-thaw durability was good for both the control and water-reduced mixes. Values reported for relative dynamic modulus were all in the mid-nineties, and the values for the water-reduced mixes were one to two points higher than the control mix.

The results obtained from freeze-thaw tests performed for this research are summarized in Figure 4.5. Durability factors for the concrete mixes are shown. From the figure, it can be seen that the durability factors measured for all of the water-reducer mixes were lower than the control. Further, Figure 4.6 indicates that the general trend was for the durability factor of the concrete to decrease as the w/c ratio decreased. Considering the freeze-thaw results reported in the Reference 3 and the strength vs. w/c ratio trends observed in this study, the freeze-thaw results obtained for the water-reducer mixes in this study were initially surprising. Possible reasons for the apparent loss of freeze-thaw durability caused by addition of water-reducing admixtures will be discussed in Chapter 5.

The method used for the freeze-thaw tests in this research was slightly different from that specified in ASTM C 666. See Section 2.6 for a description of the test procedure used.

Figure 4.5 Durability Factors from Freeze-Thaw Tests

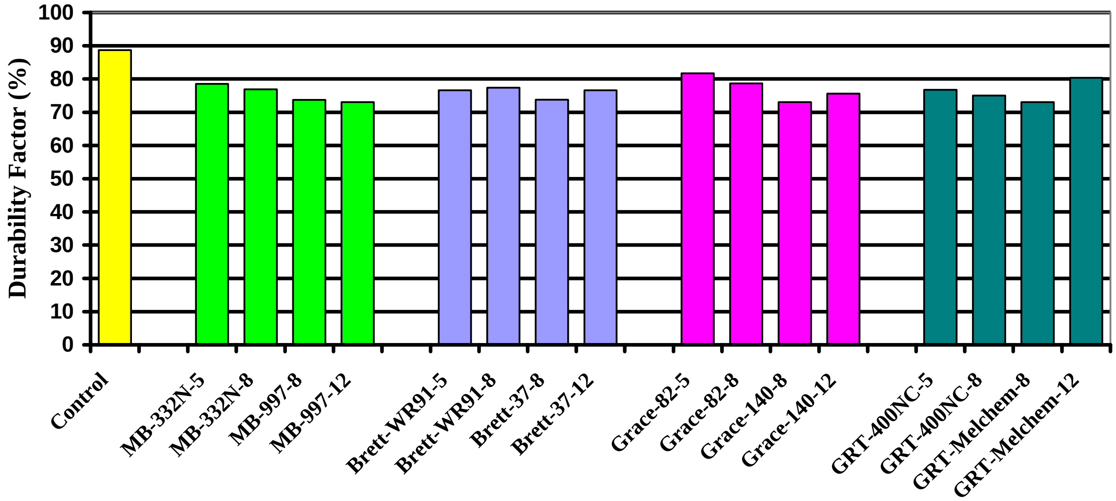
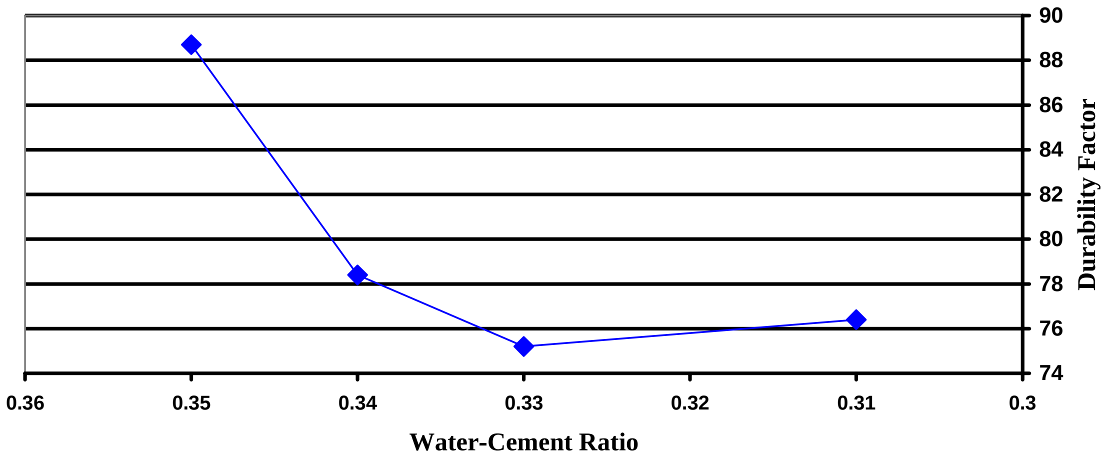


Figure 4.6 Freeze-Thaw Durability Factor VS. Water-Cement Ratio

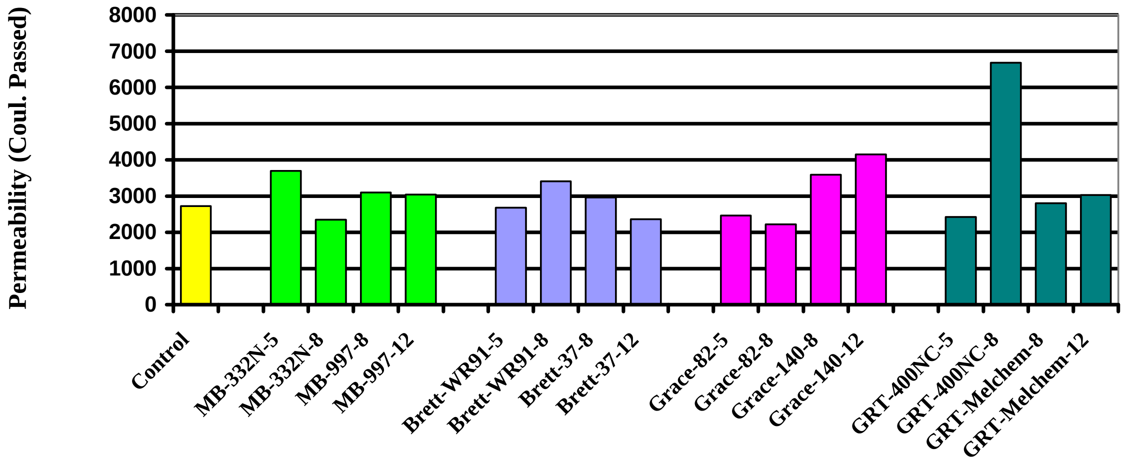


4.3 Rapid Chloride Ion Permeability Test Results

Rapid chloride ion permeability of concrete prepared with Type F water reducing admixtures was evaluated in Reference 2. For that research, a control concrete mix was prepared with a cement content of 545 lb/yd^3, a w/c of 0.5, a slump of 3 to 5 inches, and an air content of 6% +/- 1%. Concrete mixes were then prepared with water contents about 16% lower than the control using three different Type F admixtures. Results from rapid chloride ion permeability tests (AASHTO T 277) performed on specimens from the top 2 inches of concretes prepared for this study indicated that the control and water-reducer mixes all exhibited rapid chloride ion permeabities in the moderate range (i.e., 2000 to 4000 coulombs passed).

The results of rapid chloride ion permeability tests performed for this research are presented in Figure 4.7. The figure shows the charge passed by specimens cut from the top two inches of concrete slabs prepared for the control and sixteen water-reducer mixes. The control and fourteen of the water-reducer mixes exhibited moderate permeability (i.e., 2000 to 4000 coulombs passed). Two of the water-reducer mixes exhibited high permeability (i.e., > 4000 coulombs passed). The rapid chloride ion permeability results obtained for this study are similar to those contained in Reference 2, however the mixes discussed in Reference 2 exhibited better ASTM C 666 freeze-thaw durability. Their values for relative dynamic modulus were in the range of 94% to 98% for the control and water-reducer mixes.

Figure 4.7 Rapid Chloride Ion Permeabilities - Top 2 Inches of Water-Reduced Concrete Slabs



4.4 Resistance to Deicer Scaling Test Results

Resistance to deicer scaling (ASTM C 672) was also measured for concretes prepared with Type F water reducing admixtures in the two previous studies discussed above (Refs. 2 and 3). The results from these two studies indicated that after 50 cycles of freezing and thawing, the water-reducer mixes exhibited very slight to moderate scaling (i.e., ratings of 1 to 3 as per ASTM C 672).

The results of the deicer scaling tests performed on the water-reducer mixes for this study are contained in Table 3.12. These results indicate that after 50 cycles of freezing and thawing, the water-reducer mixes exhibited scaling characteristics ranging from slight-moderate to moderate-severe (i.e., ratings of 2 to 4 as per ASTM C 672). However there is one difference between the methods used to conduct the deicer scaling tests, the current study used sodium chloride as the deicing chemical and the previous studies used calcium chloride. (See Section 2.6 for further discussion of the deicer test method.)

4.5 Analysis of Air Void System Test Results

Air-void spacing and air-void size in hardened concrete are two important factors contributing to freeze-thaw resistance in concrete. Research has shown that in general for a concrete to have adequate resistance to freezing and thawing, the air-void spacing factor should not exceed 0.008 inches and the air-void specific surface should be 600 sq in./cu in. or greater (Ref.1, pg 131).

The results of air-void analyses conducted for this research are contained in Table 3.9. The results show that (1) all of the air-void spacing factors were less than 0.008 inches and (2) all of the air-void specific surfaces were greater than 600 sq in./cu in. The results indicate that for these two parameters, the samples from the control all of the water-reduced mixes were within acceptable limits for adequate freeze-thaw resistance.

Chapter 5

Summary and Conclusions

The objective of this research was to determine the effects of water-reducing admixtures on the strength and durability characteristics of concrete materials designed based on current mix design procedures used by the NDDOT per their standards and specifications. Four brands of water reducers that are commonly used in the State of North Dakota were selected for study. Brett, GRT, Grace, and Master Builders supplied the admixtures. Each company sent two different water reducers along with an air-entraining admixture. Batches of concrete were prepared using each product. The characteristics of the concretes produced were evaluated by performing the following tests on appropriately prepared specimens:

- Compressive strength (AASHTO T-22)
- Flexural strength (AASHTO T-97)
- Resistance of concrete to rapid freezing and thawing (ASTM C 666)
- Rapid chloride ion permeability (ASTM C 1202)
- Air-void analysis on hardened concrete (ASTM C 457), and
- Resistance of concrete surface to deicing chemicals (ASTM C 672)

One of the water reducers supplied by each company was used to produce two concrete mixes with targeted water reduction percentages of 5% and 8%, and the other was used to produce two concrete mixes with targeted water reduction percentages of 8% and 12%. Thus a total of sixteen different concrete mixes were prepared for this research using eight different water-reducing admixtures. In addition, a control mix was prepared without water reducer for comparison purposes. The control mix was designed based on the *NDDOT's Standards and Specifications for Road and Bridge Construction, 1997, Volumes 1 and 2.*

The results obtained from this study for the water-reduced concrete mixes studied are summarized as follows:

- Results obtained from the strength tests done on the control and water-reducer mixes prepared for this study appear to be generally consistent with results obtained from previous research. Compressive and flexural strengths were consistently higher than the control mix and the strengths tended to increase as the w/c ratio of the concrete decreased.
- Results obtained from the freeze-thaw tests done for this study indicate that all of the concrete mixes that contained water-reducing admixtures had significantly lower freeze-thaw durability compared to the control mix. These freeze-thaw test results do not agree with results obtained from previous studies.
- Results from the deicer scaling tests obtained for this study generally indicate scaling in the moderate to moderate/severe range. Previous studies reported results from deicer scaling tests in the slight/moderate to moderate range.
- Results from rapid chloride ion permeability tests obtained for this study were in the moderate range for the control and most of the water-reduced mixes. Two of the water-reduced mixes exhibited permeabilities in the high range.
- For the control and the water reduced mixes, all of the air-void specific surfaces measured were greater than 600 sq in./cu in. and all of the air-void spacing factors measured were less than 0.008 inches. The average air-void spacing factor and specific surface measured for all of the water-reduced mixes were 0.0054 inches and 858 sq in./cu

in. respectively. The results indicate that for these two parameters, the samples prepared from the control mix and all of the water-reduced mixes were within acceptable limits for adequate freeze-thaw resistance.

In general, the concretes prepared for this study using water-reducing admixtures did not perform as well as the water-reduced mixes studied in previous research (as reported in Refs. 2 and 3). The major difference between the mix designs used for the current research and previous research (aside from obvious differences such as sources of cement, aggregate, and water reducer admixtures) are (1) the current study used 30% fly ash for cement replacement while previous studies did not use fly ash, (2) the current study used slightly lower w/c ratios for some mixes, (3) the current study used a target slump of 1.5 inches while the previous studies used target slumps of 3 to 6 inches, and (4) the current study used lower water reducer dosages than previous studies to maintain the 1.5-inch target slump.

It is unlikely that fly ash addition had a significant adverse effect on the durability of the water-reduced concretes. This conclusion is supported by previous research which has shown that properly air-entrained and cured concrete containing fly ash has similar freeze-thaw resistance to non-fly ash amended concrete (Ref. 1, pp 66 – 67).

It is also unlikely that the air-void system in the hardened concrete caused the observed low freeze-thaw durability, since all of the specimens exhibited air-void spacing factors and specific surface areas generally recognized to be acceptable for good freeze-thaw durability. This suggests that the problem may have been with the bonding of the cement paste to the aggregate rather than with formation of the air-voids.

It is more likely that the combined effects produced by using low w/c ratios and low water-reducer dosages resulted in the poor freeze-thaw durability observed for the water-reduced concrete mixes. The low w/c ratios for the water-reduced mixes were necessary because of the initial low w/c ratio (0.35) used for the control mix. The low dosages of water-reducing admixture were necessary to maintain a 1.5-inch target slump in the concrete mixes; and the 1.5-inch target slump was required for slipform pavement construction.

Table 3.1 contains some information that supports this conclusion. The suggested dosages (based on manufacturers recommendations) for the various water-reducing admixtures used for this study are listed in column 5 and the actual dosages used are listed in column 6. In every case, the dosage used was either below or just slightly above the minimum suggested dosage for the admixture.

Water-reducing admixtures tend to disperse the cement as concrete is mixed, which can help to compensate for low water content. But in this study, the amount of admixture added was limited because the admixture increased the slump. The net result may have been that too little admixture was added to the mixes to effectively disperse the cement. Thus it may be that the combination of low w/c ratio and low admixture dosage limited the dispersal and hydration of cement in the concrete mixes.

Some visual observations made during the compressive strength tests also suggest that there was a problem with cement activation. It was noticed that many of the specimens broke around the top rim of the cylinders and that the concrete was crumbling and pulling away from the aggregate at the point of the break. These observations suggest that the cement paste was not adhering properly to the aggregate, which could occur if the cement was not properly activated.

Chapter 6

Recommendations

The results of this research indicate that the water-reduced concrete mixes studied exhibited poor freeze-thaw durability. The reason for the poor durability may have been that there was not enough water and/or water-reducing admixture being added to the mixes. The following recommendations suggest some possible ways to increase the durability of the water-reduced mixes.

One possible way of increasing the durability of the water-reduced concretes could be to redesign the control mix with a higher w/c ratio while maintaining a 1.5-inch slump. If for example, the w/c ratio of the control mix was increased to 0.40, then the w/c ratios of the water-reduced mixes could be increased proportionately. Increased durability might be achieved with more water available to hydrate the cement.

Another way to improve the performance of the water-reduced concrete mixes might be to use a water-reducing admixture that does not increase the slump of the mix as much as the additives used for this study. Thus more of the admixture could be added to the concrete while still maintaining a low slump. This approach could be studied in future research.

A different means of increasing the durability of the water-reduced mixes could be to increase the target slump for the mixes. Previous research reported in Reference 3 suggests that initial design slumps for water-reduced concretes used for highway pavement should be in the range of 5 to 6 inches and that this slump should be obtained by increasing the dosage of water reducer, not by increasing water content. Thus by increasing the allowable slump, more water reducer could be added to the concrete and the cement would be more effectively activated.

Using a higher slump for the mix design might cause a problem with placing the concrete. However, a significant amount of initial slump loss is fairly typical of water-reduced concrete. Thus a higher initial slump could actually help to counter the expected slump loss.

Appendix A
Sample Mix Spreadsheet and Material Information

- **Sample Mix Spreadsheets**
- **Description of Materials**
- **Cement Properties**
- **Fly Ash Properties**

Project	Effects of Water Reducer on Concrete Durability				Date:	10/9/2003	
Reported to:	ND DOT				Project No:	#REF!	
Mix Number:	1						
Mix Description:	Master Builders/ 322N/ 5% water reduction						
Total Cementitious:	564	lb/yd^3	Percent Fly Ash:	30	%		
Mineral Admixture:		%			.		
Slump:	1.5	inches	Air Content:	6.0	%		
Batch Design Calculations:							
		Sp. Gr.		Weights		Volume	
Fly Ash:		2.55		169.2	lb/yd^3	1.063	ft^3
Cement:		3.15		394.8	lb/yd^3	2.009	
Mineral Admixture:				0.0	lb/yd^3	0.000	
Water:		22.8	gallons	190	lb/yd^3	3.045	
Air:		6.0	%			1.62	
					total voids:	7.737	ft^3
desired w/c ratio:			calculated w/c ratio:	0.34			
ft^3/yd^3:	27.00		Cement/Voids Ratio:	0.66			
Coarse aggregate 1:		60	% =	1928	lbs.		
Coarse aggregate 2:			%	0	lbs.		
Coarse aggregate 3:		0	%	0	lbs.		
		Sp. Gr.		Weights			
Coarse Aggregate1:		2.673		1912	lb/yd^3	11.463	ft^3
Coarse Aggregate2:					lb/yd^3	0.000	ft^3
Coarse Aggregate3:					lb/yd^3	0.000	ft^3
Fine Aggregate:		2.625		1278	lb/yd^3	7.800	ft^3
Water Reducer:	4.0	oz/100-wt.		22.6	oz/yd^3		
Air Entrainment:	1.51	oz/100-wt.		8.5	oz/yd^3		
Other Admixture:		oz/100-wt.		0.0	oz/yd^3		

Table A.1
Sample Mix Spreadsheet – Batch Design Calculations (Mix A1)

Trial Batch Calculations:					
Moistures:	Total Moisture		Absorption		
Coarse Aggregate 1:	0.5	%		1.8	%
Coarse Aggregate 2:		%			%
Coarse Aggregate 3:		%			%
Fine Aggregate:	2.0	%		1.7	%

Trial Batch Weights:

Size	27.0	ft^3	1.0	ft^3	4.7	ft^3
Fly Ash	169.2	lbs.	6.27	lbs.	29.45	lbs.
Cement	394.8	lbs.	14.62	lbs.	68.72	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1888	lbs.	69.91	lbs.	328.58	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1281	lbs.	47.46	lbs.	223.06	lbs.
Water Reducer	22.6	oz.	24.71	ml	116.1	ml
Air Entrainment	8.5	oz.	9.33	ml	43.8	ml
Other Admixture		oz.		ml		ml
Free Water	-2.5	gallons	-0.76	lbs.	-3.59	lbs.
Add Water	25.3	gallons	7.80	lbs.	36.67	lbs.
Total Batch Weight	3943.7	lbs.	146.1	lbs.	686.49	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/2	1 3/4	1 1/4	1	Initial Wt.	
Air	6.1	6.9	6.0	5.7	Final Wt.	
Total Wt.	44.04	43.82	44.12	44.6	Net Wt.	
Con. Wt.	36.32	36.10	36.40	36.86	Free Water	
Unit Wt.	146.45	145.56	146.77	148.63	Add Water	
Temp.	71	70	70	70	Total	
Yield	26.93	27.09	26.87	26.53	W/C Ratio	
Time	16:15	17:00	17:30	18:15		

Table A.2
Sample Mix Spreadsheet – Trial Batch Calculations and Weights (Mix A1)

Cement:	Lafarge Type I Portland. Meets ASTM C 150. Supplied by Lafarge Dakota, Inc. of Grand Forks, ND
Fly Ash:	Class "C" meeting ASTM C 618. Supplied by Lafarge Dakota, Inc. of Grand Forks, ND.
Fine Aggregate:	#4 Minus Sand meeting both ASTM C 33 and ND DOT 816.01. Supplied by Aggregate Industries from their Sheyenne Pit. Located Southwest of Devils Lake, ND in Sheyenne, ND.
Coarse Aggregate:	Natural gravel no bigger than 1" meeting ASTM C 33 and ND DOT 816.02. Supplied by Aggregate Industries from their Sheyenne Pit. Located Southwest of Devils Lake, ND in Sheyenne, ND.
Admixtures:	See sections 2.2.1-2.2.3 for admixture details.

Table A.3 Description of Materials

Chemical Analysis	Percent
Silicon Dioxide	20.9
Alumina	4.2
Iron Oxide	2.8
Calcium Oxide, Total	62.9
Magnesium Oxide	4.5
Sulfur Trioxide	2.5
Calcium Oxide, Free	1.1
Alkalies	0.54
Loss on Ignition	1.38
Chemical Composition	**Percent**
Tricalcium Silicate	57.8
Dicalcium Silicate	16.4
Tricalcium Aluminate	6.3
Tetracalcium Aluminoferrite	8.6
Insoluble Residue	0.26
Physical Properties	
Passing #325 Sieve	96.20%
Blaine	356m^2/kg
Setting Time-Initial	111 min.
False Set	88%
Autoclave Expansion	0.10%
Air Content	5.10%

Table A.4 Type I Cement Properties

Chemical Analysis	Percent %	ASTM C 618 Limits
Silicon Dioxide	49.3	
Aluminum Oxide	17.1	
Iron Oxide	7.7	
Sum of Constituents	74.1	70% min
Sulfur Trioxide	1.2	5% max
Calcium Oxide	15.2	
Moisture Content	0.1	3% max
Loss on Ignition, % Carbon	0.1	2% max*
Available Alkalies	1.2	1.5 % max

* 2% maximum Loss on Ignition is a NDDOT requirement, but not an ASTM requirement.

Table A.5 Fly Ash Properties

Appendix B
Control Mix Experimental Data

- **Compressive Strength**
- **Flexural Strength**
- **Detailed Strength Data**

Mix Designation:	Control 1	Control 2
1-Day Strength (psi):	**1230**	**1335**
3-Day Strength (psi):	**1835**	**2265**
7-Day Strength (psi):	**2330**	**2720**
14-Day Strength (psi):	**2590**	**3125**
28-Day Strength (psi):	**3035**	**3425**
56-Day Strength (psi):	**3505**	**3955**
90-Day Strength (psi):	**3940**	**4140**

Table B.1
Compressive Strength Data for Control Mix

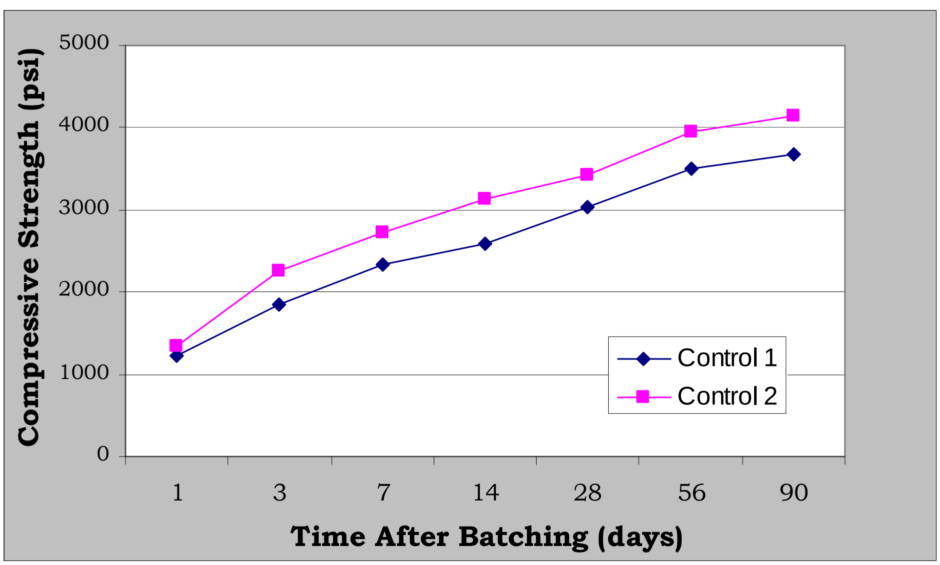


Figure B.1
Control Mix Compressive Strength Development

Mix Designation:	MB-332N-5	MB-332N-8	MB-997-8	MB-997-12
1-Day Strength (psi):	**325**	**490**	**385**	**330**
7-Day Strength (psi):	**520**	**580**	**615**	**620**
14-Day Strength (psi):	**555**	**615**	**585**	**595**
28-Day Strength (psi):	**580**	**620**	**635**	**665**
56-Day Strength (psi):	**660**	**695**	**670**	**715**
90-Day Strength (psi):	**675**	**715**	**685**	**760**

Table B.2
Flexural Strength Data for Control Mix

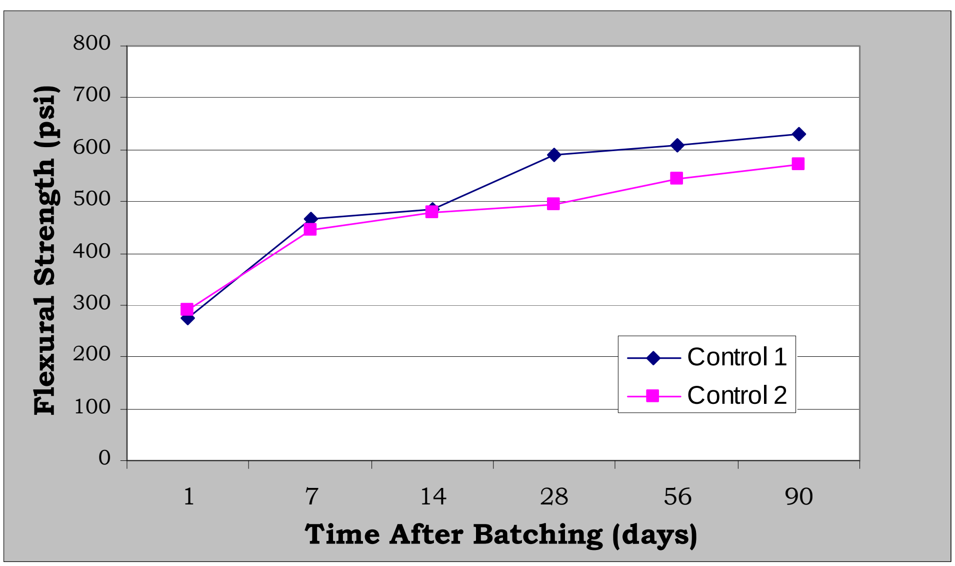


Figure B.2
Control Mix Flexural Strength Development

Mix:	Control Mix (1)					Control Mix (2)				
Trial Batch:	1	2	3	4	Average	1	2	3	4	Average
Slump:	1	1 3/4	1 1/4	1 1/2	1 3/8	1 1/4	1 3/4	1 1/2	1	1 3/8
Air Content:	5.8	6.1	6.1	6.3	6.1	5.7	6.3	5.9	6.4	6.1
Unit Weight:	148.1	147.2	146.8	146.3	147.1	148.4	145.8	147.3	145.0	146.6
Temperature:	70	72	73	72	71.8	71	71	72	71	71.3
w/c ratio:	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Compressive Strength										
1-Day Total Load	29,338	40,345	34,625			44,111	34,850	34,017		
Unit Load	**1,037**	**1,426**	**1,223**		**1230**	**1560**	**1233**	**1203**		**1335**
3-Day Total Load	51,240	53,412	50,870			69,640	60,833	61,316		
Unit Load	**1,811**	**1,887**	**1,798**		**1835**	**2463**	**2152**	**2169**		**2265**
7-Day Total Load	67,970	64,672	65,155			79,883	76,520	73,962		
Unit Load	**2,402**	**2,285**	**2,302**		**2330**	**2825**	**2706**	**2616**		**2720**
14-Day Total Load	73,098	73,042	73,430			87,520	91,243	85,962		
Unit Load	**2,583**	**2,581**	**2,595**		**2590**	**3095**	**3227**	**3040**		**3125**
28-Day Total Load	89,094	85,338	82,873			94,532	99,073	96,854		
Unit Load	**3,148**	**3,015**	**2,928**		**3035**	**3343**	**3504**	**3426**		**3425**
56-Day Total Load	102,798	99,033	95,686			119,577	114,375	101,147		
Unit Load	**3,632**	**3,499**	**3,381**		**3505**	**4229**	**4045**	**3577**		**3955**
90-Day Total Load	114,256	112,214	107,569			121,833	116,024	113,266		
Unit Load	**4041**	**3969**	**3804**		**3940**	**4309**	**4104**	**4006**		**4140**
Flexural Strength										
1-Day Total Load	3,395	3,426	3,444			3,685	3,624	3,301		
Width	6 1/8	6 1/16	6 1/4			6 1/16	6 1/8	6 1/8		
Depth	6 1/8	6	6			6	6	6 1/16		
Unit Load	**266**	**283**	**276**		**275**	**304**	**296**	**264**		**288**
7-Day Total Load	5,421	5,576	6,190			5,820	5,604	5,021		
Width	6 1/8	6 1/16	6 1/4			6 1/8	6 1/8	6 1/8		
Depth	6	6	6			6	6	6		
Unit Load	**443**	**460**	**495**		**466**	**475**	**457**	**410**		**447**
14-Day Total Load	5,512	5,841	6,401			6,009	5,986	5,586		
Width	6 1/8	6 1/16	6 1/8			6	6	6		
Depth	6	6	6			6 1/16	6 1/16	6 1/16		
Unit Load	**450**	**482**	**523**		**485**	**490**	**489**	**456**		**478**
28-Day Total Load	7,448	6,501	7,640			6,146	6,237	6,218		
Width	6 1/16	6 1/8	6 1/8			6	6	6		
Depth	6	6	6			6 1/8	6 1/8	6 1/8		
Unit Load	**614**	**531**	**624**		**590**	**491**	**499**	**497**		**496**
56-Day Total Load	7,598	7,890	7,580			6,384	6,510	7,129		
Width	6 3/16	6 1/4	6 1/4			6	6	6		
Depth	6	6 1/16	6 1/16			6 1/16	6 1/16	6 1/16		
Unit Load	**614**	**618**	**594**		**609**	**521**	**531**	**582**		**545**
90-Day Total Load	7,698	8,147	7,465			7,182	6,980	7,186		
Width	6 1/8	6 1/4	6 3/16			6 1/8	6	6 1/16		
Depth	6	6	6			6 1/8	6 1/16	6 1/16		
Unit Load	**628**	**652**	**603**		**628**	**563**	**570**	**581**		**571**

Table B.3
Detailed Control Mix Data

Appendix C
Master Builders Experimental Data

- **Compressive Strength**
- **Flexural Strength**
- **Detailed Strength Data**

Mix Designation:	MB-332N-5	MB-332N-8	MB-997-8	MB-997-12
1-Day Strength (psi):	**1255**	**1835**	**1845**	**1590**
3-Day Strength (psi):	**2345**	**3070**	**3090**	**3555**
7-Day Strength (psi):	**3035**	**3930**	**3745**	**4605**
14-Day Strength (psi):	**3450**	**4210**	**4295**	**4855**
28-Day Strength (psi):	**3910**	**5080**	**5150**	**5570**
56-Day Strength (psi):	**4485**	**5635**	**5455**	**5935**
90-Day Strength (psi):	**4750**	**5860**	**5725**	**6310**

Table C.1
Compressive Strength Data for MB Mix

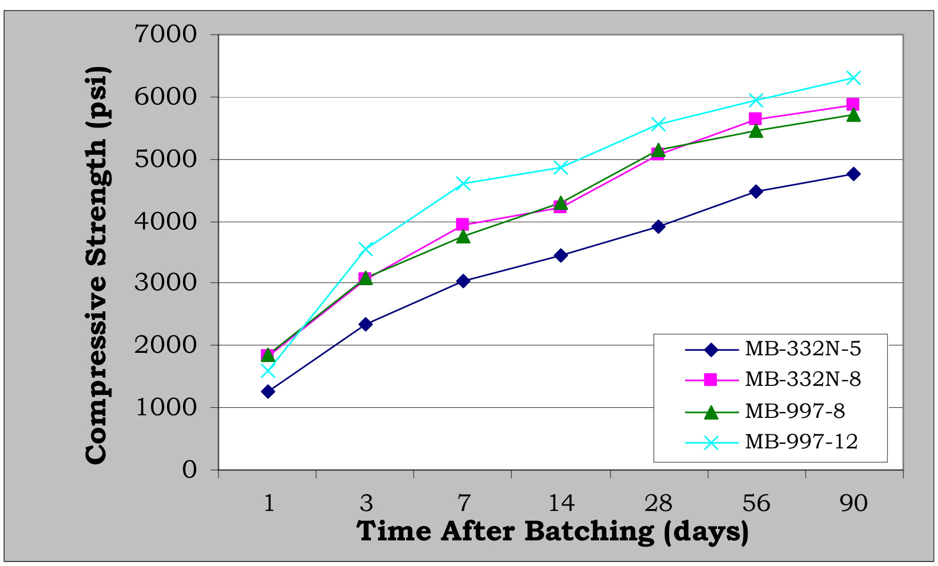


Figure C.1
MB Compressive Strength Development

Mix Designation:	MB-332N-5	MB-332N-8	MB-997-8	MB-997-12
1-Day Strength (psi):	**325**	**490**	**385**	**330**
7-Day Strength (psi):	**520**	**580**	**615**	**620**
14-Day Strength (psi):	**555**	**615**	**585**	**595**
28-Day Strength (psi):	**580**	**620**	**635**	**665**
56-Day Strength (psi):	**660**	**695**	**670**	**715**
90-Day Strength (psi):	**675**	**715**	**685**	**760**

Table C.2
Flexural Strength Data for MB Mix

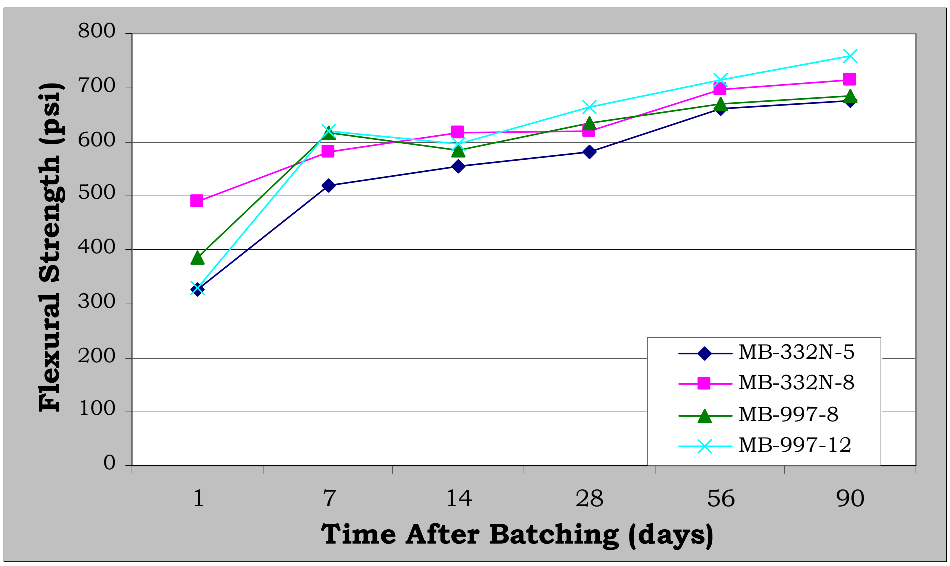


Figure C.2
MB Flexural Strength Development

Mix:	1					2					3					4				
Trial Batch:	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
Slump:	1 1/2	1 3/4	1 1/4	1	1 3/8	1 1/4	1 1/2	1 1/4	1 1/4	1 1/3	1 1/4	1 1/4	1 1/2	1 1/2	1 3/8	1	1 1/4	3/4	1 1/2	1 1/8
Air Content:	6.1	6.9	6.0	5.7	6.2	6.8	6.4	6.2	5.9	6.3	5.7	5.8	6.0	6.5	6.0	5.1	6.0	5.2	5.7	5.5
Unit Weight:	146.5	145.6	146.8	148.6	146.9	146.3	146.1	147.0	147.3	146.7	148.3	148.1	147.1	145.8	147.3	148.8	147.6	149.5	147.9	148.5
Temperature:	71	70	70	70	70	71	72	72	71	72	70	71	70	69	70	71	71	72	71	71
w/c ratio:	0.34	0.34	0.34	0.34	0.34	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.31	0.31	0.31	0.31	0.31
Compressive Strength																				
1-Day Total Load	33,777	32,172	40,465			53,607	50,760	50,890			54,990	49,490	51,980			43,418	44,898	46,356		
Unit Load	**1195**	**1138**	**1431**		**1255**	**1896**	**1795**	**1800**		**1835**	**1945**	**1750**	**1838**		**1845**	**1536**	**1588**	**1640**		**1590**
3-Day Total Load	69,394	62,125	67,353			77,781	88,670	93,554			88,100	88,905	84,795			103,057	98,425	99,762		
Unit Load	**2454**	**2197**	**2382**		**2345**	**2751**	**3136**	**3309**		**3070**	**3116**	**3144**	**2999**		**3090**	**3645**	**3481**	**3528**		**3555**
7-Day Total Load	86,315	82,540	88,380			111,696	108,679	112,962			107,275	107,720	102,557			134,944	124,757	130,755		
Unit Load	**3053**	**2919**	**3126**		**3035**	**3950**	**3844**	**3995**		**3930**	**3794**	**3810**	**3627**		**3745**	**4773**	**4412**	**4625**		**4605**
14-Day Total Load	110,979	87,306	94,007			121,880	113,942	121,238			120,486	122,274	121,402			150,261	130,618	130,720		
Unit Load	**3925**	**3088**	**3325**		**3450**	**4311**	**4030**	**4288**		**4210**	**4261**	**4325**	**4294**		**4295**	**5314**	**4620**	**4623**		**4855**
28-Day Total Load	114,816	99,073	117,666			140,406	139,515	150,924			156,134	144,638	136,015			156,586	158,027	157,652		
Unit Load	**4061**	**3504**	**4162**		**3910**	**4966**	**4934**	**5338**		**5080**	**5522**	**5116**	**4811**		**5150**	**5538**	**5589**	**5576**		**5570**
56-Day Total Load	137,620	119,650	122,994			154,371	151,996	171,376			162,541	152,456	147,523			165,896	167,254	169,875		
Unit Load	**4867**	**4232**	**4350**		**4485**	**5460**	**5376**	**6061**		**5635**	**5749**	**5392**	**5218**		**5455**	**5867**	**5915**	**6008**		**5935**
90-Day Total Load	142,569	128,741	131,258			162,541	157,496	176,982			166,524	158,742	160,258			178,151	174,332	182,614		
Unit Load	**5042**	**4553**	**4642**		**4750**	**5749**	**5570**	**6259**		**5860**	**5890**	**5614**	**5668**		**5725**	**6301**	**6166**	**6459**		**6310**
Flexural Strength																				
1-Day Total Load	4,105	4,038	3,995			6,286	5,900	6,259			5,228	4,380	4,510			4,150	4,042	3,964		
Width	6	6	6			6 1/8	6 3/16	6 1/16			6 3/16	6 1/8	6 1/8			6 1/8	6 1/8	6 1/8		
Depth	6 1/8	6 1/8	6 1/8			6	6 1/8	6 1/8			6	6 1/16	6			6 1/8	6	6		
Unit Load	**328**	**323**	**319**		**325**	**513**	**458**	**495**		**490**	**422**	**350**	**368**		**385**	**325**	**330**	**324**		**330**
7-Day Total Load	6,251	6,827	6,532			7,323	7,436	7,245			7,920	7,436	7,326			7,922	7,448	7,318		
Width	6 1/8	6 3/16	6 1/8			6 1/8	6 1/8	6 1/8			6 1/8	6 1/4	6 3/16			6 1/16	6 1/16	6 1/16		
Depth	6 1/16	6 1/16	6 1/8			6	6 3/16	6 1/8			6	6	6			6	6	6 1/16		
Unit Load	**500**	**540**	**512**		**520**	**598**	**571**	**568**		**580**	**647**	**595**	**592**		**615**	**653**	**614**	**591**		**620**
14-Day Total Load	6,884	6,739	6,975			7,863	7,650	7,346			7,321	7,124	7,045			7,285	7,178	7,183		
Width	6 1/8	6 1/8	6 1/8			6 1/4	6 1/8	6 1/8			6 1/8	6 1/8	6 1/8			6 1/16	6 1/8	6 1/8		
Depth	6	6 1/8	6			6	6	6 1/16			6	6	6			6	6	6		
Unit Load	**562**	**528**	**569**		**555**	**629**	**624**	**587**		**615**	**598**	**582**	**575**		**585**	**601**	**586**	**586**		**595**
28-Day Total Load	6,890	7,214	7,334			7,642	7,450	7,549			8,219	7,380	7,731			8,543	7,421	8,230		
Width	6 1/8	6 3/16	6			6 1/16	6 1/8	6 1/16			6 1/8	6 1/16	6 1/16			6 1/16	6 1/8	6 1/16		
Depth	6	6 1/8	6			6	6	6 1/16			6 1/16	6 1/16	5 15/16			6	6	6		
Unit Load	**562**	**559**	**611**		**580**	**630**	**608**	**610**		**620**	**657**	**596**	**651**		**635**	**705**	**606**	**679**		**665**
56-Day Total Load	8,251	8,033	7,816			8,545	8,515	8,235			8,452	7,841	8,165			8,951	8,611	8,752		
Width	6 1/16	6	6			6	6 1/8	6 1/8			6 1/8	6 1/8	6 1/8			6 1/16	6 1/8	6 1/8		
Depth	6 1/16	6	6 1/16			6	6	6			6	6	6			6	6	6 1/16		
Unit Load	**667**	**669**	**638**		**660**	**712**	**695**	**672**		**695**	**690**	**640**	**667**		**670**	**738**	**703**	**700**		**715**
90-Day Total Load	8,425	8,521	8,145			8,754	8,854	8,655			8,695	8,254	8,398			9,543	8,880	9,321		
Width	6 1/8	6 1/8	6 1/8			6 1/16	6 1/8	6 1/16			6 1/8	6 1/4	6 3/16			6 1/16	6 1/8	6 1/8		
Depth	6	6 1/8	6			6	6	6 1/16			6	6	6			6	6	6		
Unit Load	**688**	**667**	**665**		**675**	**722**	**723**	**699**		**715**	**710**	**660**	**679**		**685**	**787**	**725**	**761**		**760**

Table C.3 Detailed Master Builders Mix Data

Appendix D
Brett Admixtures Experimental Data

- **Compressive Strength**
- **Flexural Strength**
- **Detailed Strength Data**

Mix Designation:	Brett-WR91-5	Brett-WR91-8	Brett-37-8	Brett-37-12
1-Day Strength (psi):	**1025**	**1240**	**1850**	**1710**
3-Day Strength (psi):	**2125**	**2330**	**2380**	**2775**
7-Day Strength (psi):	**2810**	**3450**	**2835**	**3245**
14-Day Strength (psi):	**3200**	**4280**	**3210**	**3315**
28-Day Strength (psi):	**3510**	**4525**	**3325**	**3530**
56-Day Strength (psi):	**4135**	**4735**	**3755**	**4065**
90-Day Strength (psi):	**4630**	**4965**	**4105**	**4325**

Table D.1
Compressive Strength Data for Brett Mix

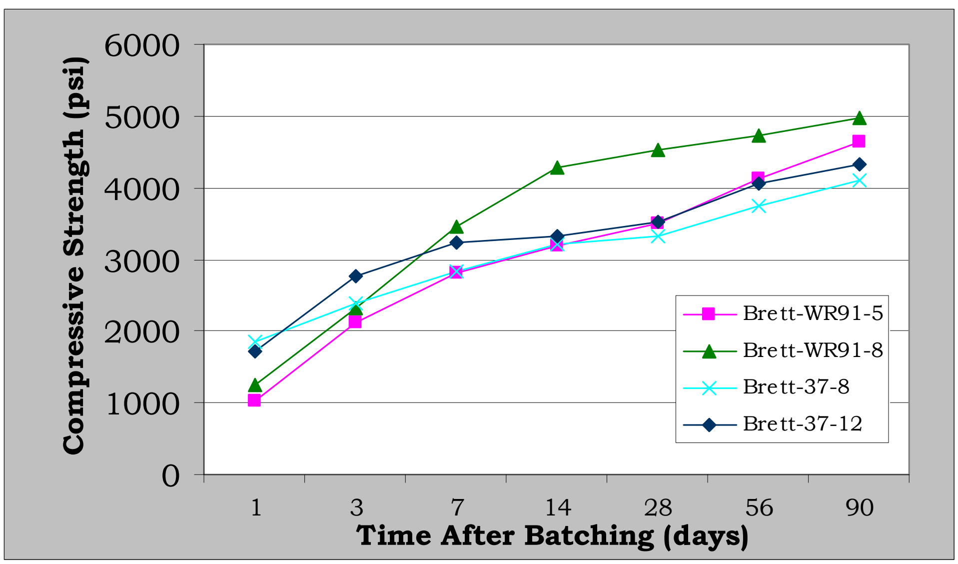


Figure D.1
Brett Compressive Strength Development

Mix Designation:	Brett-WR91-5	Brett-WR91-8	Brett-37-8	Brett-37-12
1-Day Strength (psi):	**255**	**285**	**380**	**310**
7-Day Strength (psi):	**470**	**535**	**540**	**520**
14-Day Strength (psi):	**530**	**560**	**560**	**525**
28-Day Strength (psi):	**525**	**600**	**585**	**540**
56-Day Strength (psi):	**610**	**630**	**615**	**610**
90-Day Strength (psi):	**645**	**675**	**630**	**615**

Table D.2
Flexural Strength Data for Brett Mix

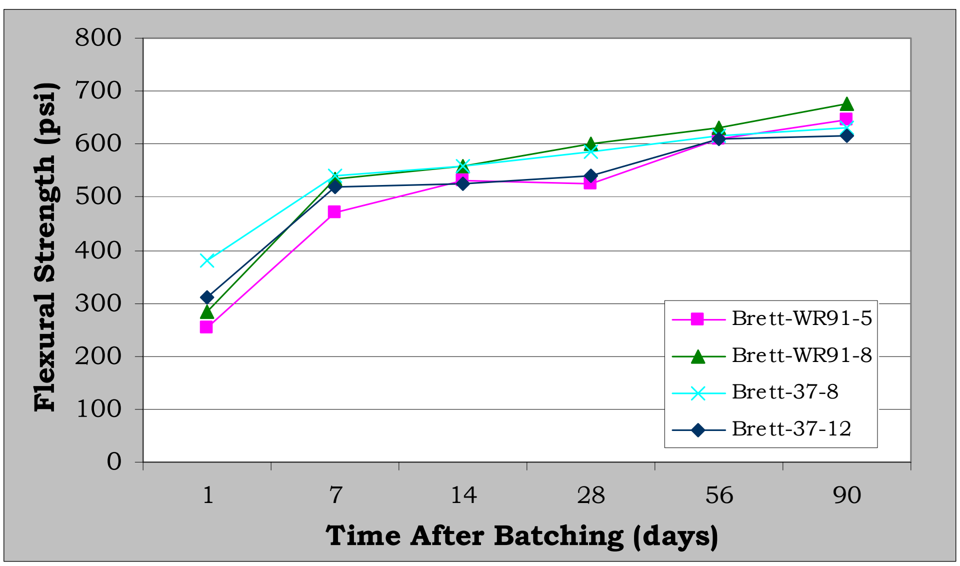


Figure D.2
Brett Flexural Strength Development

Mix:	5					6					7					8				
Trial Batch:	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average	1	2	3	4	Average
Slump:	1 3/4	1 3/4	1 1/2	2	1 3/4	3/4	1 3/4	2	1 3/4	1 4/7	3/4	1	1	3/4	7/8	1 1/2	1	1	1	1 1/8
Air Content:	6.8	6.5	6.4	6.1	6.5	5.8	6.5	6.2	6.8	6.3	5.1	5.6	6.1	6.0	5.7	4.5	6.1	5.8	5.4	5.5
Unit Weight:	144.4	145.1	144.8	146.7	145.3	148.8	142.5	145.9	144.8	145.5	149.2	148.0	147.3	147.8	148.1	150.3	147.9	148.0	148.6	148.7
Temperature:	70	71	71	72	71	72	71	73	72	72	71	72	72	71	72	71	71	72	71	71
w/c ratio:	0.34	0.34	0.34	0.34	0.34	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.31	0.31	0.31	0.31	0.31
Compressive Strength																				
1-Day Total Load	24,418	33,272	28,950			34,694	36,548	33,577			58,280	54,056	44,369			51,285	46,772	46,840		
Unit Load	**864**	**1177**	**1024**		**1025**	**1227**	**1293**	**1188**		**1240**	**2061**	**1912**	**1569**		**1850**	**1814**	**1654**	**1657**		**1710**
3-Day Total Load	66,080	58,762	55,189			64,079	65,289	68,140			70,209	69,668	61,658			79,652	81,367	74,278		
Unit Load	**2337**	**2078**	**1952**		**2125**	**2266**	**2309**	**2410**		**2330**	**2483**	**2464**	**2181**		**2380**	**2817**	**2878**	**2627**		**2775**
7-Day Total Load	77,584	79,021	81,452			111,540	88,451	92,456			88,430	83,928	67,770			94,685	93,948	86,467		
Unit Load	**2744**	**2795**	**2881**		**2810**	**3945**	**3128**	**3270**		**3450**	**3128**	**2968**	**2397**		**2835**	**3349**	**3323**	**3058**		**3245**
14-Day Total Load	77,437	96,252	97,613			124,334	123,210	115,361			98,141	84,362	89,570			90,376	94,238	96,207		
Unit Load	**2739**	**3404**	**3452**		**3200**	**4397**	**4358**	**4080**		**4280**	**3471**	**2984**	**3168**		**3210**	**3196**	**3333**	**3403**		**3315**
28-Day Total Load	88,434	108,966	100,126			128,745	130,541	124,520			111,238	80,756	89,715			92,147	109,141	97,979		
Unit Load	**3128**	**3854**	**3541**		**3510**	**4553**	**4617**	**4404**		**4525**	**3934**	**2856**	**3173**		**3325**	**3259**	**3860**	**3465**		**3530**
56-Day Total Load	111,420	120,241	118,952			134,125	135,852	131,257			121,411	97,452	99,521			115,623	118,474	110,289		
Unit Load	**3941**	**4253**	**4207**		**4135**	**4744**	**4805**	**4642**		**4735**	**4294**	**3447**	**3520**		**3755**	**4089**	**4190**	**3901**		**4065**
90-Day Total Load	128,575	134,701	129,261			140,652	142,854	137,524			124,255	108,475	115,410			124,587	123,598	118,524		
Unit Load	**4547**	**4764**	**4572**		**4630**	**4975**	**5052**	**4864**		**4965**	**4395**	**3837**	**4082**		**4105**	**4406**	**4371**	**4192**		**4325**
Flexural Strength																				
1-Day Total Load	3,162	3,016	3,136			3,314	3,542	3,496			4,825	4,562	4,710			3,958	4,424	2,994		
Width	6 3/16	6 1/8	6 1/16			6 1/8	6 1/8	6 1/8			6 1/8	6 3/16	6 1/8			6 3/16	6 1/8	6 1/8		
Depth	6	6	6			6	6	6			6	6 1/8	6			6	6	6		
Unit Load	**256**	**246**	**259**		**255**	**271**	**289**	**285**		**285**	**394**	**354**	**384**		**380**	**320**	**361**	**244**		**310**
7-Day Total Load	5,478	5,768	5,981			7,025	6,274	6,425			7,025	6,420	6,231			5,441	6,475	7,296		
Width	6 1/8	6 1/8	6 1/8			6 1/8	6 3/16	6 1/8			6 1/16	6 1/8	6 3/16			6 1/8	6 1/16	6 1/16		
Depth	6	6 1/16	6			6	6	6			6	6	6			6	6 1/16	6 1/16		
Unit Load	**447**	**461**	**488**		**470**	**573**	**507**	**524**		**535**	**579**	**524**	**504**		**540**	**444**	**523**	**589**		**520**
14-Day Total Load	6,112	6,382	7,164			7,046	6,676	6,985			7,536	6,432	6,695			5,447	7,310	6,772		
Width	6 3/16	6 1/8	6 1/16			6 3/16	6 1/8	6 1/8			6	6	6 1/8			6 1/16	6 1/16	6 1/16		
Depth	6 1/16	6	6 1/16			6	6 1/16	6			6	6	6 1/4			6 1/16	6 1/16	6 1/8		
Unit Load	**484**	**521**	**579**		**530**	**569**	**534**	**570**		**560**	**628**	**536**	**504**		**560**	**440**	**591**	**536**		**525**
28-Day Total Load	6,741	6,932	6,300			7,398	7,145	7,362			7,913	7,201	7,006			5,846	6,966	7,080		
Width	6 1/16	6 3/16	6 1/8			6 1/16	6 1/8	6 1/16			6 1/16	6 1/4	6 1/8			6 1/8	6 1/8	6 3/16		
Depth	6 1/8	6 1/8	6 1/16			6	6	6 1/16			6	6 3/16	6 1/16			6	6	6		
Unit Load	**533**	**538**	**504**		**525**	**610**	**583**	**595**		**600**	**653**	**542**	**560**		**585**	**477**	**569**	**572**		**540**
56-Day Total Load	7,541	7,365	7,625			7,741	7,521	7,658			8,025	7,294	7,436			7,219	7,380	7,731		
Width	6 1/8	6 3/16	6			6 1/16	6 1/8	6 1/16			6 1/8	6 1/8	6 1/16			6 1/8	6 1/16	6 1/16		
Depth	6	6 1/8	6			6	6	6			6	6	6 1/8			6 1/16	6 1/16	5 15/16		
Unit Load	**616**	**571**	**635**		**610**	**638**	**614**	**632**		**630**	**655**	**595**	**589**		**615**	**577**	**596**	**651**		**610**
90-Day Total Load	8,380	7,840	8,241			8,495	8,072	8,145			8,135	7,612	7,521			7,632	7,821	8,024		
Width	6 1/8	6 1/8	6 1/8			6 1/16	6	6			6	6 1/4	6			6	6	6		
Depth	6	6 3/16	6 1/8			6 1/16	6	6 1/16			6	6 1/16	6 1/8			6 1/4	6 1/16	6 1/4		
Unit Load	**684**	**602**	**646**		**645**	**686**	**673**	**665**		**675**	**678**	**596**	**601**		**630**	**586**	**638**	**616**		**615**

Table D.3 Detailed Brett Mix Data

Appendix E

GRACE Experimental Data

- **Compressive Strength**
- **Flexural Strength**
- **Detailed Strength Data**

Mix Designation:	Grace-82-5	Grace-82-8	Grace-140-8	Grace-140-12
1-Day Strength (psi):	**1360**	**1375**	**1105**	**1295**
3-Day Strength (psi):	**2315**	**2765**	**1650**	**1865**
7-Day Strength (psi):	**3100**	**3320**	**2580**	**3065**
14-Day Strength (psi):	**3280**	**3795**	**2755**	**2925**
28-Day Strength (psi):	**3990**	**4310**	**3075**	**3575**
56-Day Strength (psi):	**4240**	**5420**	**3495**	**4125**
90-Day Strength (psi):	**4420**	**5475**	**4080**	**4560**

Table E.1
Compressive Strength Data for GRACE Mix

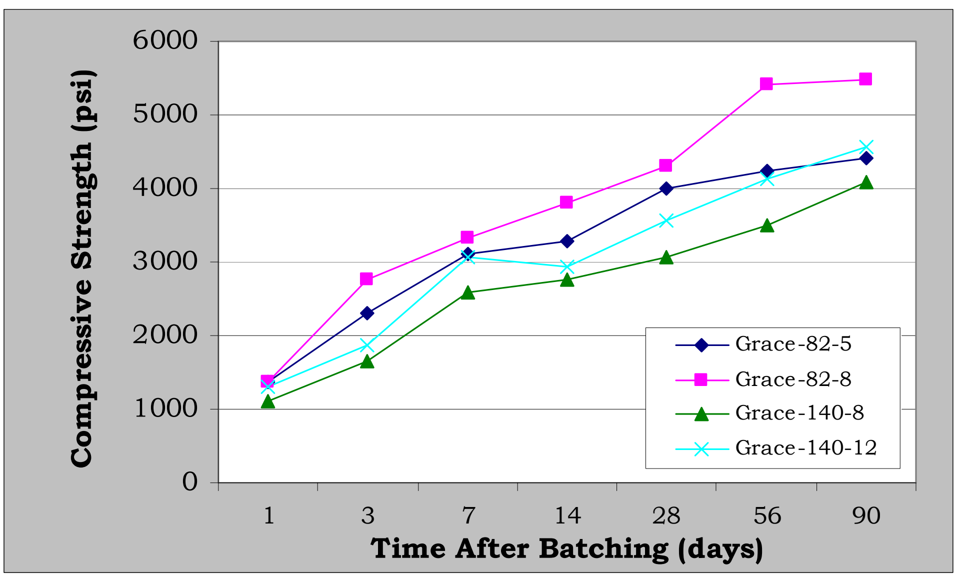


Figure E.1
GRACE Compressive Strength Development

Mix Designation:	Grace-82-5	Grace-82-8	Grace-140-8	Grace-140-12
1-Day Strength (psi):	**355**	**480**	**265**	**285**
7-Day Strength (psi):	**570**	**525**	**470**	**490**
14-Day Strength (psi):	**595**	**610**	**515**	**560**
28-Day Strength (psi):	**610**	**685**	**575**	**635**
56-Day Strength (psi):	**615**	**690**	**575**	**630**
90-Day Strength (psi):	**625**	**730**	**625**	**700**

Table E.2
Flexural Strength Data for GRACE Mix

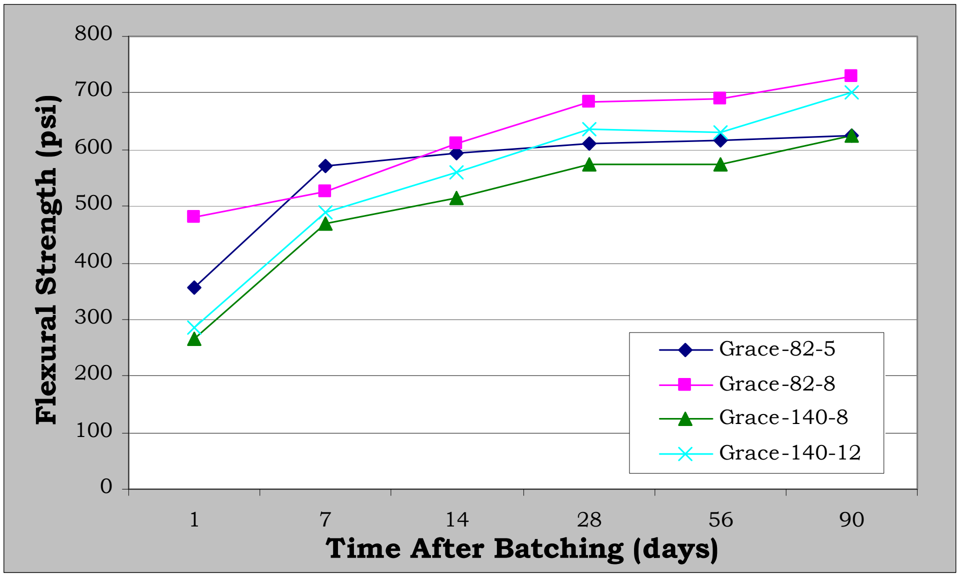


Figure E.2
GRACE Flexural Strength Development

Mix:	9				10				11				12			
Trial Batch:	1	2	3	Average	1	2	3	Average	1	2	3	Average	1	2	3	Average
Slump:	1 1/4	1	1	1	1 3/4	3/4	3/4	1	1 1/2	1 1/2	1 3/4	1 4/7	1 1/4	1 1/2	1	1 1/4
Air Content:	6.1	5.7	6.2	6.0	7.0	6.0	6.6	6.5	5.7	6.2	5.7	5.9	5.5	6.4	6.1	6.0
Unit Weight:	146.5	147.9	145.6	146.67	145.5	147.9	147.6	147.0	147.3	146.3	147.3	147.0	148.4	145.8	149.6	147.9
Temperature:	71	72	72	72	71	73	73	72	72	72	72	72	72	71	71	71
w/c ratio:	0.34	0.34	0.34	0.34	0.33	0.33	.33.	0.33	0.33	0.33	0.33	0.33	0.31	0.31	0.31	0.31
Compressive Strength																
1-Day Total Load	36,801	40,050			32,624	45,018			34,895	27,420			40,846	32,136		
Unit Load	**1302**	**1416**		**1360**	**1154**	**1592**		**1375**	**1234**	**970**		**1105**	**1445**	**1137**		**1295**
3-Day Total Load	60,194	70,681			72,694	83,541			52,168	40,880			57,296	47,908		
Unit Load	**2129**	**2500**		**2315**	**2571**	**2955**		**2765**	**1845**	**1446**		**1650**	**2026**	**1694**		**1865**
7-Day Total Load	89,447	85,613			85,417	102,084			66,658	79,067			98,754	74,419		
Unit Load	**3164**	**3028**		**3100**	**3021**	**3610**		**3320**	**2358**	**2796**		**2580**	**3493**	**2632**		**3065**
14-Day Total Load	91,832	93,368			85,544	128,791			77,655	78,129			85,221	80,097		
Unit Load	**3248**	**3302**		**3280**	**3026**	**4555**		**3795**	**2746**	**2763**		**2755**	**3014**	**2833**		**2925**
28-Day Total Load	112,326	113,263			112,531	131,065			99,039	74,709			92,114	109,949		
Unit Load	**3973**	**4006**		**3990**	**3980**	**4635**		**4310**	**3503**	**2642**		**3075**	**3258**	**3889**		**3575**
56-Day Total Load	110,245	129,503			139,711	166,546			108,654	88,767			128,367	104,630		
Unit Load	**3899**	**4580**		**4240**	**4941**	**5890**		**5420**	**3843**	**3139**		**3495**	**4540**	**3701**		**4125**
90-Day Total Load	118,505	131,240			145,870	163,540			114,250	116,320			132,045	125,640		
Unit Load	**4191**	**4642**		**4420**	**5159**	**5784**		**5475**	**4041**	**4114**		**4080**	**4670**	**4444**		**4560**
Flexural Strength																
1-Day Total Load	4,231	4,632			5,769	6,212			3,528	2,982			3,558	3,483		
Width	6	6			6 1/8	6 1/8			6 1/8	6 3/16			6 1/8	6 3/16		
Depth	6 1/8	6 1/8			6 1/8	6			6	6			6 1/16	6 1/16		
Unit Load	**338**	**370**		**355**	**452**	**507**		**480**	**288**	**241**		**265**	**284**	**276**		**285**
7-Day Total Load	7,167	6,928			6,617	6,217			5,700	5,930			6,476	5,456		
Width	6 1/16	6 1/16			6	6 1/8			6 1/8	6 1/16			6	6 1/16		
Depth	6 1/16	6 1/16			6	6 1/16			6 1/16	6 1/16			6 1/16	6		
Unit Load	**579**	**560**		**570**	**551**	**497**		**525**	**456**	**479**		**470**	**529**	**450**		**490**
14-Day Total Load	7,228	7,242			6,421	8,357			6,967	5,763			7,274	6,714		
Width	6 1/16	6 1/16			6	6 1/8			6 1/16	6 3/16			6 3/16	6 1/8		
Depth	6 1/16	6			6	6			6	6 1/8			6 1/8	6		
Unit Load	**584**	**597**		**595**	**535**	**682**		**610**	**575**	**447**		**515**	**564**	**548**		**560**
28-Day Total Load	7,349	7,719			7,409	9,372			6,770	7,205			8,421	7,078		
Width	6 1/8	6 3/16			6 1/8	6 3/16			6 1/16	6 1/8			6 1/4	6		
Depth	6	6 1/16			6	6			6	6			6	6		
Unit Load	**600**	**611**		**610**	**605**	**757**		**685**	**558**	**588**		**575**	**674**	**590**		**635**
56-Day Total Load	6,979	7,831			7,724	10,161			7,783	6,715			8,767	7,810		
Width	6 1/16	6 1/16			6 3/16	6 3/8			6 1/8	6 1/16			6 3/8	6 3/16		
Depth	5 15/16	6 1/16			6 1/8	6 1/16			6 1/8	6 1/8			6 1/8	6 3/16		
Unit Load	**588**	**633**		**615**	**599**	**781**		**690**	**610**	**531**		**575**	**660**	**593**		**630**
90-Day Total Load	7,814	7,815			8,524	9,385			7,952	7,421			8,863	8,592		
Width	6 3/16	6 1/8			6 1/16	6 1/8			6 1/8	6 3/16			6 1/8	6		
Depth	6 1/8	6			6	6 1/16			6	6			6 1/16	6 1/8		
Unit Load	**606**	**638**		**625**	**703**	**750**		**730**	**649**	**600**		**625**	**709**	**687**		**700**

Table E.3 Detailed GRACE Mix Data

Appendix F
GRT Experimental Data

- **Compressive Strength**
- **Flexural Strength**
- **Detailed Strength Data**

Mix Designation:	Grace-82-5	Grace-82-8	Grace-140-8	Grace-140-12
1-Day Strength (psi):	**1360**	**1375**	**1105**	**1295**
3-Day Strength (psi):	**2315**	**2765**	**1650**	**1865**
7-Day Strength (psi):	**3100**	**3320**	**2580**	**3065**
14-Day Strength (psi):	**3280**	**3795**	**2755**	**2925**
28-Day Strength (psi):	**3990**	**4310**	**3075**	**3575**
56-Day Strength (psi):	**4240**	**5420**	**3495**	**4125**
90-Day Strength (psi):	**4420**	**5475**	**4080**	**4560**

Table F.1
Compressive Strength Data for GRT Mix

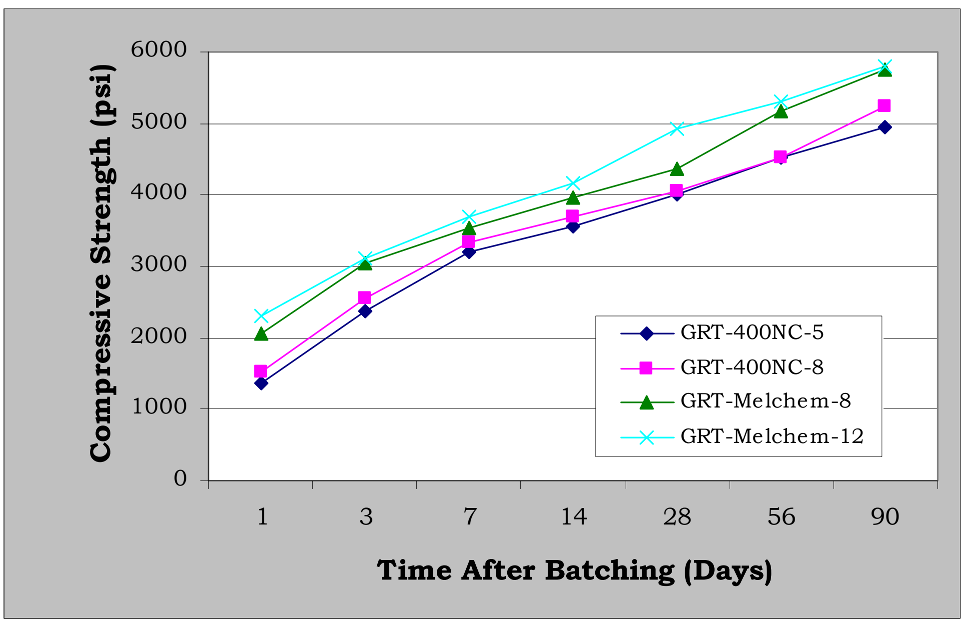


Figure F.1
GRT Compressive Strength Development

Mix Designation:	Grace-82-5	Grace-82-8	Grace-140-8	Grace-140-12
1-Day Strength (psi):	**355**	**480**	**265**	**285**
7-Day Strength (psi):	**570**	**525**	**470**	**490**
14-Day Strength (psi):	**595**	**610**	**515**	**560**
28-Day Strength (psi):	**610**	**685**	**575**	**635**
56-Day Strength (psi):	**615**	**690**	**575**	**630**
90-Day Strength (psi):	**625**	**730**	**625**	**700**

Table F.2
Flexural Strength Data for GRT Mix

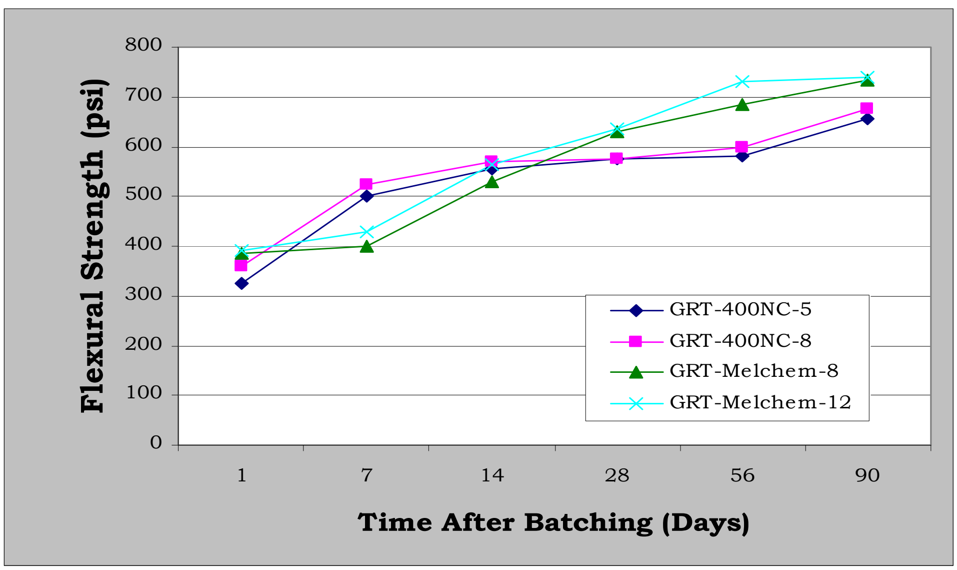


Figure F.2
GRT Flexural Strength Development

Mix:	13				14				15				16			
Trial Batch:	1	2	3	Average	1	2	3	Average	1	2	3	Average	1	2	3	Average
Slump:	1 3/4	1 1/4	1 1/4	1 3/7	1 1/2	1 1/2	1	1 1/3	2	2	1 1/2	1 5/6	1 1/4	1 1/2	1 1/2	1 3/7
Air Content:	7.0	5.2	5.0	5.7	6.4	5.9	5.6	6.0	6.5	5.6	5.3	5.8	5.0	5.9	5.5	5.5
Unit Weight:	143.3	147.5	148.7	146.50	146.3	146.9	147.2	146.8	145.9	147.0	147.7	146.9	149.2	146.8	148.0	148.0
Temperature:	71	71	70	71	70	71	71	71	71	71	72	71	72	71	71	71
w/c ratio:	0.34	0.34	0.34	0.34	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.31	0.31	0.31	0.31
Compressive Strength																
1-Day Total Load	37,856	39,487			44,285	41,135			61,628	55,342			64,710	65,871		
Unit Load	**1339**	**1397**		**1370**	**1566**	**1455**		**1515**	**2180**	**1957**		**2070**	**2289**	**2330**		**2310**
3-Day Total Load	62,355	71,559			70,508	73,224			85,213	87,412			87,452	88,471		
Unit Load	**2205**	**2531**		**2370**	**2494**	**2590**		**2545**	**3014**	**3092**		**3055**	**3093**	**3129**		**3115**
7-Day Total Load	89,254	91,415			94,201	93,652			98,426	101,400			102,540	106,741		
Unit Load	**3157**	**3233**		**3195**	**3332**	**3312**		**3325**	**3481**	**3586**		**3535**	**3627**	**3775**		**3705**
14-Day Total Load	102,365	98,754			107,854	101,456			110,245	114,230			116,520	118,254		
Unit Load	**3620**	**3493**		**3560**	**3815**	**3588**		**3705**	**3899**	**4040**		**3970**	**4121**	**4182**		**4155**
28-Day Total Load	115,884	110,306			111,425	117,982			121,421	124,671			146,759	132,151		
Unit Load	**4099**	**3901**		**4000**	**3941**	**4173**		**4060**	**4294**	**4409**		**4355**	**5191**	**4674**		**4935**
56-Day Total Load	128,540	126,740			125,740	130,015			144,500	147,895			153,468	146,091		
Unit Load	**4546**	**4483**		**4515**	**4447**	**4598**		**4525**	**5111**	**5231**		**5175**	**5428**	**5167**		**5300**
90-Day Total Load	138,790	141,250			146,820	148,725			165,893	158,740			165,408	162,100		
Unit Load	**4909**	**4996**		**4955**	**5193**	**5260**		**5230**	**5867**	**5614**		**5745**	**5850**	**5733**		**5795**
Flexural Strength																
1-Day Total Load	3,875	3,921			4,212	4,638			4,757	4,661			4,825	4,785		
Width	6	6			6 1/8	6 1/16			6	6 1/16			6 1/8	6 1/16		
Depth	6	6			6 1/8	6			6 1/16	6 1/16			6	6 1/8		
Unit Load	**323**	**327**		**325**	**330**	**383**		**360**	**388**	**377**		**385**	**394**	**379**		**390**
7-Day Total Load	6,279	6,047			6,347	6,578			5,024	5,126			5,324	5,480		
Width	6 1/16	6 1/8			6 1/8	6 1/8			6 1/8	6 3/16			6 1/8	6 3/16		
Depth	6 1/16	6 1/16			6 1/16	6			6 1/8	6 1/16			6	6 1/8		
Unit Load	**507**	**484**		**500**	**507**	**537**		**525**	**394**	**406**		**400**	**435**	**425**		**430**
14-Day Total Load	6,785	6,692			7,167	6,928			6,825	6,741			7,084	6,925		
Width	6 1/16	6 1/8			6 1/16	6 1/16			6 1/16	6 1/8			6 1/8	6 1/8		
Depth	6	6			6 1/16	6 1/16			6 3/16	6 1/8			6	6 1/8		
Unit Load	**560**	**546**		**555**	**579**	**560**		**570**	**529**	**528**		**530**	**578**	**542**		**565**
28-Day Total Load	7,348	6,633			7,324	6,745			8,015	7,753			7,988	7,932		
Width	6	6			6	6 1/16			6 3/16	6 1/8			6 1/16	6 1/8		
Depth	6 1/8	6			6 1/16	6 1/16			6	6 1/8			6 1/16	6 1/8		
Unit Load	**588**	**553**		**575**	**598**	**545**		**575**	**648**	**607**		**630**	**645**	**621**		**635**
56-Day Total Load	7,582	7,245			7,635	7,354			8,744	8,634			8,825	8,942		
Width	6 1/8	6 1/16			6	6 1/16			6 1/8	6 3/16			6 1/8	6 1/16		
Depth	6 3/16	6 1/8			6 1/8	6 1/8			6 1/8	6 1/16			6	6		
Unit Load	**582**	**573**		**580**	**611**	**582**		**600**	**685**	**683**		**685**	**720**	**737**		**730**
90-Day Total Load	8,145	8,314			8,125	8,305			8,896	8,925			9,142	9,078		
Width	6 1/8	6 1/8			6 1/8	6			6	6			6	6 1/8		
Depth	6 1/16	6 1/8			6	6 1/16			6 1/16	6			6 1/16	6 1/16		
Unit Load	**651**	**651**		**655**	**663**	**678**		**675**	**726**	**744**		**735**	**746**	**726**		**740**

Table F.3 Detailed GRT Mix Data

Appendix G
Complete Mix Data

- **Control**
- **Master Builders**
- **Brett Admixtures**
- **Grace**
- **GRT**

Project	Effects of Water Reducer on Concrete Durability			Date:	
Reported to:	#REF!			Project No:	#REF!
Mix Number:					
Mix Description:	Control Mix				
Total Cementitious:	564	lb/yd³	Percent Fly Ash:	30	%
Mineral Admixture:		%			
Slump:		inches	Air Content:	6.0	%

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³
Cement:	3.15		394.8	lb/yd³	2.009	
Mineral Admixture:			0.0	lb/yd³	0.000	
Water:	24.0	gallons	200	lb/yd³	3.205	
Air:	6.0	%			1.62	
				total voids:	7.897	ft³

desired w/c ratio:		calculated w/c ratio:	0.35
ft³/yd³:	27.00	Cement/Voids Ratio:	0.64

Coarse aggregate 1:	60	%	=	1912	lbs.
Coarse aggregate 2:		%		0	lbs.
Coarse aggregate 3:	0	%		0	lbs.

	Sp. Gr.	Weights		Volume	
Coarse Aggregate1:	2.673	1912	lb/yd³	11.463	ft³
Coarse Aggregate2:			lb/yd³	0.000	ft³
Coarse Aggregate3:			lb/yd³	0.000	ft³
Fine Aggregate:	2.625	1251	lb/yd³	7.640	ft³

Water Reducer:		oz/100-wt.	0.0	oz/yd³
Air Entrainment:	2.16	oz/100-wt.	12.2	oz/yd³
Other Admixture:		oz/100-wt.	0.0	oz/yd³

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.5	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	3.5	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1888	lbs.	69.91	lbs.	321.59	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1274	lbs.	47.17	lbs.	216.98	lbs.
Water Reducer		oz.		ml		ml
Air Entrainment	12.2	oz.	13.34	ml	61.4	ml
Other Admixture		oz.		ml		ml
Free Water	-0.3	gallons	-0.08	lbs.	-0.39	lbs.
Add Water	24.3	gallons	7.49	lbs.	34.46	lbs.
Total Batch Weight	3927.4	lbs.	145.5	lbs.	669.11	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/4	1 3/4	1 1/2	1	Initial Wt.	
Air	5.7	6.3	5.9	6.4	Final Wt.	
Total Wt.	44.53	43.88	44.25	43.7	Net Wt.	
Con. Wt.	36.81	36.16	36.53	35.97	Free Water	
Unit Wt.	148.43	145.81	147.30	145.04	Add Water	
Temp.	70	72	73	72	Total	
Yield	26.46	26.94	26.66	27.08	W/C Ratio	0.36
Time	13:30	14:00	14:45	15:30		

Comments:

Project	Effects of Water Reducer on Concrete Durability				Date:	10/9/02	
Reported to:	#REF!				Project No:	#REF!	
Mix Number:	1						
Mix Description:	Master Builders/ 322N/ 5% water reduction						
Total Cementitious:	564	lb/yd³	Percent Fly Ash:	30	%		
Mineral Admixture:		%		.			
Slump:	1.5	inches	Air Content:	6.0	%		

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³
Cement:	3.15		394.8	lb/yd³	2.009	
Mineral Admixture:			0.0	lb/yd³	0.000	
Water:	22.8	gallons	190	lb/yd³	3.045	
Air:	6.0	%			1.62	
				total voids:	7.737	ft³
desired w/c ratio:			calculated w/c ratio:	0.34		
ft³/yd³:	27.00		Cement/Voids Ratio:	0.66		
Coarse aggregate 1:	60	%	= 1928	lbs.		
Coarse aggregate 2:		%	0	lbs.		
Coarse aggregate 3:	0	%	0	lbs.		
	Sp. Gr.		Weights			
Coarse Aggregate1:	2.673		1912	lb/yd³	11.463	ft³
Coarse Aggregate2:				lb/yd³	0.000	ft³
Coarse Aggregate3:				lb/yd³	0.000	ft³
Fine Aggregate:	2.625		1278	lb/yd³	7.800	ft³
Water Reducer:	4.0	oz/100-wt.	22.6	oz/yd³		
Air Entrainment:	1.51	oz/100-wt.	8.5	oz/yd³		
Other Admixture:		oz/100-wt.	0.0	oz/yd³		

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.5	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	2.0	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.7	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	29.45	lbs.
Cement	394.8	lbs.	14.62	lbs.	68.72	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1888	lbs.	69.91	lbs.	328.58	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1281	lbs.	47.46	lbs.	223.06	lbs.
Water Reducer	22.6	oz.	24.71	ml	116.1	ml
Air Entrainment	8.5	oz.	9.33	ml	43.8	ml
Other Admixture		oz.		ml		ml
Free Water	-2.5	gallons	-0.76	lbs.	-3.59	lbs.
Add Water	25.3	gallons	7.80	lbs.	36.67	lbs.
Total Batch Weight	3943.7	lbs.	146.1	lbs.	686.49	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/2	1 3/4	1 1/4	1	Initial Wt.	
Air	6.1	6.9	6.0	5.7	Final Wt.	
Total Wt.	44.04	43.82	44.12	44.6	Net Wt.	
Con. Wt.	36.32	36.10	36.40	36.86	Free Water	
Unit Wt.	146.45	145.56	146.77	148.63	Add Water	
Temp.	71	70	70	70	Total	
Yield	26.93	27.09	26.87	26.53	W/C Ratio	
Time	16:15	17:00	17:30	18:15		

Comments:

Project	Effects of Water Reducer on Concrete Durability	Date:	10/10/02
Reported to:	#REF!	Project No:	#REF!
Mix Number:	2		
Mix Description:	Master Builders/ 322N/ 8% water reduction		

Total Cementitious:	564	lb/yd^3	Percent Fly Ash:	30	%
Mineral Admixture:		%			
Slump:	1.5	inches	Air Content:	6.0	%

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd^3	1.063	ft^3
Cement:	3.15		394.8	lb/yd^3	2.009	
Mineral Admixture:			0.0	lb/yd^3	0.000	
Water:	22.0	gallons	183	lb/yd^3	2.938	
Air:	6.0	%			1.62	
				total voids:	7.630	ft^3

desired w/c ratio:		calculated w/c ratio:	0.33
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.67

Coarse aggregate 1:	60	%	=	1939	lbs.
Coarse aggregate 2:		%		0	lbs.
Coarse aggregate 3:	0	%		0	lbs.

	Sp. Gr.	Weights			
Coarse Aggregate1:	2.673	1912	lb/yd^3	11.463	ft^3
Coarse Aggregate2:			lb/yd^3	0.000	ft^3
Coarse Aggregate3:			lb/yd^3	0.000	ft^3
Fine Aggregate:	2.625	1295	lb/yd^3	7.907	ft^3

Water Reducer:	6.5	oz/100-wt.	36.7	oz/yd^3
Air Entrainment:	1.36	oz/100-wt.	7.7	oz/yd^3
Other Admixture:		oz/100-wt.	0.0	oz/yd^3

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.2	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	3.3	%	1.7	%

Trial Batch Weights:

Size	27.0	ft^3	1.0	ft^3	4.6	ft^3
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1882	lbs.	69.70	lbs.	320.63	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1316	lbs.	48.72	lbs.	224.13	lbs.
Water Reducer	36.7	oz.	40.15	ml	184.7	ml
Air Entrainment	7.7	oz.	8.40	ml	38.6	ml
Other Admixture		oz.		ml		ml
Free Water	-1.2	gallons	-0.36	lbs.	-1.65	lbs.
Add Water	23.2	gallons	7.15	lbs.	32.88	lbs.
Total Batch Weight	3954.5	lbs.	146.5	lbs.	673.73	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/4	1 1/2	1 1/4	1 1/4	Initial Wt.	
Air	6.8	6.4	6.2	5.9	Final Wt.	
Total Wt.	43.99	43.95	44.17	44.3	Net Wt.	
Con. Wt.	36.27	36.23	36.45	36.53	Free Water	
Unit Wt.	146.25	146.09	146.98	147.30	Add Water	
Temp.	71	72	72	71	Total	
Yield	27.04	27.07	26.91	26.85	W/C Ratio	
Time	16:00	16:45	17:25	18:00		

Comments:

The first batch was mixed using 1.51 oz/ 100wt of air-entraining admixture.
We reduced air by 10% for the following three batches.

Project	Effects of Water Reducer on Concrete Durability					Date:	10/13/02	
Reported to:	#REF!					Project No:	#REF!	
Mix Number:								
Mix Description:	Master Builders/ 927/ 8% water reduction							
Total Cementitious:	564	lb/yd³	Percent Fly Ash:		30	%		
Mineral Admixture:		%						
Slump:	1.5	inches	Air Content:		6.0	%		

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³
Cement:	3.15		394.8	lb/yd³	2.009	
Mineral Admixture:			0.0	lb/yd³	0.000	
Water:	22.0	gallons	183	lb/yd³	2.938	
Air:	6.0	%			1.62	
			total voids:		7.630	ft³

desired w/c ratio:		calculated w/c ratio:	0.33
ft³/yd³:	27.00	Cement/Voids Ratio:	0.67

Coarse aggregate 1:	60	%	=	1939	lbs.
Coarse aggregate 2:		%		0	lbs.
Coarse aggregate 3:	0	%		0	lbs.

	Sp. Gr.	Weights		Volume	
Coarse Aggregate1:	2.673	1912	lb/yd³	11.463	ft³
Coarse Aggregate2:			lb/yd³	0.000	ft³
Coarse Aggregate3:			lb/yd³	0.000	ft³
Fine Aggregate:	2.625	1295	lb/yd³	7.907	ft³

Water Reducer:	5.98	oz/100-wt.	33.7	oz/yd³
Air Entrainment:	1.76	oz/100-wt.	9.9	oz/yd³
Other Admixture:		oz/100-wt.	0.0	oz/yd³

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.3	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	3.0	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1883	lbs.	69.74	lbs.	320.79	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1312	lbs.	48.58	lbs.	223.48	lbs.
Water Reducer	33.7	oz.	36.94	ml	169.9	ml
Air Entrainment	9.9	oz.	10.87	ml	50.0	ml
Other Admixture		oz.		ml		ml
Free Water	-1.5	gallons	-0.47	lbs.	-2.14	lbs.
Add Water	23.5	gallons	7.26	lbs.	33.37	lbs.
Total Batch Weight	3954.5	lbs.	146.5	lbs.	673.73	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/4	1 1/4	1 1/2	1 1/2	Initial Wt.	
Air	5.7	5.8	6.0	6.5	Final Wt.	
Total Wt.	44.50	44.44	44.20	43.9	Net Wt.	
Con. Wt.	36.78	36.72	36.48	36.15	Free Water	
Unit Wt.	148.31	148.06	147.10	145.77	Add Water	
Temp.	70	71	70	69	Total	
Yield	26.66	26.71	26.88	27.13	W/C Ratio	
Time	15:00	15:45	16:30	17:15		

Comments:

Project	Effects of Water Reducer on Concrete Durability	Date:	10/23/02
Reported to:	#REF!	Project No:	#REF!
Mix Number:			
Mix Description:	Master Builders/ 922/12% water reduction		

Total Cementitious:	564	lb/yd^3	Percent Fly Ash:	30	%
Mineral Admixture:		%			
Slump:	1.5	inches	Air Content:	6.0	%

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd^3	1.063	ft^3
Cement:	3.15		394.8	lb/yd^3	2.009	
Mineral Admixture:			0.0	lb/yd^3	0.000	
Water:	21.1	gallons	176	lb/yd^3	2.818	
Air:	6.0	%			1.62	
				total voids:	7.510	ft^3

desired w/c ratio:		calculated w/c ratio:	0.31
ft^3/yd^3:	27.00	Cement/Voids Ratio:	0.69

Coarse aggregate 1:	60	%	=	1951	lbs.
Coarse aggregate 2:		%		0	lbs.
Coarse aggregate 3:	0	%		0	lbs.

	Sp. Gr.	Weights			
Coarse Aggregate1:	2.673	1912	lb/yd^3	11.463	ft^3
Coarse Aggregate2:			lb/yd^3	0.000	ft^3
Coarse Aggregate3:			lb/yd^3	0.000	ft^3
Fine Aggregate:	2.625	1315	lb/yd^3	8.027	ft^3

Water Reducer:	9.00	oz/100-wt.	50.8	oz/yd^3
Air Entrainment:	1.65	oz/100-wt.	9.3	oz/yd^3
Other Admixture:		oz/100-wt.	0.0	oz/yd^3

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.3	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	2.9	%	1.7	%

Trial Batch Weights:

Size	27.0	ft^3	1.0	ft^3	4.6	ft^3
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1883	lbs.	69.74	lbs.	320.79	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1330	lbs.	49.27	lbs.	226.65	lbs.
Water Reducer	50.8	oz.	55.60	ml	255.8	ml
Air Entrainment	9.3	oz.	10.19	ml	46.9	ml
Other Admixture		oz.		ml		ml
Free Water	-1.6	gallons	-0.50	lbs.	-2.32	lbs.
Add Water	22.7	gallons	7.02	lbs.	32.27	lbs.
Total Batch Weight	3966.7	lbs.	146.9	lbs.	675.80	lbs.

Tests	1	2	3	4	Water Added	
Slump	1	1 1/4	3/4	1 1/2	Initial Wt.	
Air	5.1	6.0	5.2	5.7	Final Wt.	
Total Wt.	44.63	44.33	44.80	44.4	Net Wt.	
Con. Wt.	36.91	36.61	37.08	36.69	Free Water	
Unit Wt.	148.83	147.62	149.52	147.94	Add Water	
Temp.	69	68	69	70	Total	
Yield	26.65	26.87	26.53	26.81	W/C Ratio	
Time	15:00	15:45	16:30	17:15		

Comments:

Project	Effects of Water Reducer on Concrete Durability					Date:	10/28/02
Reported to:	#REF!					Project No:	#REF!
Mix Number:							
Mix Description:	Bret Admixtures/ EUCON WR 91/5% water reduction						
Total Cementitious:	564	lb/yd³	Percent Fly Ash:		30	%	
Mineral Admixture:		%			.		
Slump:	1.5	inches	Air Content:		6.0	%	

Batch Design Calculations:

		Sp. Gr.		Weights		Volume	
Fly Ash:		2.55		169.2	lb/yd³	1.063	ft³
Cement:		3.15		394.8	lb/yd³	2.009	
Mineral Admixture:				0.0	lb/yd³	0.000	
Water:		22.8	gallons	190	lb/yd³	3.045	
Air:		6.0	%			1.62	
					total voids:	7.737	ft³
desired w/c ratio:			calculated w/c ratio:		0.34		
ft³/yd³:	27.00		Cement/Voids Ratio:		0.66		
Coarse aggregate 1:		60	%	= 1928	lbs.		
Coarse aggregate 2:			%	0	lbs.		
Coarse aggregate 3:		0	%	0	lbs.		
		Sp. Gr.		Weights			
Coarse Aggregate1:		2.673		1912	lb/yd³	11.463	ft³
Coarse Aggregate2:					lb/yd³	0.000	ft³
Coarse Aggregate3:					lb/yd³	0.000	ft³
Fine Aggregate:		2.625		1278	lb/yd³	7.800	ft³
Water Reducer:	4.50	oz/100-wt.		25.4	oz/yd³		
Air Entrainment:	1.00	oz/100-wt.		5.6	oz/yd³		
Other Admixture:		oz/100-wt.		0.0	oz/yd³		

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.3	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	2.5	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1883	lbs.	69.74	lbs.	320.79	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1288	lbs.	47.69	lbs.	219.39	lbs.
Water Reducer	25.4	oz.	27.80	ml	127.9	ml
Air Entrainment	5.6	oz.	6.18	ml	28.4	ml
Other Admixture		oz.		ml		ml
Free Water	-2.3	gallons	-0.71	lbs.	-3.25	lbs.
Add Water	25.1	gallons	7.74	lbs.	35.62	lbs.
Total Batch Weight	3943.7	lbs.	146.1	lbs.	671.88	lbs.

Tests	1	2	3	4
Slump	1 3/4	1 3/4	1 1/2	2
Air	6.8	6.5	6.4	6.1
Total Wt.	43.54	43.70	43.64	44.1
Con. Wt.	35.82	35.98	35.92	36.38
Unit Wt.	144.44	145.08	144.84	146.69
Temp.	70	71	71	72
Yield	27.30	27.18	27.23	26.88
Time	16:00	16:45	17:20	17:50

Water Added	
Initial Wt.	
Final Wt.	
Net Wt.	
Free Water	
Add Water	
Total	
W/C Ratio	

Comments: WR was reduced from 1.5 to 1.0oz/100 wt.

Project	Effects of Water Reducer on Concrete Durability					Date:	11/1/02
Reported to:	#REF!					Project No:	#REF!
Mix Number:							
Mix Description:	Bret Admixtures/ EUCON WR 91/8% water reduction						
Total Cementitious:	564	lb/yd³	Percent Fly Ash:		30	%	
Mineral Admixture:		%			.		
Slump:	1.5	inches	Air Content:		6.0	%	

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³
Cement:	3.15		394.8	lb/yd³	2.009	
Mineral Admixture:			0.0	lb/yd³	0.000	
Water:	22.0	gallons	183	lb/yd³	2.938	
Air:	6.0	%			1.62	
			total voids:		7.630	ft³

desired w/c ratio:		calculated w/c ratio:	0.33	
ft³/yd³:	27.00	Cement/Voids Ratio:	0.67	

Coarse aggregate 1:	60	%	=	1939	lbs.
Coarse aggregate 2:		%		0	lbs.
Coarse aggregate 3:	0	%		0	lbs.

	Sp. Gr.	Weights			
Coarse Aggregate1:	2.673	1912	lb/yd³	11.463	ft³
Coarse Aggregate2:			lb/yd³	0.000	ft³
Coarse Aggregate3:			lb/yd³	0.000	ft³
Fine Aggregate:	2.625	1295	lb/yd³	7.907	ft³

Water Reducer:	5.67	oz/100-wt.	32.0	oz/yd³
Air Entrainment:	1.35	oz/100-wt.	7.6	oz/yd³
Other Admixture:		oz/100-wt.	0.0	oz/yd³

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.3	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	4.5	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1883	lbs.	69.74	lbs.	320.79	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1331	lbs.	49.29	lbs.	226.73	lbs.
Water Reducer	32.0	oz.	35.03	ml	161.1	ml
Air Entrainment	7.6	oz.	8.34	ml	38.4	ml
Other Admixture		oz.		ml		ml
Free Water	0.8	gallons	0.24	lbs.	1.12	lbs.
Add Water	21.2	gallons	6.55	lbs.	30.12	lbs.
Total Batch Weight	3954.5	lbs.	146.5	lbs.	673.73	lbs.

Tests	1	2	3	4	Water Added	
Slump	3/4	1 3/4	2	1 3/4	Initial Wt.	
Air	5.8	6.5	6.2	6.8	Final Wt.	
Total Wt.	44.63	43.07	43.89	43.6	Net Wt.	
Con. Wt.	36.91	35.35	36.17	35.91	Free Water	
Unit Wt.	148.83	142.54	145.85	144.80	Add Water	
Temp.	72	71	73	72	Total	
Yield	26.57	27.74	27.11	27.31	W/C Ratio	
Time	13:30	14:00	14:45	15:30		

Comments: 5 ml of WR and 10 ml of air entraining admixture was added to the first batch

Project	Effects of Water Reducer on Concrete Durability				Date:	11/1/02	
Reported to:	#REF!				Project No:	#REF!	
Mix Number:							
Mix Description:	Bret Admixtures/ EUCON WR 37/8% water reduction						
Total Cementitious:	564	lb/yd³	Percent Fly Ash:	30	%		
Mineral Admixture:		%		.			
Slump:	1.5	inches	Air Content:	6.0	%		

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³
Cement:	3.15		394.8	lb/yd³	2.009	
Mineral Admixture:			0.0	lb/yd³	0.000	
Water:	22.0	gallons	183	lb/yd³	2.938	
Air:	6.0	%			1.62	
			total voids:		7.630	ft³
desired w/c ratio:		calculated w/c ratio:	0.33			
ft³/yd³:	27.00	Cement/Voids Ratio:	0.67			
Coarse aggregate 1:	60	% =	1939	lbs.		
Coarse aggregate 2:		%	0	lbs.		
Coarse aggregate 3:	0	%	0	lbs.		
	Sp. Gr.		Weights			
Coarse Aggregate1:	2.673		1912	lb/yd³	11.463	ft³
Coarse Aggregate2:				lb/yd³	0.000	ft³
Coarse Aggregate3:				lb/yd³	0.000	ft³
Fine Aggregate:	2.625		1295	lb/yd³	7.907	ft³
Water Reducer:	4.85	oz/100-wt.	27.4	oz/yd³		
Air Entrainment:	2.00	oz/100-wt.	11.3	oz/yd³		
Other Admixture:		oz/100-wt.	0.0	oz/yd³		

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.2	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	2.0	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1881	lbs.	69.67	lbs.	320.47	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1299	lbs.	48.11	lbs.	221.31	lbs.
Water Reducer	27.4	oz.	29.96	ml	137.8	ml
Air Entrainment	11.3	oz.	12.36	ml	56.8	ml
Other Admixture		oz.		ml		ml
Free Water	-3.3	gallons	-1.01	lbs.	-4.63	lbs.
Add Water	25.3	gallons	7.80	lbs.	35.86	lbs.
Total Batch Weight	3954.5	lbs.	146.5	lbs.	673.73	lbs.

Tests	1	2	3	4	Water Added	
Slump	3/4	1	1	3/4	Initial Wt.	
Air	5.1	5.6	6.1	6.0	Final Wt.	
Total Wt.	44.72	44.43	44.25	44.4	Net Wt.	
Con. Wt.	37.00	36.71	36.53	36.66	Free Water	
Unit Wt.	149.19	148.02	147.30	147.82	Add Water	
Temp.	71	72	72	71	Total	
Yield	26.51	26.72	26.85	26.75	W/C Ratio	
Time	15:15	16:00	16:30	17:00		

Comments:

Project	Effects of Water Reducer on Concrete Durability				Date:	11/1/02	
Reported to:	#REF!				Project No:	#REF!	
Mix Number:							
Mix Description:	Bret Admixtures/ EUCON WR 37/12% water reduction						
Total Cementitious:	564	lb/yd³	Percent Fly Ash:	30	%		
Mineral Admixture:		%		.			
Slump:	1.5	inches	Air Content:	6.0	%		

Batch Design Calculations:

		Sp. Gr.		Weights		Volume	
Fly Ash:		2.55		169.2	lb/yd³	1.063	ft³
Cement:		3.15		394.8	lb/yd³	2.009	
Mineral Admixture:				0.0	lb/yd³	0.000	
Water:		21.1	gallons	176	lb/yd³	2.818	
Air:		6.0	%			1.62	
					total voids:	7.510	ft³
desired w/c ratio:			calculated w/c ratio:	0.31			
ft³/yd³:	27.00		Cement/Voids Ratio:	0.69			
Coarse aggregate 1:		60	% =	1951	lbs.		
Coarse aggregate 2:			%	0	lbs.		
Coarse aggregate 3:		0	%	0	lbs.		
		Sp. Gr.		Weights			
Coarse Aggregate1:		2.673		1912	lb/yd³	11.463	ft³
Coarse Aggregate2:					lb/yd³	0.000	ft³
Coarse Aggregate3:					lb/yd³	0.000	ft³
Fine Aggregate:		2.625		1315	lb/yd³	8.027	ft³
Water Reducer:	9.80	oz/100-wt.		55.3	oz/yd³		
Air Entrainment:	2.00	oz/100-wt.		11.3	oz/yd³		
Other Admixture:		oz/100-wt.		0.0	oz/yd³		

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.2	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	2.5	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1881	lbs.	69.67	lbs.	320.47	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1325	lbs.	49.08	lbs.	225.77	lbs.
Water Reducer	55.3	oz.	60.54	ml	278.5	ml
Air Entrainment	11.3	oz.	12.36	ml	56.8	ml
Other Admixture		oz.		ml		ml
Free Water	-2.5	gallons	-0.76	lbs.	-3.52	lbs.
Add Water	23.6	gallons	7.28	lbs.	33.47	lbs.
Total Batch Weight	3966.7	lbs.	146.9	lbs.	675.80	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/2	1	1	1	Initial Wt.	
Air	4.5	6.1	5.8	5.4	Final Wt.	
Total Wt.	45.00	44.41	44.42	44.6	Net Wt.	
Con. Wt.	37.28	36.69	36.70	36.86	Free Water	
Unit Wt.	150.32	147.94	147.98	148.63	Add Water	
Temp.	71	71	72	71	Total	
Yield	26.39	26.81	26.80	26.69	W/C Ratio	
Time	13:30	14:00	15:00	15:30		

Comments: 20ml of air was added and 5ml of WR was subracted from the first batch

Project	Effects of Water Reducer on Concrete Durability					Date:	2/18/03
Reported to:	#REF!					Project No:	#REF!
Mix Number:	1						
Mix Description:	GRACE/ WRDA 82/ 5% water reduction						
Total Cementitious:	564	lb/yd³	Percent Fly Ash:		30	%	
Mineral Admixture:		%			.		
Slump:	1.5	inches	Air Content:		6.0	%	

Batch Design Calculations:

	Sp. Gr.		Weights		Volume		
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³	
Cement:	3.15		394.8	lb/yd³	2.009		
Mineral Admixture:			0.0	lb/yd³	0.000		
Water:	22.8	gallons	190	lb/yd³	3.045		
Air:	6.0	%			1.62		
				total voids:	7.737	ft³	
desired w/c ratio:			calculated w/c ratio:	0.34			
ft³/yd³:	27.00		Cement/Voids Ratio:	0.66			
Coarse aggregate 1:	60	%	=	1928	lbs.		
Coarse aggregate 2:		%		0	lbs.		
Coarse aggregate 3:	0	%		0	lbs.		
	Sp. Gr.		Weights				
Coarse Aggregate1:	2.673		1912	lb/yd³	11.463	ft³	
Coarse Aggregate2:				lb/yd³	0.000	ft³	
Coarse Aggregate3:				lb/yd³	0.000	ft³	
Fine Aggregate:	2.625		1278	lb/yd³	7.800	ft³	
Water Reducer:	4.0	oz/100-wt.	22.6	oz/yd³			
Air Entrainment:	1.35	oz/100-wt.	7.6	oz/yd³			
Other Admixture:		oz/100-wt.	0.0	oz/yd³			

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.2	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	5.0	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1881	lbs.	69.67	lbs.	320.47	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1319	lbs.	48.86	lbs.	224.74	lbs.
Water Reducer	22.6	oz.	24.71	ml	113.7	ml
Air Entrainment	7.6	oz.	8.34	ml	38.4	ml
Other Admixture		oz.		ml		ml
Free Water	1.3	gallons	0.39	lbs.	1.78	lbs.
Add Water	21.5	gallons	6.65	lbs.	30.59	lbs.
Total Batch Weight	3943.7	lbs.	146.1	lbs.	671.88	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/4	1	1		Initial Wt.	
Air	6.1	5.7	6.2		Final Wt.	
Total Wt.	44.05	44.39	43.82		Net Wt.	
Con. Wt.	36.33	36.67	36.10	-7.72	Free Water	
Unit Wt.	146.49	147.86	145.56	-31.13	Add Water	
Temp.	71	72	72		Total	
Yield	26.92	26.67	27.09	-126.69	W/C Ratio	
Time	13:00	13:35	14:15			

Comments:

Project	Effects of Water Reducer on Concrete Durability					Date:	2/21/03
Reported to:	#REF!					Project No:	#REF!
Mix Number:	1						
Mix Description:	GRACE/ WRDA 82/ 8% water reduction						
Total Cementitious:	564	lb/yd³	Percent Fly Ash:		30	%	
Mineral Admixture:		%			.		
Slump:	1.5	inches	Air Content:		6.0	%	

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³
Cement:	3.15		394.8	lb/yd³	2.009	
Mineral Admixture:			0.0	lb/yd³	0.000	
Water:	22.0	gallons	183	lb/yd³	2.938	
Air:	6.0	%			1.62	
				total voids:	7.630	ft³

desired w/c ratio:		calculated w/c ratio:	0.33
ft³/yd³:	27.00	Cement/Voids Ratio:	0.67

Coarse aggregate 1:	60	%	=	1939	lbs.
Coarse aggregate 2:		%		0	lbs.
Coarse aggregate 3:	0	%		0	lbs.

	Sp. Gr.	Weights		Volume	
Coarse Aggregate1:	2.673	1912	lb/yd³	11.463	ft³
Coarse Aggregate2:			lb/yd³	0.000	ft³
Coarse Aggregate3:			lb/yd³	0.000	ft³
Fine Aggregate:	2.625	1295	lb/yd³	7.907	ft³

Water Reducer:	6.9	oz/100-wt.	38.6	oz/yd³
Air Entrainment:	1.40	oz/100-wt.	7.9	oz/yd³
Other Admixture:		oz/100-wt.	0.0	oz/yd³

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.2	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	5.0	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1881	lbs.	69.67	lbs.	320.47	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1337	lbs.	49.53	lbs.	227.82	lbs.
Water Reducer	38.6	oz.	42.32	ml	194.7	ml
Air Entrainment	7.9	oz.	8.65	ml	39.8	ml
Other Admixture		oz.		ml		ml
Free Water	1.3	gallons	0.41	lbs.	1.88	lbs.
Add Water	20.7	gallons	6.38	lbs.	29.35	lbs.
Total Batch Weight	3954.5	lbs.	146.5	lbs.	673.73	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 3/4	3/4	3/4		Initial Wt.	
Air	7.0	6.0	6.6		Final Wt.	
Total Wt.	43.80	44.39	44.32		Net Wt.	
Con. Wt.	36.08	36.67	36.60	-7.72	Free Water	
Unit Wt.	145.48	147.86	147.58	-31.13	Add Water	
Temp.	71	73	73		Total	
Yield	27.18	26.74	26.80	-127.04	W/C Ratio	
Time	12:00	12:25	13:15			

Comments:

Project	Effects of Water Reducer on Concrete Durability						Date:	2/25/03
Reported to:	#REF!						Project No:	#REF!
Mix Number:	1							
Mix Description:	GRACE/ ADVA 140/ 8% water reduction							
Total Cementitious:	564	lb/yd³		Percent Fly Ash:	30	%		
Mineral Admixture:		%						
Slump:	1.5	inches		Air Content:	6.0	%		

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³
Cement:	3.15		394.8	lb/yd³	2.009	
Mineral Admixture:			0.0	lb/yd³	0.000	
Water:	22.0	gallons	183	lb/yd³	2.938	
Air:	6.0	%			1.62	
				total voids:	7.630	ft³

desired w/c ratio:		calculated w/c ratio:	0.33
ft³/yd³:	27.00	Cement/Voids Ratio:	0.67

Coarse aggregate 1:	60	%	=	1939	lbs.
Coarse aggregate 2:		%		0	lbs.
Coarse aggregate 3:	0	%		0	lbs.

	Sp. Gr.	Weights			
Coarse Aggregate1:	2.673	1912	lb/yd³	11.463	ft³
Coarse Aggregate2:			lb/yd³	0.000	ft³
Coarse Aggregate3:			lb/yd³	0.000	ft³
Fine Aggregate:	2.625	1295	lb/yd³	7.907	ft³

Water Reducer:	6.0	oz/100-wt.	33.8	oz/yd³
Air Entrainment:	1.55	oz/100-wt.	8.7	oz/yd³
Other Admixture:		oz/100-wt.	0.0	oz/yd³

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.2	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	3.6	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1881	lbs.	69.67	lbs.	320.47	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1319	lbs.	48.86	lbs.	224.78	lbs.
Water Reducer	33.8	oz.	37.07	ml	170.5	ml
Air Entrainment	8.7	oz.	9.58	ml	44.0	ml
Other Admixture		oz.		ml		ml
Free Water	-0.8	gallons	-0.25	lbs.	-1.16	lbs.
Add Water	22.8	gallons	7.04	lbs.	32.39	lbs.
Total Batch Weight	3954.5	lbs.	146.5	lbs.	673.73	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/2	1 1/2	1 3/4		Initial Wt.	
Air	5.7	6.2	5.7		Final Wt.	
Total Wt.	44.25	44.01	44.24		Net Wt.	
Con. Wt.	36.53	36.29	36.52	-7.72	Free Water	
Unit Wt.	147.30	146.33	147.26	-31.13	Add Water	
Temp.	72	72	72		Total	
Yield	26.85	27.02	26.85	-127.04	W/C Ratio	
Time	13:00	13:25	14:00			

Comments:

Project	Effects of Water Reducer on Concrete Durability				Date:	2/25/03
Reported to:	#REF!				Project No:	#REF!
Mix Number:	1					
Mix Description:	GRACE/ ADVA 140/ 12% water reduction					
Total Cementitious:	564	lb/yd³	Percent Fly Ash:	30	%	
Mineral Admixture:		%		.		
Slump:	1.5	inches	Air Content:	6.0	%	

Batch Design Calculations:

		Sp. Gr.		Weights		Volume
Fly Ash:		2.55		169.2	lb/yd³	1.063 ft³
Cement:		3.15		394.8	lb/yd³	2.009
Mineral Admixture:				0.0	lb/yd³	0.000
Water:		21.1	gallons	176	lb/yd³	2.818
Air:		6.0	%			1.62
				total voids:		7.510 ft³
desired w/c ratio:			calculated w/c ratio:		0.31	
ft³/yd³:	27.00		Cement/Voids Ratio:		0.69	
Coarse aggregate 1:		60	%	= 1951	lbs.	
Coarse aggregate 2:			%	0	lbs.	
Coarse aggregate 3:		0	%	0	lbs.	
		Sp. Gr.		Weights		
Coarse Aggregate1:		2.673		1912	lb/yd³	11.463 ft³
Coarse Aggregate2:					lb/yd³	0.000 ft³
Coarse Aggregate3:					lb/yd³	0.000 ft³
Fine Aggregate:		2.625		1315	lb/yd³	8.027 ft³
Water Reducer:	9.5	oz/100-wt.		53.6	oz/yd³	
Air Entrainment:	1.65	oz/100-wt.		9.3	oz/yd³	
Other Admixture:		oz/100-wt.		0.0	oz/yd³	

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.2	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	4.8	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1881	lbs.	69.67	lbs.	320.47	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1355	lbs.	50.18	lbs.	230.84	lbs.
Water Reducer	53.6	oz.	58.69	ml	270.0	ml
Air Entrainment	9.3	oz.	10.19	ml	46.9	ml
Other Admixture		oz.		ml		ml
Free Water	1.1	gallons	0.34	lbs.	1.55	lbs.
Add Water	20.0	gallons	6.18	lbs.	28.41	lbs.
Total Batch Weight	3966.7	lbs.	146.9	lbs.	675.80	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/4	1 1/2	1		Initial Wt.	
Air	5.5	6.4	6.1		Final Wt.	
Total Wt.	44.52	43.89	44.82		Net Wt.	
Con. Wt.	36.80	36.17	37.10	-7.72	Free Water	
Unit Wt.	148.39	145.85	149.60	-31.13	Add Water	
Temp.	72	71	71		Total	
Yield	26.73	27.20	26.52	-127.43	W/C Ratio	
Time	13:10	13:35	14:05			

Comments:

Project	Effects of Water Reducer on Concrete Durability					Date:	4/2/03
Reported to:	#REF!					Project No:	#REF!
Mix Number:	1						
Mix Description:	GRT/ POLYCHEM 400NC/ 5% water reduction						
Total Cementitious:	564	lb/yd³	Percent Fly Ash:	30	%		
Mineral Admixture:		%		.			
Slump:	1.5	inches	Air Content:	6.0	%		

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³
Cement:	3.15		394.8	lb/yd³	2.009	
Mineral Admixture:			0.0	lb/yd³	0.000	
Water:	22.8	gallons	190	lb/yd³	3.045	
Air:	6.0	%			1.62	
				total voids:	7.737	ft³

desired w/c ratio:		calculated w/c ratio:	0.34
ft³/yd³:	27.00	Cement/Voids Ratio:	0.66

Coarse aggregate 1:	60	%	=	1928	lbs.
Coarse aggregate 2:		%		0	lbs.
Coarse aggregate 3:	0	%		0	lbs.

	Sp. Gr.	Weights			
Coarse Aggregate1:	2.673	1912	lb/yd³	11.463	ft³
Coarse Aggregate2:			lb/yd³	0.000	ft³
Coarse Aggregate3:			lb/yd³	0.000	ft³
Fine Aggregate:	2.625	1278	lb/yd³	7.800	ft³

Water Reducer:	4.0	oz/100-wt.	22.6	oz/yd³
Air Entrainment:	1.70	oz/100-wt.	9.6	oz/yd³
Other Admixture:		oz/100-wt.	0.0	oz/yd³

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	1.0	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	5.5	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1897	lbs.	70.26	lbs.	323.19	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1325	lbs.	49.09	lbs.	225.81	lbs.
Water Reducer	22.6	oz.	24.71	ml	113.7	ml
Air Entrainment	9.6	oz.	10.50	ml	48.3	ml
Other Admixture		oz.		ml		ml
Free Water	3.9	gallons	1.21	lbs.	5.57	lbs.
Add Water	18.9	gallons	5.83	lbs.	26.80	lbs.
Total Batch Weight	3943.7	lbs.	146.1	lbs.	671.88	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 3/4	1 1/4	1 1/4		Initial Wt.	
Air	7.0	5.2	5.0		Final Wt.	
Total Wt.	43.25	44.31	44.60		Net Wt.	
Con. Wt.	35.53	36.59	36.88	-7.72	Free Water	
Unit Wt.	143.27	147.54	148.71	-31.13	Add Water	
Temp.	71	71	70		Total	
Yield	27.53	26.73	26.52	-126.69	W/C Ratio	
Time	15:10	16:00	16:30			

Comments:

Project	Effects of Water Reducer on Concrete Durability				Date:	4/4/03
Reported to:	#REF!				Project No:	#REF!
Mix Number:	1					
Mix Description:	GRT/ POLYCHEM 400NC/ 8% water reduction					
Total Cementitious:	564	lb/yd³	Percent Fly Ash:	30	%	
Mineral Admixture:		%		.		
Slump:	1.5	inches	Air Content:	6.0	%	

Batch Design Calculations:

	Sp. Gr.		Weights		Volume	
Fly Ash:	2.55		169.2	lb/yd³	1.063	ft³
Cement:	3.15		394.8	lb/yd³	2.009	
Mineral Admixture:			0.0	lb/yd³	0.000	
Water:	22.0	gallons	183	lb/yd³	2.938	
Air:	6.0	%			1.62	
				total voids:	7.630	ft³
desired w/c ratio:			calculated w/c ratio:	0.33		
ft³/yd³:	27.00		Cement/Voids Ratio:	0.67		
Coarse aggregate 1:	60	%	= 1939	lbs.		
Coarse aggregate 2:		%	0	lbs.		
Coarse aggregate 3:	0	%	0	lbs.		
	Sp. Gr.		Weights			
Coarse Aggregate1:	2.673		1912	lb/yd³	11.463	ft³
Coarse Aggregate2:				lb/yd³	0.000	ft³
Coarse Aggregate3:				lb/yd³	0.000	ft³
Fine Aggregate:	2.625		1295	lb/yd³	7.907	ft³
Water Reducer:	6.0	oz/100-wt.	33.8	oz/yd³		
Air Entrainment:	1.70	oz/100-wt.	9.6	oz/yd³		
Other Admixture:		oz/100-wt.	0.0	oz/yd³		

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.6	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	5.0	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1889	lbs.	69.98	lbs.	321.91	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1337	lbs.	49.53	lbs.	227.82	lbs.
Water Reducer	33.8	oz.	37.07	ml	170.5	ml
Air Entrainment	9.6	oz.	10.50	ml	48.3	ml
Other Admixture		oz.		ml		ml
Free Water	2.3	gallons	0.72	lbs.	3.32	lbs.
Add Water	19.7	gallons	6.07	lbs.	27.91	lbs.
Total Batch Weight	3954.5	lbs.	146.5	lbs.	673.73	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/2	1 1/2	1		Initial Wt.	
Air	6.4	5.9	5.6		Final Wt.	
Total Wt.	44.00	44.14	44.23		Net Wt.	
Con. Wt.	36.28	36.42	36.51	-7.72	Free Water	
Unit Wt.	146.29	146.85	147.22	-31.13	Add Water	
Temp.	70	71	71		Total	
Yield	27.03	26.93	26.86	-127.04	W/C Ratio	
Time	13:10	13:35	14:05			

Comments:

Project	Effects of Water Reducer on Concrete Durability					Date:	2/25/03
Reported to:	#REF!					Project No:	#REF!
Mix Number:	1						
Mix Description:	GRT/Melchem/8% WR						
Total Cementitious:	564	lb/yd³		Percent Fly Ash:	30	%	
Mineral Admixture:		%			.		
Slump:	1.5	inches		Air Content:	6.0	%	

Batch Design Calculations:

		Sp. Gr.		Weights		Volume	
Fly Ash:		2.55		169.2	lb/yd³	1.063	ft³
Cement:		3.15		394.8	lb/yd³	2.009	
Mineral Admixture:				0.0	lb/yd³	0.000	
Water:		21.1	gallons	176	lb/yd³	2.818	
Air:		6.0	%			1.62	
				total voids:		7.510	ft³
desired w/c ratio:			calculated w/c ratio:		0.31		
ft³/yd³:	27.00		Cement/Voids Ratio:		0.69		
Coarse aggregate 1:		60	%	=	1951	lbs.	
Coarse aggregate 2:			%		0	lbs.	
Coarse aggregate 3:		0	%		0	lbs.	
		Sp. Gr.		Weights			
Coarse Aggregate1:		2.673		1912	lb/yd³	11.463	ft³
Coarse Aggregate2:					lb/yd³	0.000	ft³
Coarse Aggregate3:					lb/yd³	0.000	ft³
Fine Aggregate:		2.625		1315	lb/yd³	8.027	ft³
Water Reducer:	6.0	oz/100-wt.		33.8	oz/yd³		
Air Entrainment:	2.50	oz/100-wt.		14.1	oz/yd³		
Other Admixture:		oz/100-wt.		0.0	oz/yd³		

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	1.1	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	5.5	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1899	lbs.	70.33	lbs.	323.51	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1364	lbs.	50.52	lbs.	232.38	lbs.
Water Reducer	33.8	oz.	37.07	ml	170.5	ml
Air Entrainment	14.1	oz.	15.44	ml	71.0	ml
Other Admixture		oz.		ml		ml
Free Water	4.3	gallons	1.33	lbs.	6.13	lbs.
Add Water	16.8	gallons	5.18	lbs.	23.83	lbs.
Total Batch Weight	3966.7	lbs.	146.9	lbs.	675.80	lbs.

Tests	1	2	3	4	Water Added	
Slump	2	2	1 1/2		Initial Wt.	
Air	6.5	5.6	5.3		Final Wt.	
Total Wt.	43.90	44.18	44.35		Net Wt.	
Con. Wt.	36.18	36.46	36.63	-7.72	Free Water	
Unit Wt.	145.89	147.02	147.70	-31.13	Add Water	
Temp.	71	71	72		Total	
Yield	27.19	26.98	26.86	-127.43	W/C Ratio	
Time	13:10	13:35	14:05			

Comments:

Project	Effects of Water Reducer on Concrete Durability				Date:	2/25/03	
Reported to:	#REF!				Project No:	#REF!	
Mix Number:	1						
Mix Description:	GRACE/ Melchem/ 12% water reduction						
Total Cementitious:	564	lb/yd³	Percent Fly Ash:	30	%		
Mineral Admixture:		%					
Slump:	1.5	inches	Air Content:	6.0	%		

Batch Design Calculations:

		Sp. Gr.		Weights		Volume	
Fly Ash:		2.55		169.2	lb/yd³	1.063	ft³
Cement:		3.15		394.8	lb/yd³	2.009	
Mineral Admixture:				0.0	lb/yd³	0.000	
Water:		21.1	gallons	176	lb/yd³	2.818	
Air:		6.0	%			1.62	
					total voids:	7.510	ft³
desired w/c ratio:			calculated w/c ratio:		0.31		
ft³/yd³:	27.00		Cement/Voids Ratio:		0.69		
Coarse aggregate 1:		60	% =	1951	lbs.		
Coarse aggregate 2:			%	0	lbs.		
Coarse aggregate 3:		0	%	0	lbs.		
		Sp. Gr.		Weights			
Coarse Aggregate1:		2.673		1912	lb/yd³	11.463	ft³
Coarse Aggregate2:					lb/yd³	0.000	ft³
Coarse Aggregate3:					lb/yd³	0.000	ft³
Fine Aggregate:		2.625		1315	lb/yd³	8.027	ft³
Water Reducer:	9.5	oz/100-wt.		53.6	oz/yd³		
Air Entrainment:	1.75	oz/100-wt.		9.9	oz/yd³		
Other Admixture:		oz/100-wt.		0.0	oz/yd³		

Trial Batch Calculations:

Moistures:	Total Moisture		Absorption	
Coarse Aggregate 1:	0.5	%	1.8	%
Coarse Aggregate 2:		%		%
Coarse Aggregate 3:		%		%
Fine Aggregate:	4.8	%	1.7	%

Trial Batch Weights:

Size	27.0	ft³	1.0	ft³	4.6	ft³
Fly Ash	169.2	lbs.	6.27	lbs.	28.83	lbs.
Cement	394.8	lbs.	14.62	lbs.	67.26	lbs.
Mineral Admixture		lbs.		lbs.		lbs.
Coarse Aggregate 1	1888	lbs.	69.91	lbs.	321.59	lbs.
Coarse Aggregate 2		lbs.		lbs.		lbs.
Coarse Aggregate 3		lbs.		lbs.		lbs.
Fine Aggregate	1355	lbs.	50.18	lbs.	230.84	lbs.
Water Reducer	53.6	oz.	58.69	ml	270.0	ml
Air Entrainment	9.9	oz.	10.81	ml	49.7	ml
Other Admixture		oz.		ml		ml
Free Water	1.9	gallons	0.58	lbs.	2.67	lbs.
Add Water	19.2	gallons	5.93	lbs.	27.29	lbs.
Total Batch Weight	3966.7	lbs.	146.9	lbs.	675.80	lbs.

Tests	1	2	3	4	Water Added	
Slump	1 1/4	1 1/2	1 1/2		Initial Wt.	
Air	5.0	5.9	5.5		Final Wt.	
Total Wt.	44.72	44.13	44.43		Net Wt.	
Con. Wt.	37.00	36.41	36.71	-7.72	Free Water	
Unit Wt.	149.19	146.81	148.02	-31.13	Add Water	
Temp.	72	71	71		Total	
Yield	26.59	27.02	26.80	-127.43	W/C Ratio	
Time	13:10	13:35	14:05			

Comments:

Appendix H
Permeability Test Data

- **Complete Test Results**

	NUMBER OF COULOMBS PASSED											
	0-2 inches			2-4 inches			4-6 inches			6-8 inches		
MIX #	A	B	C	A	B	C	A	B	C	A	B	C
Control	3091	2980	2098	1318	1289	1058	86	847	869	551	137	11
MB-332N-5	4521	3186	3384	1133	1056	1244	1142	952	1139	1704	1148	794
MB-332N-8	2646	2279	2117	1375	822	1138	1179	1095	804	1387	1270	1219
MB-997-8	3020	3167	3096	1158	983	1257	815	896	693	724	559	964
MB-997-12	2785	3360	2980	872	1241	1042	876	687	953	1002	1064	972
Brett-WR91-5	2185	2996	2850	975	1298	1114	798	887	823	784	698	885
Brett-WR91-8	3871	3581	2765	1587	1469	1068	951	749	855	623	594	669
Brett-37-8	1469	3027	4378	1161	615	952	741	857	758	735	547	273
Brett-37-12	878	3101	3112	1292	1008	215	179	892	850	723	816	940
Grace-82-5	2244	924	4219	1132	2338	757	35	1121	180	283	1244	976
Grace-82-8	4028	2502	123	934	1054	835	455	948	794	73	910	871
Grace-140-8	5324	5324	119	2725	2106	1331	1204	1001	801	74	899	895
Grace-140-12	197	7091	5158	3028	1991	829	1270	151	12	769	808	972
GRT-400NC-5	2752	1974	2541	1875	4125	2541	754	90	641	542	1124	1365
GRT-400NC-8	6211	2947	1878	2249	3032	1426	523	1148	1674	88	276	458
GRT-Melchem-8	1942	3421	3049	1245	2247	1845	841	1345	642	76	1241	96
GRT-Melchem-12	2947	1547	4581	2147	1008	1654	1478	269	84	1354	359	604

Table H.1 Permeability Data

	CLASSIFICATION OF PERMEABILITY											
	0-2 inches			2-4 inches			4-6 inches			6-8 inches		
MIX #	A	B	C	A	B	C	A	B	C	A	B	C
Control	MODERATE	MODERATE	MODERATE	LOW	LOW	LOW	NEGLIGIBLE	VERY LOW	VERY LOW	VERY LOW	VERY LOW	NEGLIGIBLE
MB-332N-5	HIGH	MODERATE	MODERATE	LOW	LOW	LOW	LOW	VERY LOW	LOW	LOW	LOW	VERY LOW
MB-332N-8	MODERATE	MODERATE	MODERATE	LOW	VERY LOW	LOW	LOW	LOW	VERY LOW	LOW	LOW	LOW
MB-997-8	MODERATE	MODERATE	MODERATE	LOW	VERY LOW	LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	LOW	VERY LOW
MB-997-12	MODERATE	MODERATE	MODERATE	VERY LOW	LOW	LOW	VERY LOW	VERY LOW	VERY LOW	LOW	LOW	VERY LOW
Brett-WR91-5	MODERATE	MODERATE	MODERATE	VERY LOW	LOW	LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW
Brett-WR91-8	MODERATE	MODERATE	MODERATE	LOW	LOW	LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW
Brett-37-8	LOW	MODERATE	HIGH	LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW
Brett-37-12	VERY LOW	MODERATE	MODERATE	LOW	LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW
Grace-82-5	MODERATE	VERY LOW	HIGH	LOW	MODERATE	VERY LOW	NEGLIGIBLE	LOW	VERY LOW	VERY LOW	LOW	VERY LOW
Grace-82-8	HIGH	MODERATE	VERY LOW	VERY LOW	LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW	NEGLIGIBLE	VERY LOW	VERY LOW
Grace-140-8	HIGH	HIGH	VERY LOW	MODERATE	MODERATE	LOW	LOW	LOW	VERY LOW	NEGLIGIBLE	VERY LOW	VERY LOW
Grace-140-12	VERY LOW	HIGH	HIGH	MODERATE	LOW	VERY LOW	LOW	VERY LOW	NEGLIGIBLE	VERY LOW	VERY LOW	VERY LOW
GRT-400NC-5	MODERATE	LOW	MODERATE	LOW	HIGH	MODERATE	VERY LOW	NEGLIGIBLE	VERY LOW	VERY LOW	LOW	LOW
GRT-400NC-8	HIGH	MODERATE	LOW	MODERATE	MODERATE	LOW	VERY LOW	LOW	LOW	NEGLIGIBLE	VERY LOW	VERY LOW
GRT-Melchem-8	LOW	MODERATE	MODERATE	LOW	MODERATE	LOW	VERY LOW	LOW	VERY LOW	NEGLIGIBLE	LOW	NEGLIGIBLE
GRT-Melchem-12	MODERATE	LOW	HIGH	MODERATE	LOW	LOW	LOW	VERY LOW	NEGLIGIBLE	LOW	VERY LOW	VERY LOW

Table H.2 Classifications

Appendix I
Deicing Values

- **Scaling from Deicing Chemical Scores**
- **Example Pictures of Each Score**

Raw Deicing Data at 5, 10, 15, 25, and 50 Days																	
Cycle #	**Control**	**A1A**	**A1B**	**A2A**	**A2B**	**A3A**	**A3B**	**A4A**	**A4B**	**A5A**	**A5B**	**A6A**	**A6B**	**A7A**	**A7B**	**A8A**	**A8B**
5	1	2	2	1	1	1	2	1	2	2	1	1	1	3	2	3	2
10	1	3	3	2	1	2	3	2	3	3	1.5	1.5	1.5	4	3	4	3
15	2	3	3	2	2	2	3	2.5	3.5	3.5	1.5	2	2	4	3	4	3
25	2.5	3	3	2	2	2	3	3	4	4	2	3	3	4	3	4	3
50	3	3	3	2	2	3	3	3	4	4	2.5	3	3	4	3.5	4	3
		A9A	**A9B**	**A10A**	**A10B**	**A11A**	**A11B**	**A12A**	**A12B**	**A13A**	**A13B**	**A14A**	**A14B**	**A15A**	**A15B**	**A16A**	**A16B**
5		1	1	2	1	2	1	2	1	1	1	1	1	2	2	1	1
10		1	2	3	1	3.5	2.5	2	1	2	3	2	2	3	3	2	2
15		1.5	2	3	2	4	3	3	2	2	3	2	2	3	3	2	2
25		2	3	3.5	2	4	3	3	2	3	3	2	2	3	3	2.5	2
50		3	3	4	2	4	3	3	2	3	3.5	2	2	3	3	2.5	2

Table I-1: Deicing Experimental Data

MB-332N-5	A1
MB-332N-8	A2
MB-997-8	A3
MB-997-12	A4
Brett-WR91-5	A5
Brett-WR91-8	A6
Brett-37-8	A7
Brett-37-12	A8
Grace-82-5	A9
Grace-82-8	A10
Grace-140-8	A11
Grace-140-12	A12
GRT-400NC-5	A13
GRT-400NC-8	A14
GRT-Melchem-8	A15
GRT-Melchem-12	A16

Table I-2: Mix Design Designations

Figure I-1: Example of a Deicing Score of 1

Figure I-2: Example of Deicing Score of 2

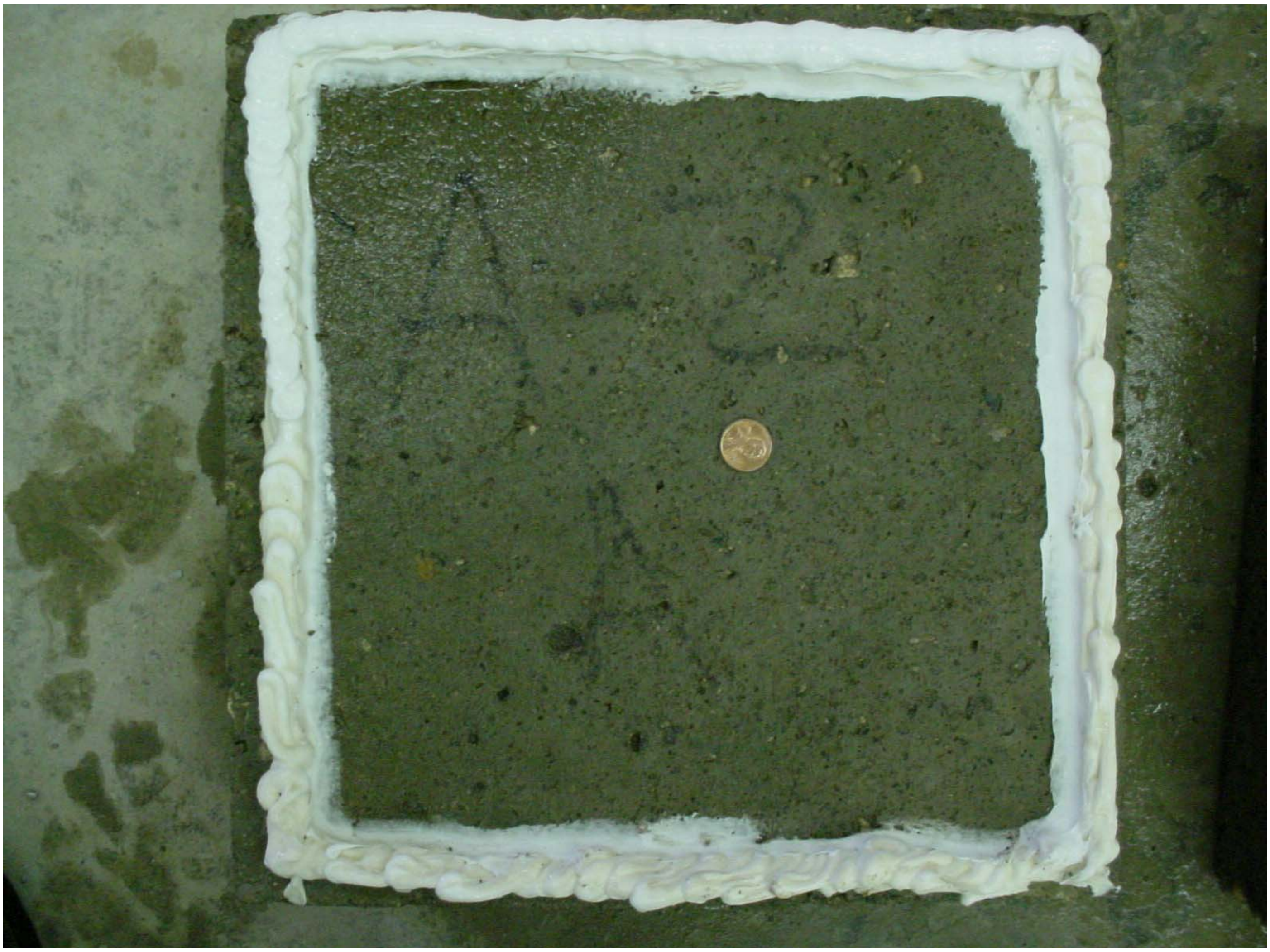
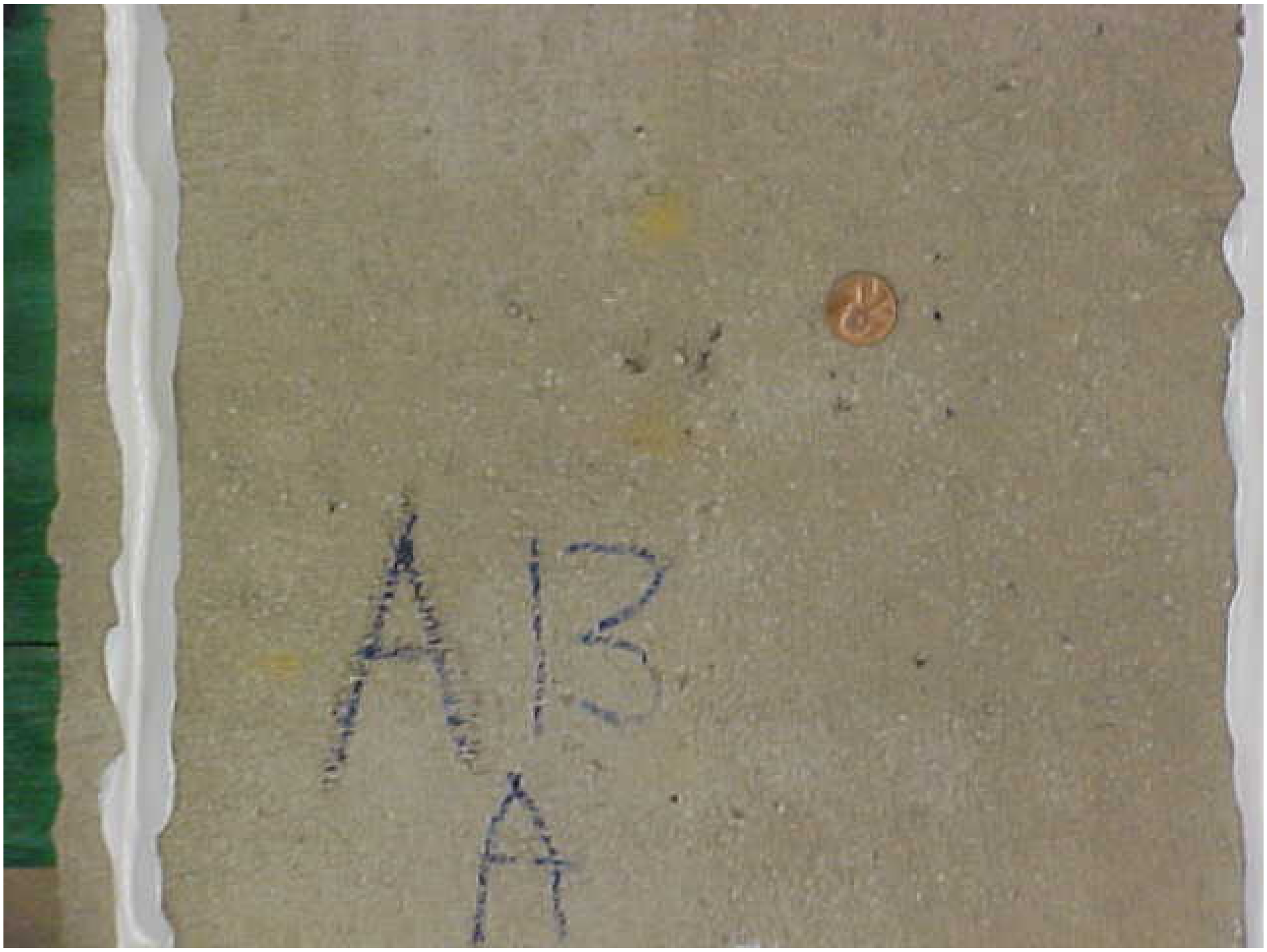


Figure I-3: Example of a Deicing Score of 3

Figure I-4: Example of a Deicing Score of 4

Figure I-5: Example of a Deicing Specimen at 0 Cycles



Appendix J
Freeze Thaw Data

- **Durability Factor**
- **Specimen Weight Change**
- **Specimen Length Change**

Mix Designation	**Product**	**Durability Factor (%)**	**Specimen Weight Loss (%)**	**Specimen Length Change (%)**
Control	N/A	90.1	-0.121	0.005
B		83.6	-0.457	0.018
C		92.4	-0.154	-0.002
MB-332N-5	Pozzolith 322N	73.1	2.385	0.103
B		80.7	-1.440	0.094
C		81.7	-0.734	0.075
MB-332N-8	Pozzolith 322N	74.4	-0.798	0.063
B		81.2	-1.217	0.113
C		75.0	-0.120	0.119
MB-997-8	Polyheed 997	73.2	0.305	0.007
B		80.2	0.128	0.065
C		67.6	0.131	-0.045
MB-997-12	Polyheed 997	74.9	0.388	0.001
B		82.4	0.188	0.037
C		61.4	0.106	-0.011
Brett-WR91-5	Eucon WR 91	73.4	-0.320	0.015
B		78.2	0.158	0.087
C		78.4	-0.240	0.127
Brett-WR91-8	Eucon WR 91	73.6	0.301	0.009
B		71.2	0.217	-0.013
C		87.4	0.379	0.007
Brett-37-8	Eucon 37	75.1	-0.484	0.009
B		73.7	-0.718	0.031
C		72.6	-0.061	0.038
Brett-37-12	Eucon 37	74.9	-0.606	0.059
B		79.2	-1.411	0.053
C		75.8	0.396	0.025
Grace-82-5	WRDA-82	83.6	-0.244	0.003
B		79.9	-1.551	0.044
Grace-82-8	WRDA-82	83.6	-0.496	0.041
B		73.9	-1.035	0.046
Grace-140-8	ADVA 140	74.1	0.122	0.022
B		71.8	-0.062	0.003
Grace-140-12	ADVA 140	78.3	-0.125	0.028
B		72.8	-0.858	0.022
GRT-400NC-5	Polychem 400NC	76.7	0.063	0.031
B		76.8	0.120	0.041
GRT-400NC-8	Polychem 400NC	74.1	-0.485	0.025
B		73.3	-0.120	0.028
GRT-Melchem-8	Melchem	71.9	-0.619	0.025
B		74.1	-0.361	0.034
GRT-Melchem-12	Melchem	76.2	-0.542	0.088
B		84.6	-0.122	0.031

Table J.1 Freeze-Thaw Data