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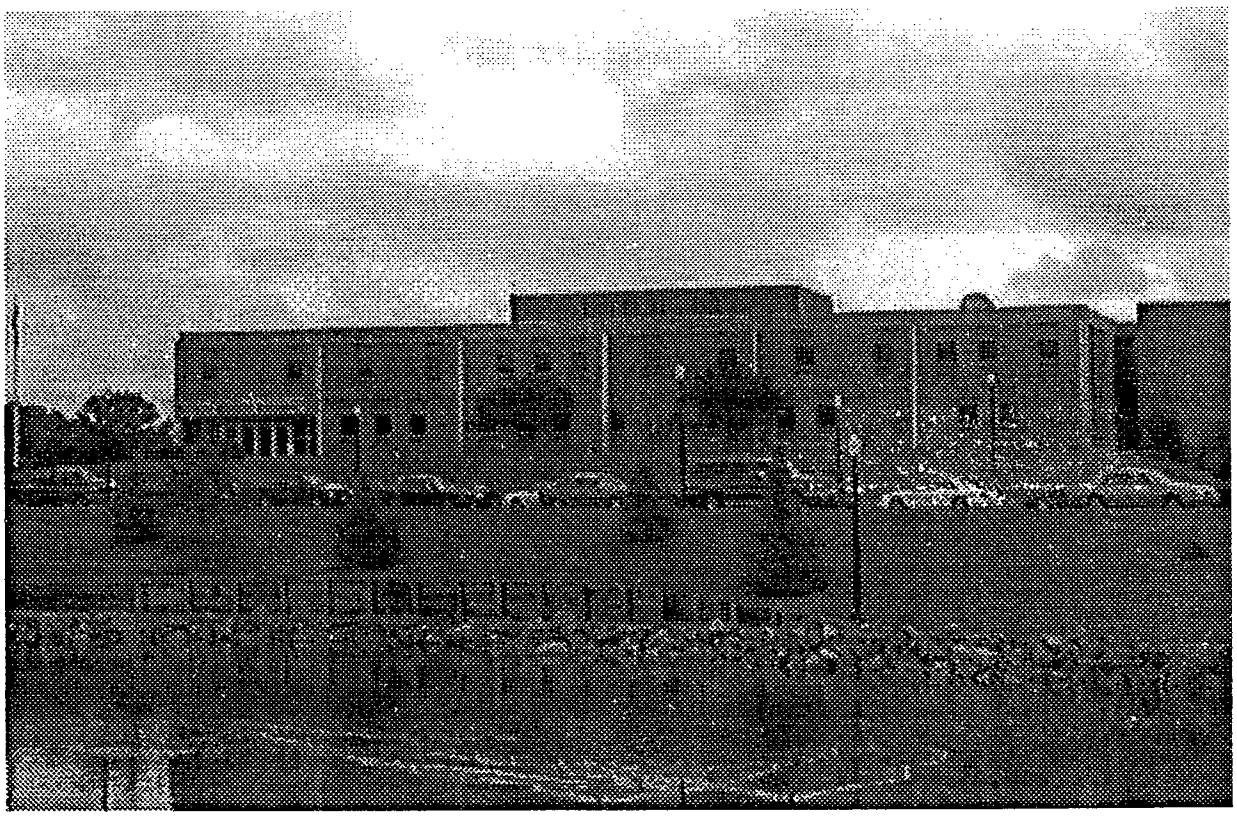
SD Department of Transportation
Office of Research



# Field Performance of Concrete Admixtures

Study SD97-09
Final Report

Prepared by

South Dakota School of Mines and Technology
501 East St. Joseph Street
Rapid City, SD 57702

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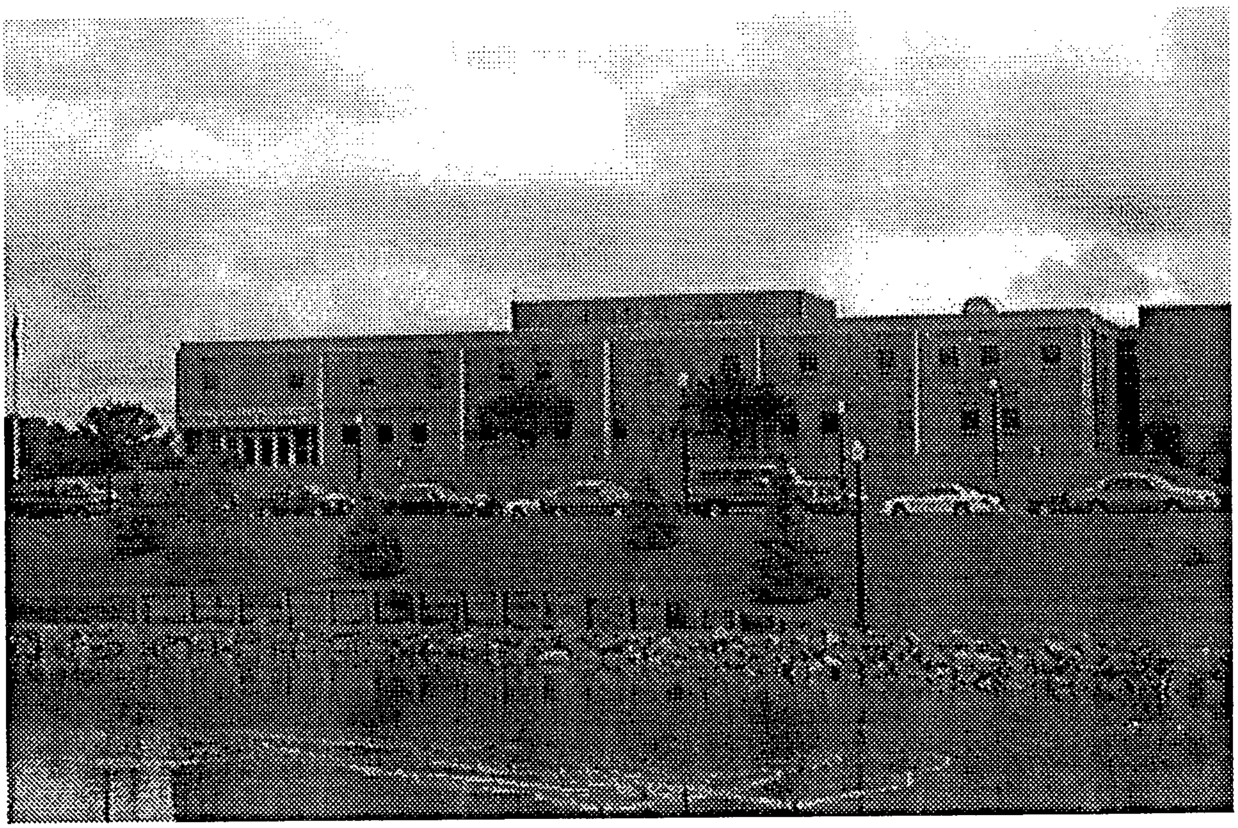

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## DISCLAIMER



## ACKNOWLEDGMENTS

This work was performed under the supervision of the SD97-09 Technical Panel:

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Jim Meyer ............................... W.R. Grace Products
Claus Smith .................................... Dacotah Cement
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16. Abstract

This report investigates compatibility problems involving two concrete admixtures from W.R. Grace Products and *Dacotah* portland cement. The problems experienced by the South Dakota Department of Transportation (SDDOT) are described as rapid slump loss, premature stiffening, and low compressive strengths. The materials investigated in this report are commonly used by the SDDOT in concrete construction projects.

The objectives of this report were to: 1) verify compatibility between Dacotah portland cement and selected concrete admixtures; 2) develop written guidelines for routine use of admixtures; and 3) familiarize DOT field personnel and contractors in South Dakota with the use of admixtures and their applications.

The objectives were met by performing mortar and concrete flow table tests to verify compatibility between Dacotah cement and a high-range water-reducing admixture and a retarder. The flow table tests were also used to determine an optimum time of addition for the admixtures. A five factorial statistical design to create thirty-three concrete mix designs was used in an effort to reproduce a compatibility problem. Finally, a field demonstration project was conducted to verify compatibility between the cement and admixtures under field conditions. Maximum dosages of each admixture during the field demonstration project was used in an attempt to create a compatibility problem. The addition time of the admixtures were varied to evaluate the performance of the admixtures. No general compatibility problems were found.


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## 1.0 EXECUTIVE SUMMARY

South Dakota Department of Transportation (SDDOT) field personnel have experienced concrete performance problems on construction projects. These problems have been identified as rapid slump loss, premature stiffening, and low compressive strengths. As a result, laboratory testing was conducted by the SDDOT Office of Research in 1992. SDDOT Study No. SD92-07 - ***"Evaluation of the Performance of Set Retarders and High-Range Water Reducers in Typical SDDOT Concrete Mixes"*** investigated these concrete performance problems by conducting a series of laboratory tests. The conclusion that resulted from this study was that the concrete performance problems experienced by SDDOT field personnel were the result of a compatibility problem between the cement and admixtures.

Ongoing concrete performance problems on SDDOT construction projects has compelled the SDDOT to make a decision to implement a directive prohibiting the use of many chemical admixtures. To resolve the concrete performance problems, SDDOT contracted with the South Dakota School of Mines and Technology (SDSM&T). Three primarily objectives were involved in this research project. First, to determine if the problems experienced by the SDDOT were the result of a compatibility problem between ***Dacotah*** brand portland cement having the higher $C_3S$ content and selected admixtures. Once the results of the research are determined, SDSM&T would provide written guidelines to SDDOT field personnel on the use of water-reducers, high-range water-reducing admixtures, set retarders and set accelerators. Finally, these guidelines could then serve an educational purpose to familiarize DOT field personnel and contractors in South Dakota with the use of admixtures and their applications

The objectives were accomplished with a combination of gathering literature and regional admixture usage data, laboratory, and field tests. A major portion of the research project focused on determining if a compatibility problem exists between ***Dacotah*** brand portland cement and the admixtures selected by SDDOT personnel.

## FINDINGS AND CONCLUSIONS

1. The regional questionnaire revealed that although a common cement source is shared by the six states surrounding South Dakota, no common problems exist in terms of

cement/admixture compatibility. A variety of problems were reported, but these were not necessarily compatibility problems.

2. Analysis of the thirty-three concrete mixture proportions showed that no incompatibility exists between ***Dacotah*** portland cements (Type I/II and V) and the high-range water-reducing admixture (***Daracem 100***) and the retarder (***Daratard 17***) from W.R. Grace Products, Inc.

3. The mortar flow table test combination of Type V ***Dacotah*** portland cement and HRWRA (***Daracem 100***) exhibit an optimum time of addition of the HRWRA to be at four minutes after water and cement contact.

4. Compatibility exists between the four combinations of cement types (Type I/II and Type V) and a HRWRA (***Daracem 100***) and a retarder (***Daratard 17***) as evidenced by the mortar and concrete flow table tests.

5. Concrete mortar flow table results as illustrated in Figures 5.0 and 6.0 show an improved performance with delayed addition of the HRWRA (***Daracem 100***) and retarder (***Daratard*** 17) admixtures. Improved flow with delayed addition, is illustrated on the vertical axis.

6. The field demonstration project verified compatibility between the admixtures (***Daracem 100*** and ***Daratard 17***) and ***Dacotah*** cement. The intent of the field demonstration was to verify the performance of the admixtures using maximum dosages, not to produce a "user-friendly" concrete.

7. As shown in Figure 13, during the field demonstration project the concrete mixture proportion using maximum dosage of HRWRA possessed a low w/c which resulted in a high early strength gain. The retarder concrete mixture exhibited a slow initial strength gain but surpassed the control mixture by the fifth day of monitoring compressive strengths.

8. As illustrated in Figure 14, the time of set test conducted during the field demonstration, on the concrete mixture proportion having a maximum dosage, exhibited a 34 hour initial set with a 2.5 minute delay prior to adding the retarder. Note: The ambient temperature was approximately 42 °F and given warmer conditions the time of set would be significantly less.

9. Broad guidelines can only suggest in advance which admixture could or should be used. Written guidelines to trouble-shoot any problem encountered with concrete are not possible due to the multitude of components and conditions which can affect concrete. Experience with a particular mixture is the best avenue to success.
10. Workability or other problems can occur any time, due to many things other than incompatibility.

## IMPLEMENTATION AND RECOMMENDATIONS

1. Cement/admixture performance problems should be evaluated on a case by case basis. Prior to incorporating an admixture into a concrete mixture, laboratory testing followed by a field trial to verify its compatibility and performance under field conditions should be done.
2. Use enclosed guidelines for training throughout SDDOT educational programs.
3. Incorporating admixtures into a concrete mixture proportions requires knowledge by all parties from the design engineer to the concrete finisher. A preconstruction educational session is strongly recommended. A higher level of quality control must be enforced when working with admixtures.
4. The existing admixture section in the SDDOT Specification Handbook is very broad and general and provides no clarification on the use of chemical admixtures. The following guidelines are proposed as changes to the SDDOT Specification Handbook, Section 752 "Chemical Admixtures for Concrete":
    - Anytime a chemical or mineral admixture is used in a concrete mixture a higher level of quality control is required before, during, and after construction.
    - Dosage rates should be utilized within the manufacturers recommendations to achieve the best performance level.
    - Laboratory tests to verify performance of the admixture should be performed followed by test pours.
    - Test pours should be conducted to simulate field conditions while using the exact materials and testing procedures that will be implemented during the construction.

- If concrete performance problems do occur the addition of the admixture may be delayed up to a maximum of two minutes after water contacts the cement.
- Mix designs and test results with statistical analysis shall be submitted to the engineer for approval.

5. If production methods will allow delayed addition of the admixture, a one to two-minute delay could be tried if concrete performance problems occur.
6. This research project was, in reality, the first step in what should be a three-step process. The focus of this project was to determine if there was a general compatibility problem between Dacotah cement and two admixtures, a high-range water-reducing admixture (***Daracem 100***) and a retarder (***Daratard 17***). This task was successfully accomplished. Step two, which is not part of this research project, should be to optimize the concrete mix design for maximum performance and minimum cost. The database is provided within this report and could be optimized for a 4000 and/or 5000 psi mix design. This could be done statistically, followed by laboratory trial batches, as demonstrated by DeMaro, Hansen, and Haeder [3]. Step three would be field trials of the optimized mix design conducted with a redi-mix producer, to create a "user-friendly" concrete.
7. Investigate the use of high-performance concrete in South Dakota. The high-performance mixtures for pavement, as defined by the Strategic Highway Research Program (SHRP), have been developed by Paulsen and Hansen [4] for crushed limestone, Sioux quartzite, and crushed granite.
8. SDDOT should develop and maintain an approved vendor list for admixtures. This list should include admixture companies and specific products which have been approved for use in South Dakota. The performance of new companies and products would have to be proven to SDDOT to be placed on the approved vendor list.
9. Only use mix designs that have an acceptable documented performance history. Do not include any admixtures that do not have a proven performance record.

## 2.0 PROBLEM DESCRIPTION

South Dakota Department of Transportation (SDDOT) field personnel have experienced concrete performance problems on construction projects. These problems have been identified as rapid slump loss, premature stiffening, and low compressive strengths. As a result, laboratory testing was conducted by the SDDOT Office of Research in 1992. SDDOT Study No. SD92-07 - ***"Evaluation of the Performance of Set Retarders and High-Range Water Reducers in Typical SDDOT Concrete Mixes"*** investigated these concrete performance problems by conducting a series of laboratory tests. The conclusion that resulted from this study was that the concrete performance problems experienced by SDDOT field personnel were the result of a compatibility problem between the cement and certain admixtures.

Ongoing concrete performance problems on SDDOT construction projects has compelled the SDDOT to make a decision to implement a directive prohibiting the use of many chemical admixtures. To resolve the concrete performance problems, SDDOT contracted with the South Dakota School of Mines and Technology (SDSM&T) to determine if the problems experienced by the SDDOT were the result of a compatibility problem between the cement and admixtures. Once the results of the research are determined, SDSM&T would provide written guidelines for use by SDDOT field personnel on the use of chemical admixtures. These guidelines could then serve an educational purpose for SDDOT personnel, contractors, and redi-mix producers working on SDDOT projects.

## 3.0 OBJECTIVES

The first objective of this research was to investigate the compatibility of the selected admixtures and ***Dacotah*** brand portland cement having the higher $C_3S$ content. Two admixtures were specified by SDDOT personnel for detailed investigation. Most of the effort in this project was to try to find the compatibility problems reported by SDDOT personnel in the lab and field. If compatibility problems were found, then an attempt would be made to "solve" the problem by delayed addition of the admixture.

The second objective was to develop a set of guidelines for routine use of admixtures, including water-reducers, high-range water-reducing admixtures, set retarders and set accelerators. The final objective was to familiarize SDDOT field personnel and contractors in South Dakota with the use of admixtures and their applications.

# 4.0 TASK DESCRIPTION

## 4.1 Research Task 1

Task 1 comprised of meeting with the technical panel to review the project scope and discuss work plan. On February 14, 1997 a research contract between the South Dakota Department of Transportation and the South Dakota School of Mines and Technology was signed.

## 4.2 Research Task 2

Task 2 involved several subtasks such as collecting information by means of a literature review, compiling information from admixture products and technical literature, and examining the SDDOT specifications. The final subtask was to prepare a questionnaire for surrounding states to request information of problems encountered using primarily high-range water-reducing admixtures and retarders.

A literature review was conducted to gather information on a compatibility problem. Several sources agreed that compatibility problems do occur due to the fact that **every type** of cement will not be compatible with **ever type** of admixture. Another important point of the literature review was that many concrete performance problems are haphazardly reported as compatibility problems between cement and admixtures when in reality the real problem may have been incorrect batching procedure or a malfunction of the redi-mix plant.

To examine regional admixture usage, a questionnaire was developed to collect information such as the types of cement and admixtures used in each state. The questionnaire primarily focused on high-range water-reducing and retarder admixtures. Appendix A contains the questionnaire and tabulated results. The questionnaire was compiled and mailed to the state surrounding South Dakota (North Dakota, Minnesota, Iowa, Nebraska, Wyoming, and Montana). Two of six states do not use retarders or high range water-reducing admixtures. Two states commented on problems using certain combinations of cement and chemical admixtures but did not target a specific cement or admixture. One similarity seen across all six states was the use of cement from Holnam cement company. States that experienced problems with rapid slump loss or premature stiffening reported that lack of agitation such as the use of a dump truck for paving purposes. This problem addressed the source of the problem and did not attribute this to a compatibility problem between a certain type of cement and an admixture. In general, no common problems were apparent among the six states surveyed.

## 4.3 Research Tasks 3 and 4

Duties for tasks 3 and 4 were as follows:

1. obtain materials such as cement, aggregates, and admixtures,
2. characterize aggregates for gradation, specific gravity, and absorption,
3. perform lab tests to find and control compatibility problems,
4. perform lab tests using the new Dacotah cement with a higher $C_3S$ content in present SDDOT mixes, and
5. develop a work plan to performing tests such as time of set, flow table tests, air content, slump, temperature, unit weight, and compressive strengths at 1, 3, 7, and 28 days.

To accomplish these tasks, first the materials were obtained for the research project. The decision was made with SDDOT personnel to investigate only one high-range water-reducing admixture and one retarder from W.R. Grace Products. These were selected because it was the most common admixture used by the SDDOT. It should be noted that, the way this project evolved, the majority of the effort was to try to find the suspected compatibility problem. Below are the research materials used for this project.

### 4.3.1 Cement

***Dacotah*** portland cement manufactured by the South Dakota Cement Plant in Rapid City, South Dakota is the primary source of cement used during construction of projects for the South Dakota Department of Transportation (SDDOT). Two types of portland cement were selected for this research project. The first type is a Type I/II type of portland cement commonly used by the SDDOT. The second type is a Type V portland cement which has a somewhat different chemical composition.

### 4.3.2 Chemical Admixtures

The chemical admixtures to be tested were selected based on the products currently used by the SDDOT. A high-range water-reducing admixture(***Daracem 100***) and a retarder(***Daratard 17***) from W.R. Grace Products, Inc. were chosen for this research. The admixtures were used at maximum dosage rates in an effort to create the problematic symptoms experienced by the SDDOT.

#### 4.3.2.1 High-Range Water-Reducing Admixture

A high-range water-reducing admixture (HRWRA) named ***Daracem 100*** from W.R. Grace Products was used for this research project. The purpose of using a HRWRA is to increase slump to produce a flowing concrete which is beneficial when used in heavily reinforced structures such as bridge columns. Another benefit of using a HRWRA is that a lower water-cement ratio can be utilized which in turn produces higher compressive and flexural strengths.

The addition rate recommended by W.R. Grace Product literature is variable based on job requirements. A normal dosage range is between 325 to 1300 mL/100 kg (5 to 20 oz/100 lb) of cement.

Use of this HRWRA in the lower dosage range meets requirements for an ASTM C494 Type F high-range water-reducing admixture. In the upper dosage range, it meets the requirements for an ASTM 494 Type G water-reducing, high-range and retarding admixture.

#### 4.3.2.2 Retarder Admixture

A retarder admixture named ***Daratard 17*** from W.R. Grace Products, Inc. was selected for this research. ***Daratard 17*** is an aqueous solution of hydroxylated organic compounds. Retarders are used on projects where high temperatures or extended setting times are primary factors.

The addition rate recommended by W.R. Grace Product literature varies between 130 to 520 mL/100 kg (2 to 8 fl oz/100 lb) of cement. Daratard 17 complies with ASTM C 494, Type D admixture.

#### 4.3.2.3 Air-Entraining Admixture

An air-entraining admixture name ***Daravair 1000*** from W.R. Grace Products was selected to be used in all laboratory and field tests. The addition rate recommended by W.R. Grace Product literature varies between 50 to 200 mL/100 kg (3/4 to 3 fl oz/100 lbs) of cement.

### 4.3.3 Aggregates

Three-quarter inch maximum Minnekahta limestone was used for the coarse aggregate. The fine aggregate consisted of well-graded sand acquired from Oral, South Dakota. Fine and coarse aggregates used solely for laboratory testing were obtained from Pete Lien, Inc., Rapid City, South Dakota. Fine and coarse aggregate used during the field demonstration portion of this project samples were obtained from Birdsall Sand and Gravel in Rapid City, South Dakota.

The next step after the selection of the research materials was to characterize the aggregates. Aggregate was characterized according to ASTM C 127 and C 128; specific gravity and absorption, ASTM C 566; moisture, and ASTM C 136; sieve analysis. Results from the sieve analysis can be seen in reference 1. Results from the characterization of the coarse and fine aggregate are illustrate in Table 1.

**Table 1 Results from the characterization of aggregates used in laboratory tests and field demonstration project.**

| Aggregate | Aggregate Type | Aggregate Size | Aggregate Source | Moisture (%) | Specific Gravity | Absorption (%) |
|---|---|---|---|---|---|---|
| Coarse | Minnekahta limestone | 3/4 in. | Birdsall Sand & Gravel, Rapid City, SD | 0.14 | 2.71 | 0.72 |
| Coarse | Minnekahta limestone | 3/4 in. | Pete Lien, Inc., Rapid City, SD | 0.48 | 2.82 | 0.77 |
| | | | | | | |
| Fines | Sand | well-graded | Birdsall Sand & Gravel, Rapid City, SD | 2.66 | 2.61 | 1.08 |
| Fines | Sand | well-graded | Pete Lien, Inc., Rapid City, SD | 1.73 | 2.60 | 1.11 |

The next three duties for tasks 3 and 4 were combined within several tests.

- To perform laboratory tests to find and control the compatibility problem between the cement and admixtures,
- utilize the new Dacotah cement, and
- to develop a work plan to performing tests such as time of set, flow table tests, air content, slump, temperature, unit weight, and compressive strengths at 1, 3, 7, and 28 days.

These tests were a series of mortar flow table tests, hand-sieved concrete mortar flow table tests, and the use of a five factorial statistical design method to create a variety of concrete mixtures. Note that the time of set test was incorporated into Task 5 (Field Demonstration).

#### 4.3.4 Mortar Flow Table Tests

The purpose of conducting the mortar flow table test was two-fold. First, the mortar flow table test would be used to evaluate compatibility between a combination of two types of cement and chemical admixtures. Secondly, by using an admixture in this test and varying the time of addition, the optimum time of addition could be determined which would result in the maximum flowing characteristics. This test was conducted according to ASTM C 230 and C305.

Four combinations of Type I/II and Type V Dacotah cement and a high range water-reducing admixture and retarder was used for this test. The time of addition of the admixture was varied throughout the test in increments of one-minute (0,1,3,4,5,6,7). In this test, time zero is referred to as the time when water and cement contact. The two-minute time increment was not included due to the mixing sequence in ASTM 305 which was a rest period.

The optimum time of addition for three of the four combinations was at time zero when water and cement met. The Type V cement and HRWRA combination produced an optimum time of addition at 4 minutes after water and cement met. Mixture proportions for each combination of cement and admixture is listed in the legend of each graph. Graphical results from the mortar flow table tests are illustrated in Figs. 1 - 4.

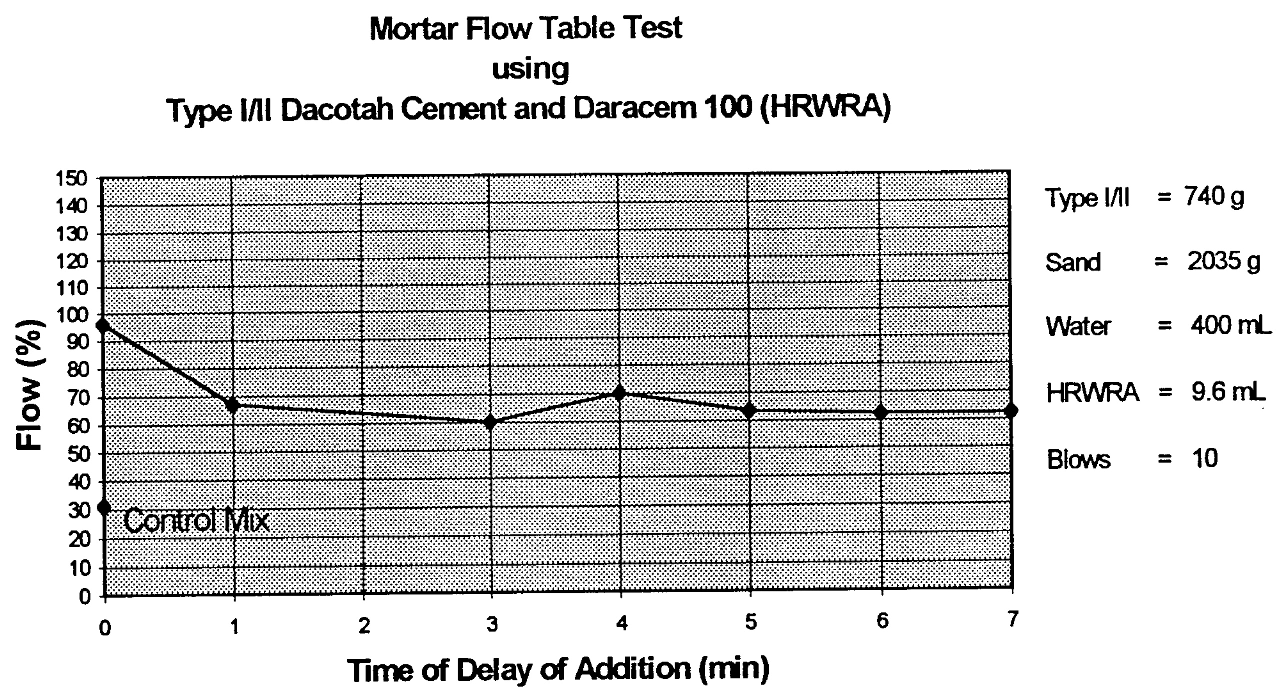



**Fig. 1** Mortar flow table test results using Type I/II *Dacotah* portland cement and a high-range water-reducing admixture (*Daracem 100).*

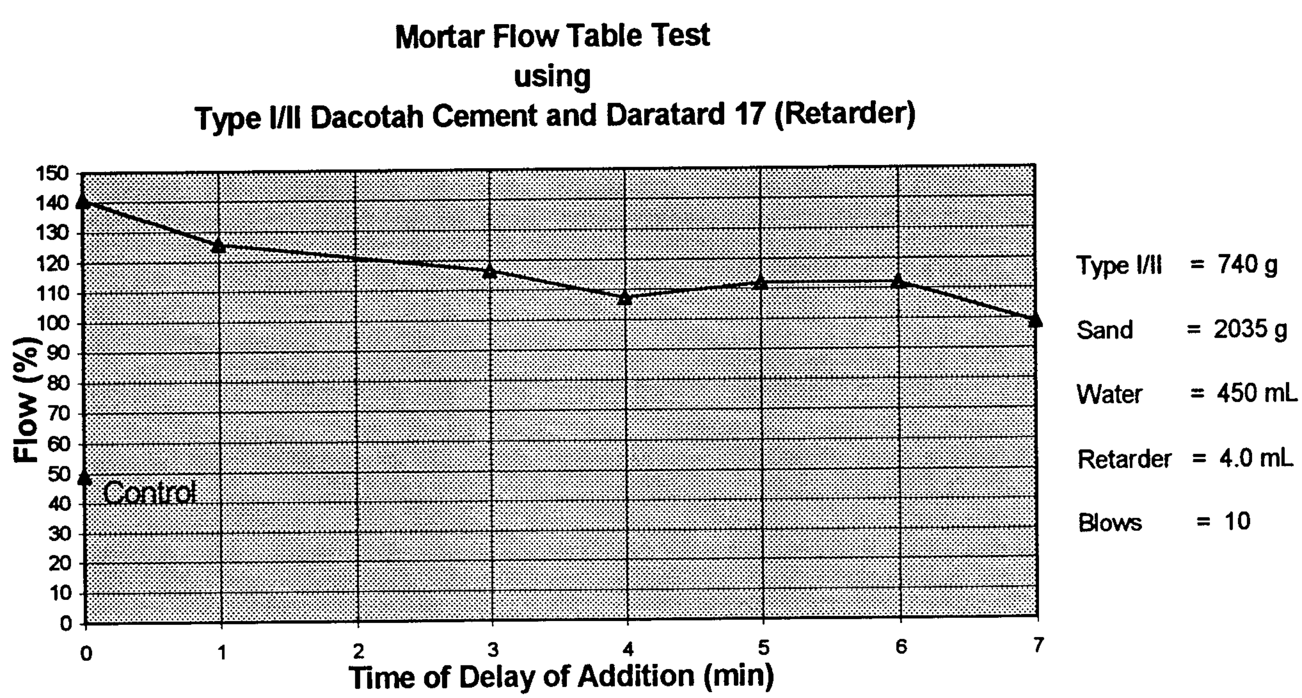



**Fig. 2** Mortar flow table test results using Type I/II *Dacotah* portland cement and a retarder (*Daratard 17).*

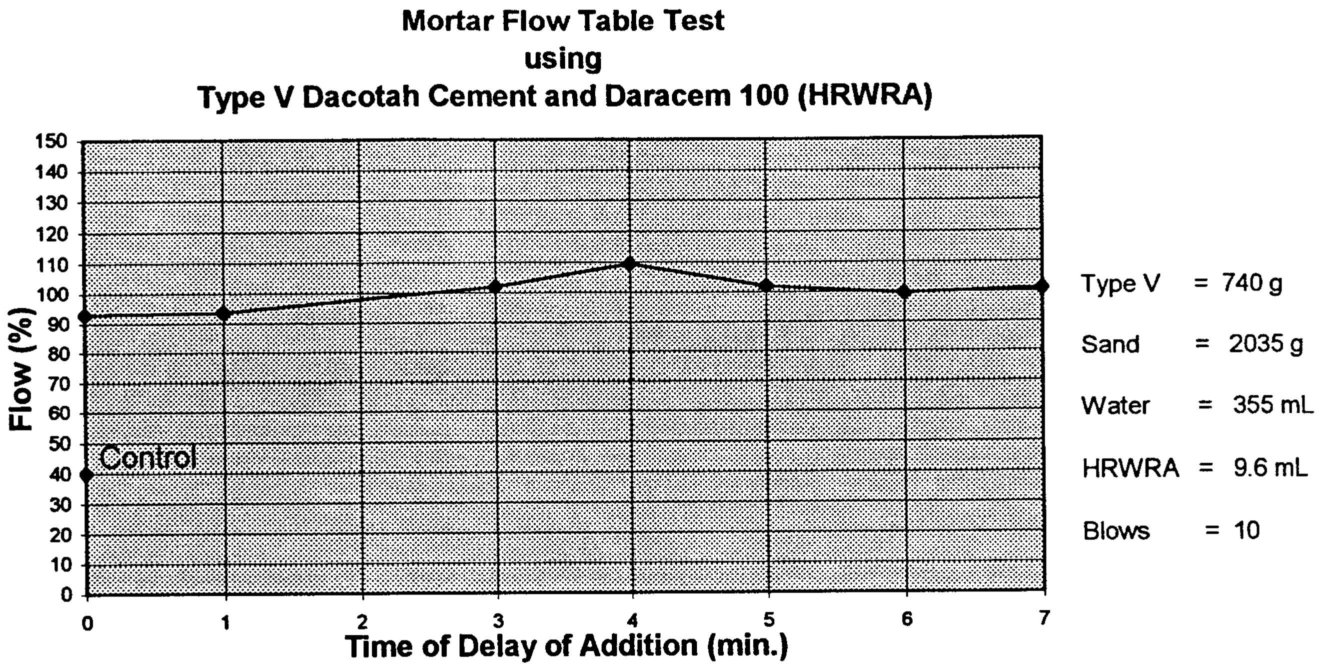



**Fig. 3** **Mortar flow table test results using Type V *Dacotah* portland cement and a high-range water-reducing admixture (*Daracem 100*).**

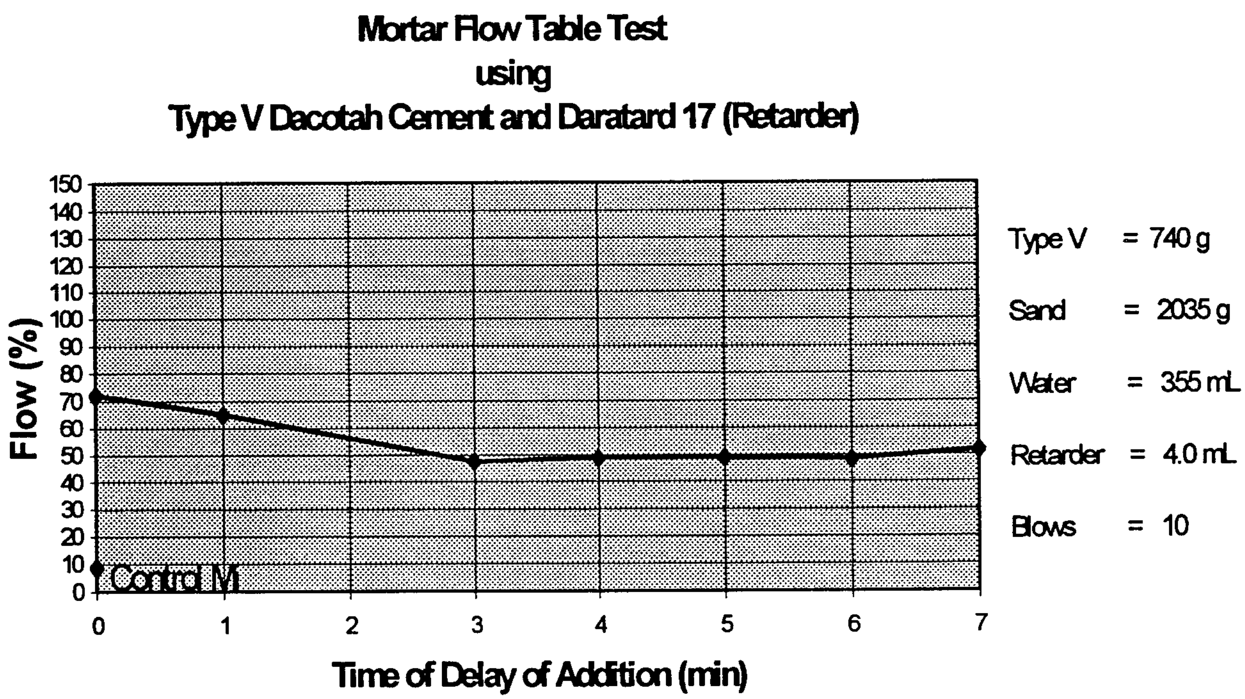



**Fig. 4** **Mortar flow table test results using Type V *Dacotah* portland cement and a retarder (*Daratard 17*).**

### 4.3.5 Concrete Flow Table Tests

Concrete mortar flow table tests were also performed and the results can be seen in Fig. 5-6. Type V Dacotah cement was exclusively used in this test after consultation with SDDOT personnel. The test was done using Type V cement and a high range water-reducing admixture (***Daracem 100***). A control mixture was established followed by three additional mixtures. The HRWRA was added at three different time intervals (0, 1, and 2 minutes). Time zero is defined as the time when water and cement contact. The concrete was hand sieved and the mortar was tested using a flow table at 10, 20, and 30 minutes after water contacted cement. As illustrated in Figs. 5 and 6, each one-minute delay prior to adding the admixture exhibited an improved performance. Thereafter, a downward trend in terms of flow versus time can be seen and would be expected. These tests were repeated using a retarder (***Daratard 17***) and Type V cement. A similar trend in terms of flow of the mortar was seen.

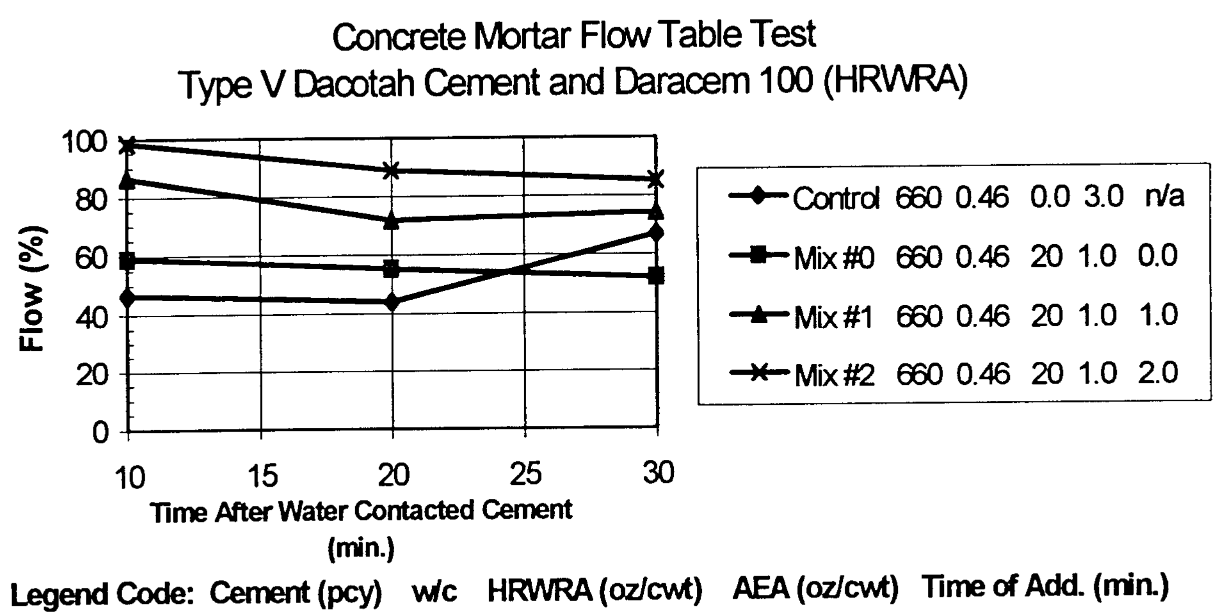



**Fig. 5** Mortar flow table test results using Type V *Dacotah* portland cement and *Daracem 100* high-range water-reducing admixture.

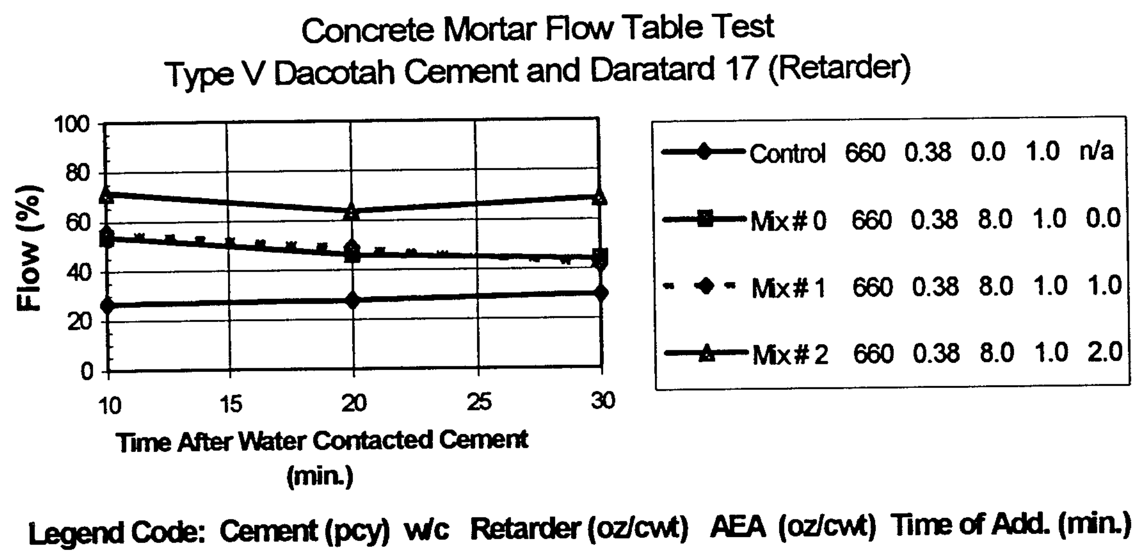



**Fig. 6** **Mortar flow table test results using Type V *Dacotah* portland cement and *Daratard 17* retarder admixture.**

### 4.3.6 Five Factorial Central Composite Statistical Design

Investigating possible compatibility problems between a cement and an admixture requires the use of an analysis tool that will allow the researcher to efficiently gather data with a reduced amount of time and materials. To successfully accomplish this task, the researcher implemented a "5 factor central composite statistical design broken into 3 blocks of 11 runs" adapted by John Luciano [2] from Master Builders Technologies. "This design is useful in fitting a quadratic model to a response using linear regression techniques[2]."

To control experimental error or "noise" the statistical design incorporated blocking. This statistical design creates three blocks with eleven concrete mixtures in each block.

Randomization was also an essential component to the 5 factor central composite statistical design to define experimental error. Each block randomized the order of mixing each concrete mixture proportion to reduce biases such as ambient temperature and other uncontrollable environmental conditions.

Five independent variables were defined by the researcher as being most significant in potentially causing compatibility problems. The independent variables were the HRWRA dosage (A), water-cement ratio (B), % blend of Type I/II and Type V cement (C), total cement content (D), and mixing time after the HRWRA dosage was added (E). The experimental region for each independent variable was also defined by the researcher on the basis of common concrete mixture proportion techniques. The five independent variables and experimental regions are illustrated in Table 2.

**Table 2 Independent variables and experimental regions**

| FIVE INDEPENDENT VARIABLES | EXPERIMENTAL REGION | | | | |
|---|---|---|---|---|---|
| | - 2 | - 1 | Middle Value | + 1 | + 2 |
| **Dosage of HRWRA (A) (oz/cwt)** | 0 | 1.25 | 2.50 | 3.75 | 5.00 |
| **W/C (B)** | 0.41 | 0.43 | 0.45 | 0.47 | 0.49 |
| **% Blend of Type I/II and V (C) (%)** | 0 / 100 | 25 / 75 | 50 / 50 | 75 / 25 | 100 / 0 |
| **Cement Quantity (D) (pcy)** | 470 | 564 | 658 | 752 | 846 |
| **Mixing Time (E) (min.)** | 1 | 2 | 3 | 4 | 5 |

Using John Luciano's template, thirty-three concrete mixture proportions were created by varying the independent variables from a middle value, in increments of +1, -1, +2, -2. Each variable has a unique value that corresponds to one increment. For example, the incremental value for the water-cement ratio (w/c) is 0.02 while the cement quantity's increment is 94 pcy and so on.

A list of the batch quantities for the independent variables of the thirty-three concrete mixture proportions can be seen in Table 3. A detailed spreadsheet of concrete batch quantities and wet and hardened concrete test results can also be seen the Appendix B.

**Table 3 Template of independent variables for the thirty-three concrete mixtures**

| | FIVE INDEPENDENT VARIABLES | | | | | QUANTITY OF EACH CEMENT | |
|---|---|---|---|---|---|---|---|
| MIX NO. | HRWRA (oz/cwt) A | W/C B | (% Type I / II and % Type V) % BLEND (%) C | TOTAL CEMENT (pcy) D | MIX TIME (min.) E | TYPE I CEMENT (pcy) | TYPE V CEMENT (pcy) |
| 1 | 1.25 | 0.47 | 75 / 25 | 564 | 2 | 423 | 141 |
| 2 | 3.75 | 0.43 | 25 / 75 | 564 | 4 | 141 | 423 |
| 3 | 1.25 | 0.47 | 75 / 25 | 752 | 4 | 564 | 188 |
| 4 | 3.75 | 0.43 | 25 / 75 | 752 | 2 | 188 | 564 |
| 5 | 3.75 | 0.43 | 75 / 25 | 564 | 2 | 423 | 141 |
| 6 | 1.25 | 0.47 | 25 / 75 | 564 | 4 | 141 | 423 |
| 7 | 3.75 | 0.43 | 75 / 25 | 752 | 4 | 564 | 188 |
| 8 | 1.25 | 0.47 | 25 / 75 | 752 | 2 | 188 | 564 |
| 9 | 2.5 | 0.45 | 50 / 50 | 658 | 3 | 329 | 329 |
| 10 | 2.5 | 0.45 | 50 / 50 | 658 | 3 | 329 | 329 |
| 11 | 2.5 | 0.45 | 50 / 50 | 658 | 3 | 329 | 329 |
| 12 | 3.75 | 0.47 | 75 / 25 | 564 | 4 | 423 | 141 |
| 13 | 1.25 | 0.43 | 25 / 75 | 564 | 2 | 141 | 423 |
| 14 | 3.75 | 0.47 | 75 / 25 | 752 | 2 | 564 | 188 |
| 15 | 1.25 | 0.43 | 25 / 75 | 752 | 4 | 188 | 564 |
| 16 | 1.25 | 0.43 | 75 / 25 | 564 | 4 | 423 | 141 |
| 17 | 3.75 | 0.47 | 25 / 75 | 564 | 2 | 141 | 423 |
| 18 | 1.25 | 0.43 | 75 / 25 | 752 | 2 | 564 | 188 |
| 19 | 3.75 | 0.47 | 25 / 75 | 752 | 4 | 188 | 564 |
| 20 | 2.5 | 0.45 | 50 / 50 | 658 | 3 | 329 | 329 |
| 21 | 2.5 | 0.45 | 50 / 50 | 658 | 3 | 329 | 329 |
| 22 | 2.5 | 0.45 | 50 / 50 | 658 | 3 | 329 | 329 |
| 23 | 0 | 0.45 | 50 / 50 | 658 | 3 | 329 | 329 |
| 24 | 5.0 | 0.45 | 50 / 50 | 658 | 3 | 329 | 329 |
| 25 | 2.5 | 0.41 | 50 / 50 | 658 | 3 | 329 | 329 |
| 26 | 2.5 | 0.49 | 50 / 50 | 658 | 3 | 329 | 329 |
| 27 | 2.5 | 0.45 | 100 / 0 | 658 | 3 | 658 | 0 |
| 28 | 2.5 | 0.45 | 0 / 100 | 658 | 3 | 0 | 658 |
| 29 | 2.5 | 0.45 | 50 / 50 | 470 | 3 | 235 | 235 |
| 30 | 2.5 | 0.45 | 50 / 50 | 846 | 3 | 423 | 423 |
| 31 | 2.5 | 0.45 | 50 / 50 | 658 | 1 | 329 | 329 |
| 32 | 2.5 | 0.45 | 50 / 50 | 658 | 5 | 329 | 329 |
| 33 | 2.5 | 0.45 | 50 / 50 | 658 | 3 | 329 | 329 |

Wet concrete properties were tested for each mixture proportion. Primarily, the focus of testing the wet concrete properties of each mixture was to look at the difference in air content and slump after the addition of the HRWRA. In order to determine whether the concrete mixture was exhibiting compatibility problems, the research team followed the definition of a HRWRA compatibility problem given by SDDOT personnel. A HRWRA compatibility problem was defined as "no increase in slump with a decrease in air content, after the addition of the HRWRA."

During the mixing sequence, a sample of concrete was taken and tested according to ASTM C 231, C 1064, C 138, and C 143 for air, temperature, unit weight, and slump. The high-range water-reducing admixture was then added to the mixture and the mixing sequence continued for a specified time. The tests were repeated to determine the difference in wet properties with and without the HRWRA. Cylinders measuring 4 by 8 in. (10 by 20 cm) were cast and cured according to ASTM C 192 for compressive testing at 1, 3, 7, and 28 days.

The general compatibility problem defined by the SDDOT involved rapid slump loss, premature stiffening, and low compressive strengths. As a result, the main focus of this statistical analysis were three response variables: change in slump, change in air content and the 28-day compressive strength.

Histograms were created to illustrate the effect of adding a HRWRA to the concrete on the slump and air content. A histogram of 28-day compressive strength was also generated to show the strength properties of concrete using a HRWRA.

The histogram in Fig. 7 illustrates the increase in slump due to the addition of the HRWRA to the concrete mixtures. This was the behavior predicted by the researcher based on the literature review on the use of HRWRA in concrete.

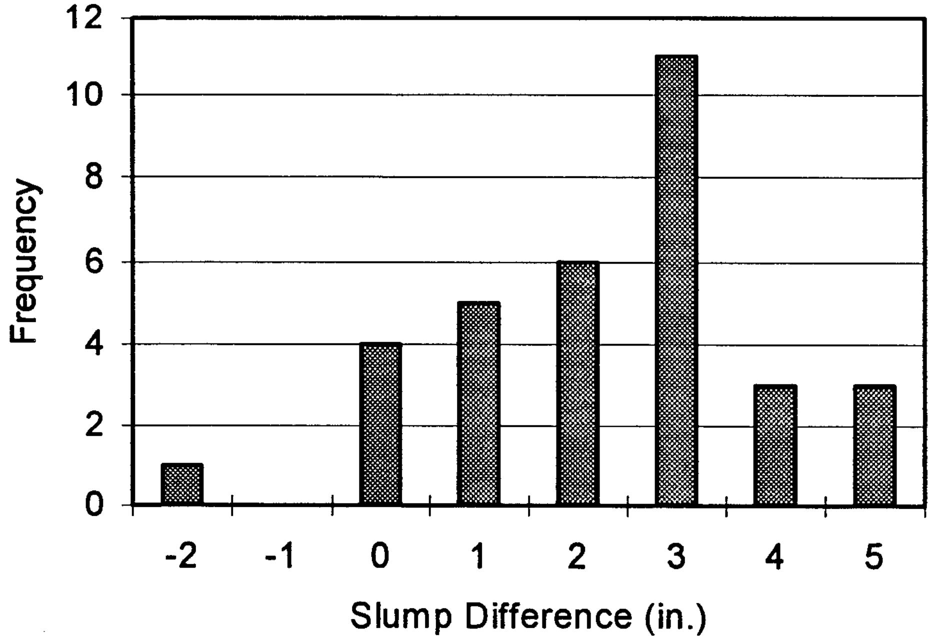



**Fig. 7** **Histogram of change in slump in thirty-three concrete mixtures.**

The histogram shown in Fig. 8 for the response variable named change in air content (Air Difference), illustrates the pattern that occurred as a result of adding the HRWRA to the concrete mixture followed by a varied mixing times. A typical trend for air content follows a pattern of an increase in slump produces an increase in air content. However, these results appear to resemble a normal distribution.

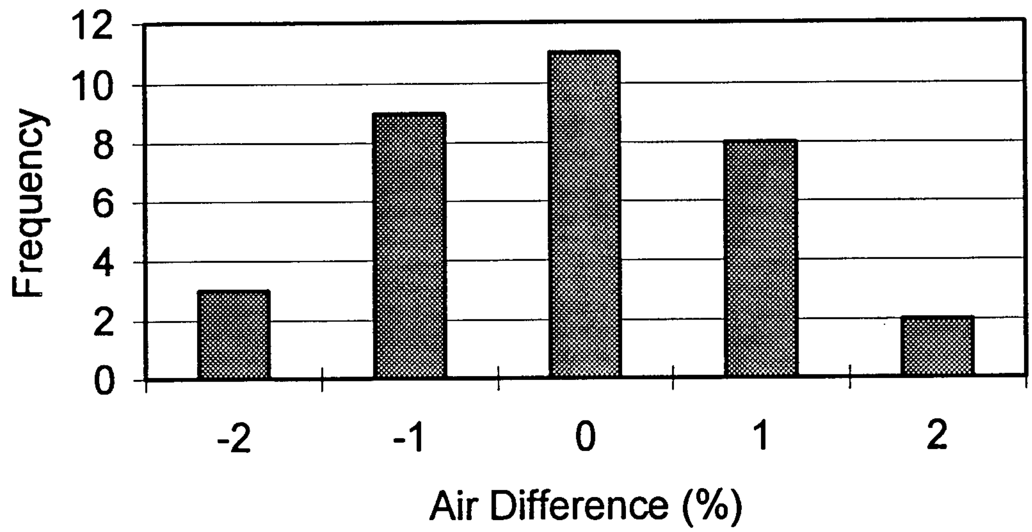



**Fig. 8** **Histogram of change in air content for the thirty-three concrete mixtures**

The histogram for the 28-day compressive strength reveals that the design strength of 4000 psi was met, except for 2 out of 33 concrete mixtures. The histogram shown in Fig. 9 was plotted for the 28-day compressive strength to illustrate the strength properties of concrete using a HRWRA.

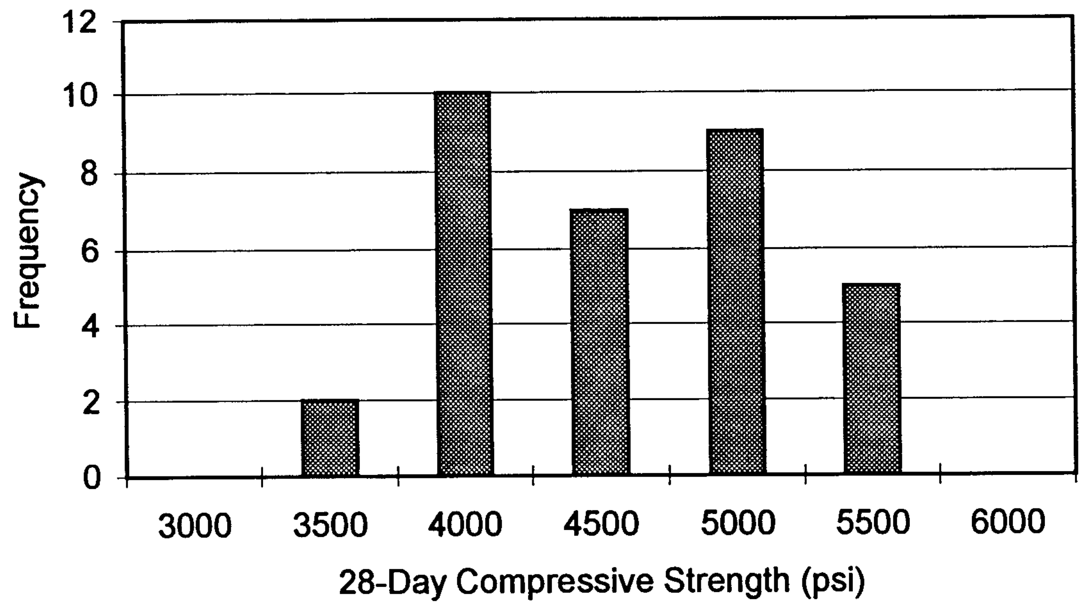



**Fig. 9** **Histogram of 28-day compressive strengths of thirty-three concrete mixtures.**

Table 4 shows the mixture proportions for the 3 highest 28-day compressive strength mixtures. This data displays that two different combinations of Type I/II and Type V cement and a moderate dosage of HRWRA will produce a concrete that will meet the design strength set by the SDDOT. These mixtures did not exhibit any signs of a general compatibility problem between either types of cement and the HRWRA.

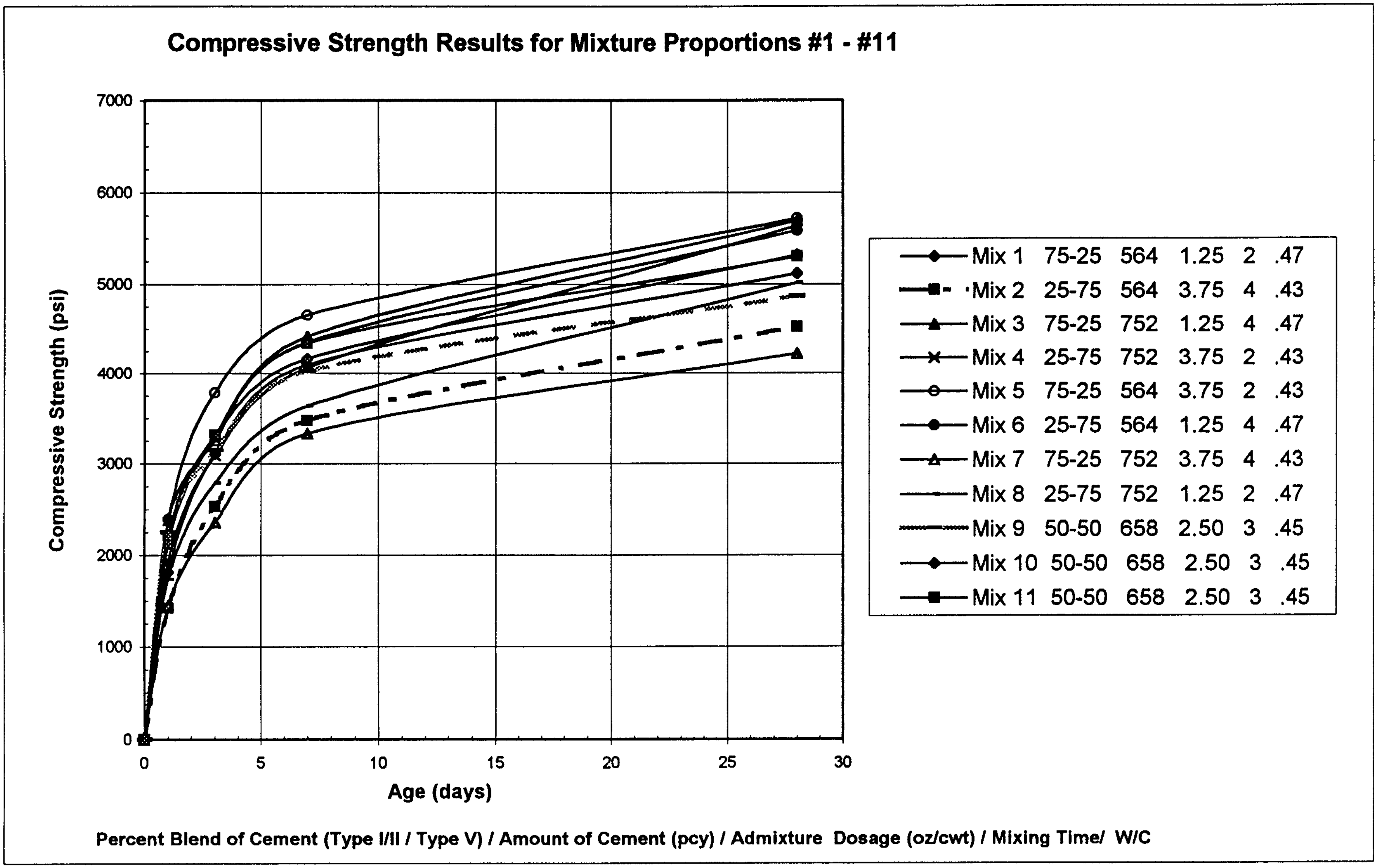
**Table 4 The highest 28-day compressive strength of each block.**

| Mix Id | Block No. | Comp. Strength psi (MPa) | Blend Cement I/II / V (%) | Total Cement (pcy) | HRWRA dose (oz/cwt) | Mixing Time (min.) | W/C |
|---|---|---|---|---|---|---|---|
| # 5 | 1 | 5716 (39.41) | 75/25 | 564 | 3.75 | 2 | 0.43 |
| # 22 | 2 | 5398 (37.22) | 50/50 | 658 | 2.50 | 3 | 0.45 |
| #25 | 3 | 5809 (40.05) | 50/50 | 658 | 2.50 | 3 | 0.41 |

The graphical data of 28-day compressive strengths for each block illustrate that all 33 concrete mixtures exhibited typical behavior in terms of strength gain. While two out of thirty-three concrete mixtures did not meet the design strength of 4000 psi, all mixtures displayed typical plastic concrete properties such as good workability and finishability during the tests for air content, slump, unit weight, temperature, and cylinders.

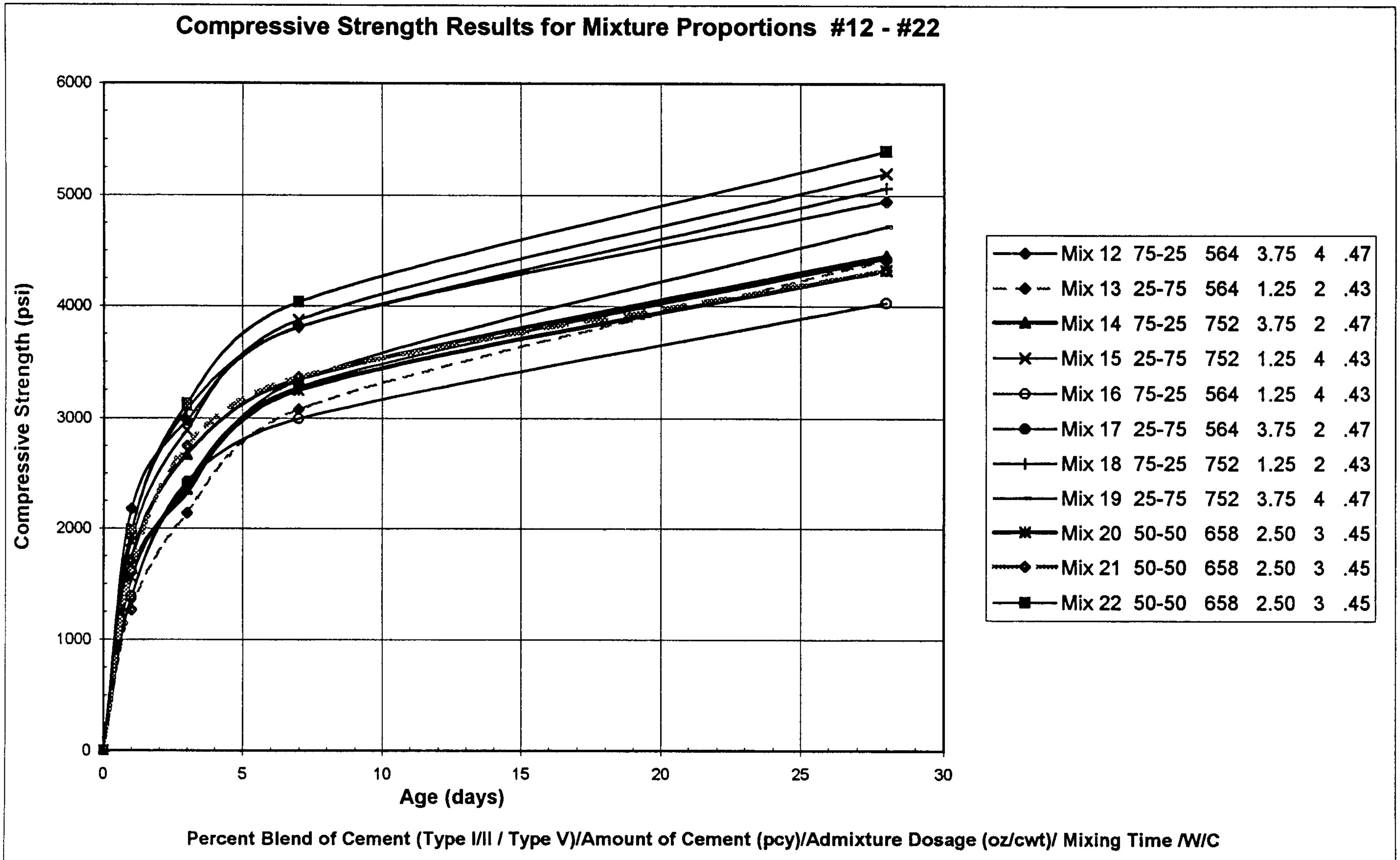
The legend of each graph gives the mix identification number followed by the quantities of the five independent variables as illustrated in Table 3. The first independent variable shown after the mix identification number in the legend is the percentage blend of Type I/II and Type V cement. The second is the cement quantity in pounds per cubic yard followed by the admixture dosage in ounces per hundred weight of cement. The fourth and fifth independent variable respectively, is the mixing time after the admixture was added to the concrete mixture and the water-cement ratio.

Complete test results are presented in Appendix B. This database could be used to optimize the mixtures for minimum cost and maximum performance, as illustrated by DeMaro, Hansen, and Haeder [3]. Compressive strength results are illustrated in Figs. 10, 11, and 12.



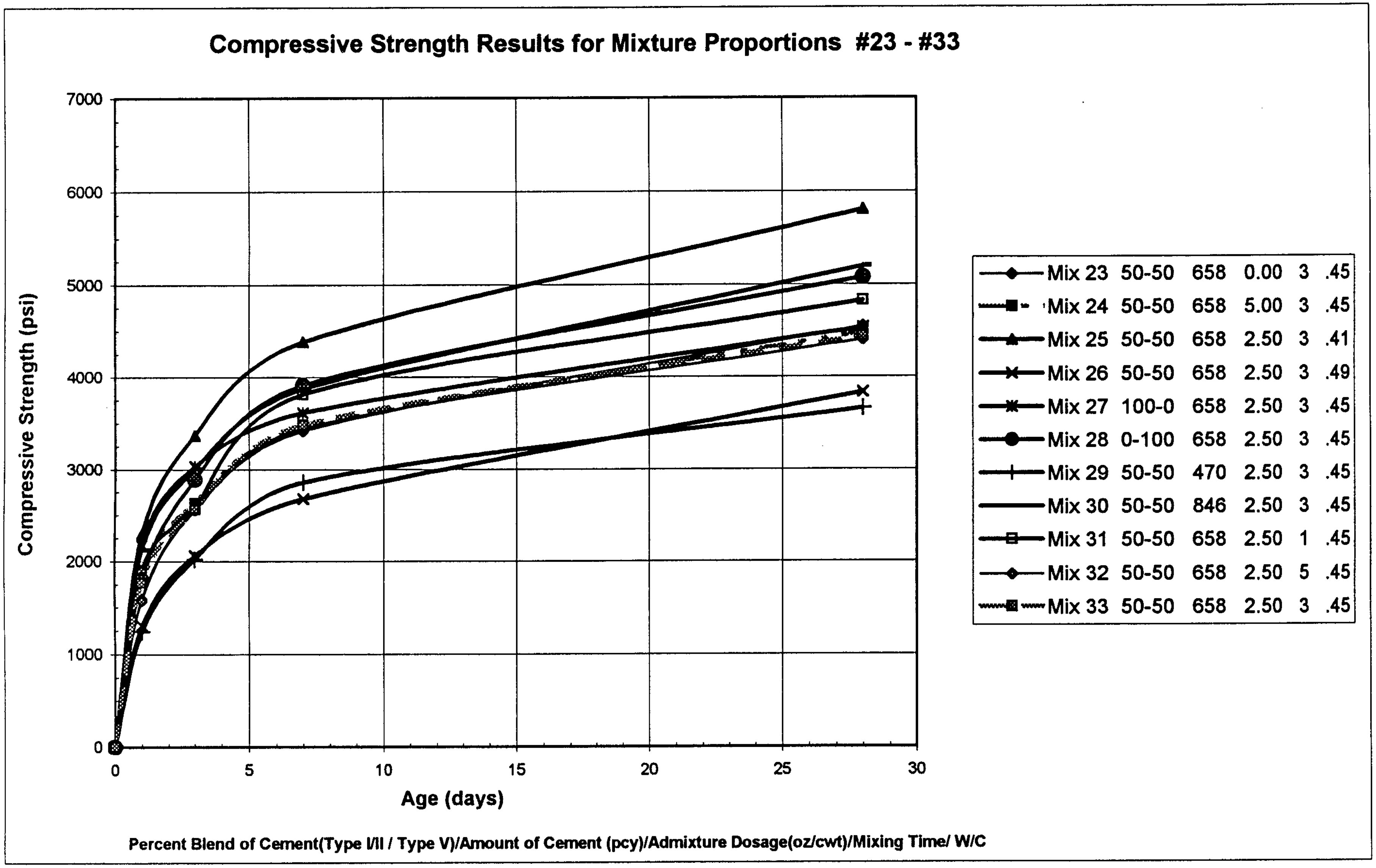

1 psi = 0.006894 MPa

**Fig. 10** Compressive strengths of 4 x 8 in. cylinders cast for concrete mixture proportions #1 - #11 on day 1 (block 1).




1 psi = 0.006894 MPa

**Fig. 11** Compressive strengths of 4 x 8 in. cylinders cast for concrete mixture proportions #12 - #22 on day 2 (block 2).




1 psi = 0.006894 MPa

Fig. 12 Compressive strengths of 4 x 8 in. cylinders cast for concrete mixture proportions #23 - #33 on day 3 (block 3).

The 5 factor central composite statistical design used to performed a backward stepwise regression analysis on the data set indicated that none of the independent variables produced a compatibility problem. The regression analysis indicated the main and interaction effects of the independent variables for the three models. These independent variables are typically used in concrete with no adverse results. In general, the behavior of the 33 concrete mixtures with a HRWRA was typical and expected by the researcher based on previous literature.

## 4.4 Research Tasks 5 and 7

Tasks 5 and 7 were combined. A meeting was held with the technical panel to review the work plan and status of the research project. This meeting was held on April 7, 1997. In addition, Task 5 proposed that a field study site be located around the Rapid City area. This study site would be used as a field demonstration in an effort to force a compatibility problem to occur under field conditions. SDDOT would provide 50,000 lb of cement that had been previous determined to cause a compatibility problem. A redi-mix plant would provide the concrete for this field demonstration. Task 7 outlines the quantity of concrete the SDDOT would provide for the field demonstration.

As a result of the laboratory testing, Dacotah cement was found to be compatible with the admixtures tested and therefore did not cause a compatibility problem under laboratory conditions. Type I/II ***Dacotah*** cement, ***Daracem 100*** (high-range water-reducing admixture), ***Daratard 17*** (retarder), and ***Daravair 1000*** (air-entraining admixture) was used for this field demonstration. In addition, the same aggregate, Minnekahta limestone and sand, as defined in Task 4, was used.

In an effort to create a compatibility problem under field conditions, maximum dosage rates of the HRWRA and retarder admixtures were used. Also, the addition times of the HRWRA and retarder were varied in an attempt to investigate the behavior of the concrete. The workability of the concrete was not an issue in this field demonstration project. The workability can be poor without a compatibility problem occurring.

### 4.4.1 Field Demonstration

After extensive searching for a project that would accept this experimental concrete, Dacotah Cement agreed that the experimental concrete could be utilized for an existing unpaved employee parking lot, provided that the concrete was properly protected from the weather and achieved (4000 psi) strength. Dacotah Cement selected Stanley Johnson as the contractor. The decision was made to place the concrete in 3 bays. This decision best fit the demonstration project goals of utilizing a combination of three different concrete mixes. The concrete for the project was supplied by a central redi-mix plant, Birdsall Sand and Gravel (BSG) of Rapid City. Concrete for the project was mixed in three batches with the first serving as a control mix (concrete with no admixture except air entraining agent), the second mix had a maximum dosage of high range water reducer and the third mix was batched with a maximum dosage of retarder.

The addition of chemical admixtures to the concrete batch was done manually by personnel at the redi-mix plant. Delay times were carefully recorded and varied as illustrated in Table 5. The delay times were selected to cover the critical time period during which compatibility problems may arise.

**Table 5 Time of delay for the three different concrete mixtures.**

| Field Demonstration Nov. 18 & 20, 1997<br>Dacotah Cement Rapid City, SD | |
|---|---|
| **LOAD #** | **Time of Delay Prior to Adding Chemical Admixture (min)** |
| Control # 1 | - |
| Control # 2 | - |
| Control # 3 | - |
| HRWR # 1 | 1.00 |
| HRWR # 2 | 1.25 |
| HRWR # 3 | 1.50 |
| HRWR # 4 | 1.75 |
| HRWR # 5 | 2.00 |
| Retarder # 1 | 2.50 |
| Retarder # 2 | 1.00 |
| Retarder # 3 | 1.25 |
| Retarder # 4 | 1.50 |
| Retarder # 5 | 1.75 |

**NOTE:** Time of delay is defined by the time period elapsed until the chemical admixture is added to the concrete, once water and cement are mixed together.

Concrete testing was performed at both BSG and Dacotah Cement to measure the effects of the chemical admixtures. These tests included unit weight, slump, temperature, and air content. Cylinders were cast at the construction site from the control, high range water reducer and retarder batches for acceptance testing. The acceptance test cylinders were placed in a curing box for the first twenty-four hours, returned to the laboratory, and cured per ASTM. These cylinders were tested for 7 and 28 day compressive strength. An additional eighteen cylinders were cast and were placed next to the slab, under the tarp, to simulate field conditions. Cylinders were taken from under the tarp each day, for seven days, and tested to monitor strength gain. Results are shown in Fig. 13 and Table 6.

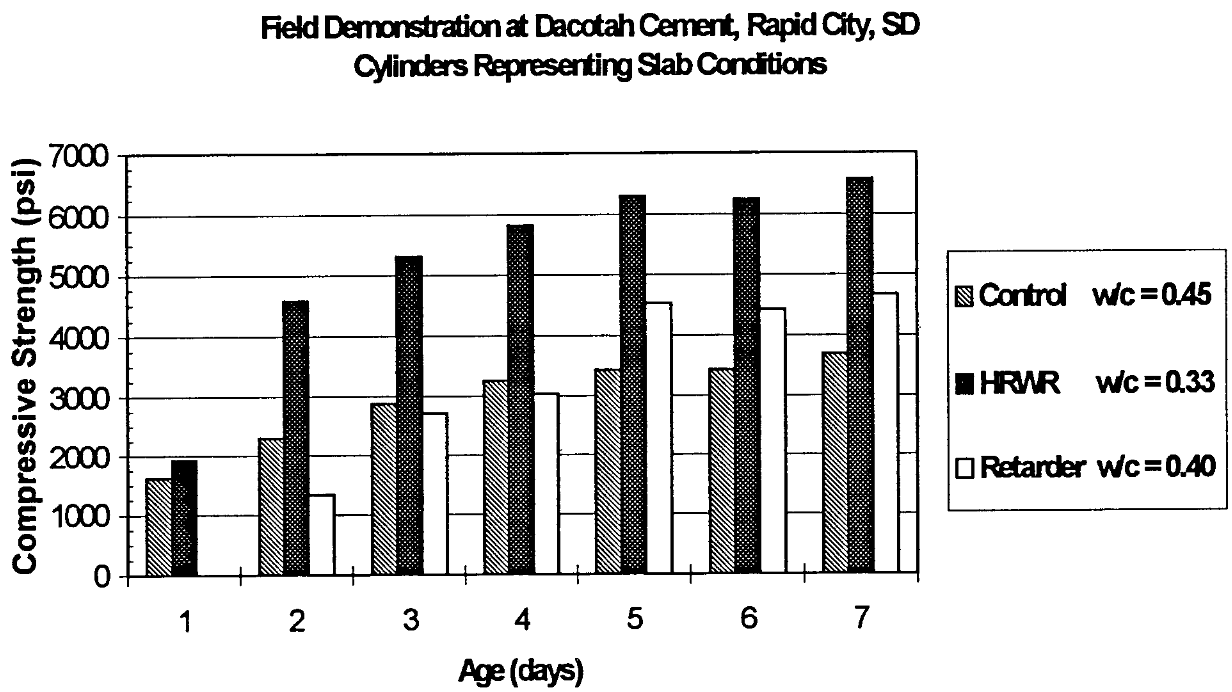



**Fig. 13** **Daily monitoring of field specimens cast during field demonstration.**

**Table 6** **Daily monitoring of compressive strengths for field specimens. Acceptance test results of lab specimens. Both set of specimens cast during field demonstration.**

| | Compressive Strength | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Field Specimens | | | | | | | Lab Specimens | |
| Mix ID | 1 Day psi (MPa) | 2 Day psi (MPa) | 3 Day psi (MPa) | 4 Day psi (MPa) | 5 Day psi (MPa) | 6 Day psi (MPa) | 7 Day psi (MPa) | 7 Day psi (MPa) | 28 Day psi (MPa) |
| Control | 1535 (105.8) | 2425 (167.2) | 2705 (186.5) | 3390 (233.7) | 3345 (230.6) | 3635 (250.6) | 3515 (242.3) | 4090 (282.0) | 4440 (306.1) |
| Control | 1705 (117.5) | 2180 (150.3) | 3060 (211.0) | 3135 (216.1) | 3520 (242.7) | 3240 (223.4) | 3870 (266.8) | 3990 (275.1) | 4695 (323.7) |
| HRWR | 2020 (139.3) | 4380 (302.0) | 5015 (345.8) | 5885 (405.7) | 6010 (414.3) | 6060 (417.8) | 6530 (450.2) | 7060 (486.7) | 7720 (532.2) |
| HRWR | 1830 (126.2) | 4775 (329.2) | 5615 (387.1) | 5765 (397.5) | 6600 (455.0) | 6430 (443.3) | 6630 (457.1) | 6845 (471.9) | 7580 (522.6) |
| Retarder | not set - | 1255 (86.52) | 2915 (201.0) | 2635 (181.7) | 4960 (342.0) | 4150 (286.1) | 4885 (336.8) | 5440 (375.1) | 7605 (524.3) |
| Retarder | not set - | 1420 (97.88) | 2520 (173.7) | 3430 (236.5) | 4100 (282.7) | 4700 (324.0) | 4450 (306.8) | 5865 (404.3) | 7840 (540.5) |

### 4.4.2 Time of Set

Time of set was performed on the concrete batches having a maximum dosage of the retarder admixture. Three samples from each load were taken back to the laboratory and tested. Results from this test are displayed in Fig. 14. As illustrated, the concrete mix with the longest delay of addition time took the longest to reach initial and final set. Conversely, the shortest delay time produced the quickest initial and final set times.

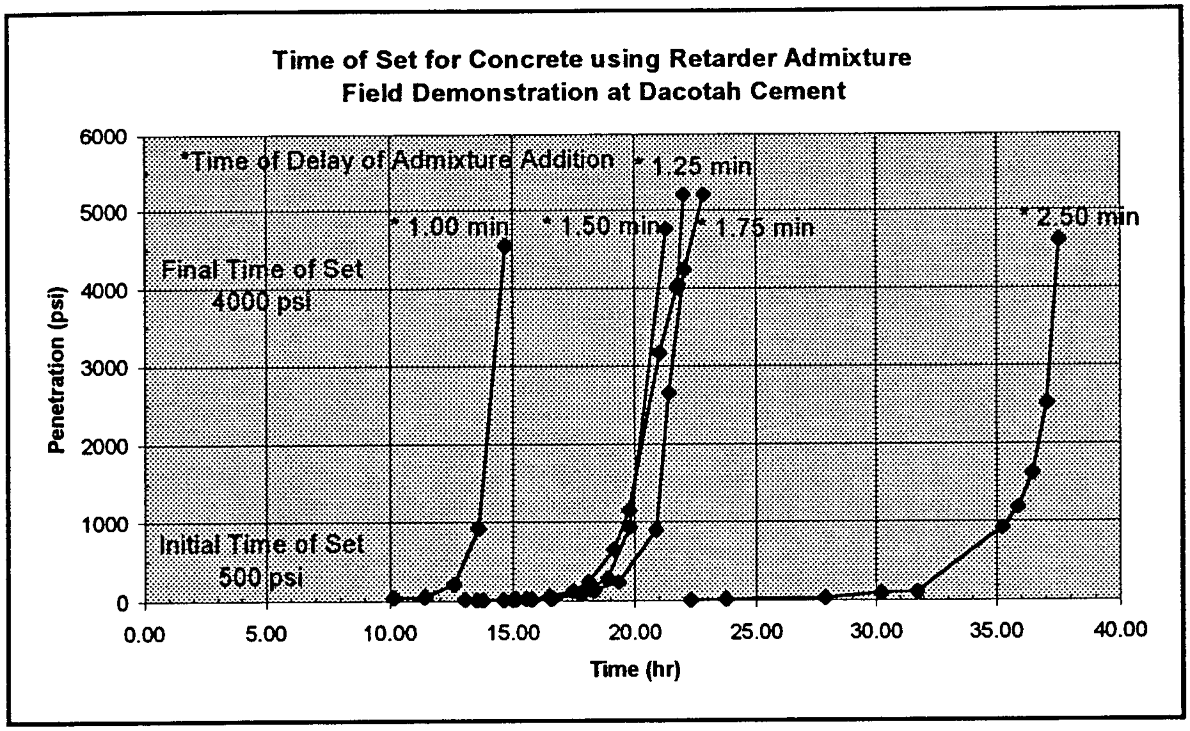



**Fig. 14** **Time of Set test conducted on concrete mixture with maximum dosage of retarder *(Daratard 17)* during field demonstration.**

The first two bays were placed on Tuesday, November 18, 1997 and the final bay on Thursday, November 20, 1997. Weather conditions for the demonstration project were as follows: November 18, 1997; temperature: 40 degrees Fahrenheit, overcast, winds: 15-20 mph; November 20, 1997; temperature: 42 degrees Fahrenheit, overcast, winds: 5-10 mph.

The first bay received the control concrete batch having only air entraining agent admixture. Concrete with maximum high range water reducer dosage was placed in the second bay and the third received the concrete having a maximum dosage of retarder. After delivery of each load, the concrete finishers were interviewed. The goal of the field demonstration was to test varied time of additions of the chemical admixture and its effect. At times, the concrete produced was difficult to finish and the finishers provided information on any unusual characteristics encountered during placement.

The control concrete produced slumps that ranged from 2.75 in. to 3.00 in. and was relatively easy to finish. Control batch concrete was delivered in 3 loads.

The high-range water-reducing admixture (HRWRA) concrete varied in its finishablity. The first load had a 60 second delay before adding the chemical admixture. This concrete exhibited unusual characteristics such as good slump but it dried very fast. The finishers needed to apply a water fog to seal the concrete surface. Without the water fog, the tools would tear the surface of the concrete. The second HRWRA load also had poor workability even though it had an 8.25 in. slump. This made the concrete so flowable that the floats would tear the surface and required water fog to seal the surface. The third HRWRA load was hard to finish because of its stickiness. Finishers commented that it was hard to work the aggregate down. The fourth and fifth HRWRA loads were not much better in terms of workability. The contractor was able to saw the slab the next day and the slab finish from the first and second bay were compared. The first bay had a satisfactory finish, but the second bay had rough areas that were pitted where the finishers could not get the surfaced sealed.

The concrete with maximum retarder dosage was placed two days later in the third bay. A hydraulic line at the redi-mix plant broke and delayed the project for approximately 45 minutes. The first load of concrete was dry batched as a result. This load had the longest delay prior to adding the retarder which resulted in very good workability, no vibration was necessary for placement. The redi-mix plant was back on line and was able to central batch the remaining concrete. The second load had the shortest delay prior to adding the retarder. This load was extremely dry and approximately 55 gallons of water had to be added at the project site. Workability was very poor and vibration was needed. The third load arrived at the project site and was visually inspected and sent back to the plant for adjustments. The fourth load was too sloppy and was sent back to the plant for adjustment. The fifth load was acceptable when it reached the project site.

In summary, the objective of the field demonstration was to verify the compatibility and performance of the cement and admixture under field conditions while using **maximum** dosage rates of the admixtures, not to make "user-friendly" concrete. In addition, the field demonstration illustrated the behavior of concrete with admixtures applied at different time intervals after the contact between water and cement.

The concrete produced from the field demonstration exceeded the nominal strengths, 4000 psi, set by Dacotah Cement. Daily monitoring of the field-cured cylinders revealed that after the fifth day all cylinders had exceeded 4000 psi. The concrete mixes with maximum dosage of high range water reducer out-performed the control and retarder mixes by reaching an average strength of 6580 psi in 7 days.

In general, the concrete placed during the field demonstration project behaved as expected with the exception of the mixture having a maximum dosage of retarder and the shortest time of addition. The poor performance of this concrete mixture may be attributed to many things, such as the problems occurring at the central redi-mix plant. For example, this was the first truck to be batched after repairs to the central redi-mix plant were made and the batching drum may have been excessively dry which may have possibly consumed the batch water of the correctly proportioned concrete, resulting in poor concrete performance. As a result, concrete produced under field conditions was exposed to a variety of uncontrollable variables such as redi-mix production and less than desirable weather conditions and performed as best as can be expected. This illustrates the need for field trials before any new mixture is used.

## 4.5 Research Tasks 6 and 8

These tasks were eliminated due to coordination problems, budgetary limitations, and the reluctance of contractors to use experimental concrete. Task 6 involved the planning of activities for visiting demonstration construction projects for educational and promotion of the use of admixtures. Also, the second portion of Task 6 was to review, visit, sample and perform field tests on one or more non-DOT construction.

Task 8 was to perform field tests on DOT constructions projects using a HRWRA for a heavily reinforced structure and a retarder on a bridge deck, as coordinated by SDDOT. This was hindered by the limitations in place for using admixtures on DOT projects and the lack of cooperation by the contractors selected for existing projects.

## 4.6 Research Task 9

The SDSM&T Concrete Conference was utilized to present information about the research project, primarily focusing on the field demonstration project. The consensus was that pre-construction sessions would be the best educational method for future projects.

## 4.7 Research Task 10

This task's purpose was to write guidelines for the routine use of admixtures and also to make recommendations for the SDDOT Specification Handbook. A copy of the guidelines are illustrated in Appendix C. Recommendations to the SDDOT Specification Handbook are found in section 6.0.

Information concerning this research project has been presented at the American Concrete Institute conference in a Research-In-Progress session held on March 23, 1998 in Houston, Texas. Other abstracts have been submitted for acceptance at an international conference in Australia in August 1998.

### 4.8 Research Task 11

This task involves preparing the final report and also providing Ms. Flottmeyer's MS thesis as a supplementary report. The MS thesis will be available in late August and will be forwarded to the research coordinator, Jon Becker.

### 4.9 Research Task 12

An executive presentation to the SDDOT Research Review Board was done on June 18, 1998.

## 5.0 FINDINGS AND CONCLUSIONS

1. The regional questionnaire revealed that although a common cement source is shared by the six states surrounding South Dakota, no common problems exist in terms of cement/admixture compatibility. A variety of problems were reported, but these were not necessarily compatibility problems.
2. Analysis of the thirty-three concrete mixture proportions showed that no incompatibility exists between ***Dacotah*** portland cements (Type I/II and V) and the high-range water-reducing admixture (***Daracem 100***) and the retarder (***Daratard 17***) from W.R. Grace Products, Inc.
3. The mortar flow table test combination of Type V ***Dacotah*** portland cement and HRWRA (***Daracem 100***) exhibit an optimum time of addition of the HRWRA to be at four minutes after water and cement contact.
4. Compatibility exists between the four combinations of cement types (Type I/II and Type V) and a HRWRA (***Daracem 100***) and a retarder (***Daratard 17***) as evidenced by the mortar and concrete flow table tests.

5. Concrete mortar flow table results as illustrated in Figures 5.0 and 6.0 show an improved performance with delayed addition of the HRWRA (***Daracem 100***) and retarder (***Daratard*** 17) admixtures. Improved flow with delayed addition, is illustrated on the vertical axis.

6. The field demonstration project verified compatibility between the admixtures (***Daracem 100*** and ***Daratard 17***) and ***Dacotah*** cement. The intent of the field demonstration was to verify the performance of the admixtures using maximum dosages, not to produce a "user-friendly" concrete.

7. As shown in Figure 13, during the field demonstration project the concrete mixture proportion using maximum dosage of HRWRA possessed a low w/c which resulted in a high early strength gain. The retarder concrete mixture exhibited a slow initial strength gain but surpassed the control mixture by the fifth day of monitoring compressive strengths.

8. As illustrated in Figure 14, the time of set test conducted during the field demonstration, on the concrete mixture proportion having a maximum dosage, exhibited a 34 hour initial set with a 2.5 minute delay prior to adding the retarder. Note: The ambient temperature was approximately 42 °F and given warmer conditions the time of set would be significantly less.

9. Broad guidelines can only suggest in advance which admixture could or should be used. Written guidelines to trouble-shoot any problem encountered with concrete are not possible due to the multitude of components and conditions which can affect concrete. Experience with a particular mixture is the best avenue to success.

10. Workability or other problems can occur any time, due to many things other than incompatibility.

## 6.0 IMPLEMENTATION AND RECOMMENDATIONS

1. Cement/admixture performance problems should be evaluated on a case by case basis. Prior to incorporating an admixture into a concrete mixture, laboratory testing followed by a field trial to verify its compatibility and performance under field conditions should be done.

2. Use enclosed guidelines for training throughout SDDOT educational programs.
3. Incorporating admixtures into a concrete mixture proportions requires knowledge by all parties from the design engineer to the concrete finisher. A preconstruction educational session is strongly recommended. A higher level of quality control must be enforced when working with admixtures.
4. The existing admixture section in the SDDOT Specification Handbook is very broad and general and provides no clarification on the use of chemical admixtures. The following guidelines are proposed as changes to the SDDOT Specification Handbook, Section 752 "Chemical Admixtures for Concrete":
   - Anytime a chemical or mineral admixture is used in a concrete mixture a higher level of quality control is required before, during, and after construction.
   - Dosage rates should be utilized within the manufacturers recommendations to achieve the best performance level.
   - Laboratory tests to verify performance of the admixture should be performed followed by test pours.
   - Test pours should be conducted to simulate field conditions while using the exact materials and testing procedures that will be implemented during the construction.
   - If concrete performance problems do occur the addition of the admixture may be delayed up to a maximum of two minutes after water contacts the cement.
   - Mix designs and test results with statistical analysis shall be submitted to the engineer for approval.
5. If production methods will allow delayed addition of the admixture, a one to two-minute delay could be tried if concrete performance problems occur.
6. This research project was, in reality, the first step in what should be a three-step process. The focus of this project was to determine if there was a general compatibility problem between Dacotah cement and two admixtures, a high-range water-reducing admixture (***Daracem 100***) and a retarder (***Daratard 17***). This task was successfully accomplished. Step two, which is not part of this research project, should be to optimize the concrete mix design for maximum performance and minimum cost. The database is provided within this report and could be optimized for a 4000 and/or 5000 psi mix design.

This could be done statistically, followed by laboratory trial batches, as demonstrated by DeMaro, Hansen, and Haeder [3]. Step three would be field trials of the optimized mix design conducted with a redi-mix producer, to create a "user-friendly" concrete.

7. Investigate the use of high-performance concrete in South Dakota. The high-performance mixtures for pavement, as defined by the Strategic Highway Research Program (SHRP), have been developed by Paulsen and Hansen [4] for crushed limestone, Sioux quartzite, and crushed granite.

8. SDDOT should develop and maintain an approved vendor list for admixtures. This list should include admixture companies and specific products which have been approved for use in South Dakota. The performance of new companies and products would have to be proven to SDDOT to be placed on the approved vendor list.

9. Only use mix designs that have an acceptable documented performance history. Do not include any admixtures that do not have a proven performance record.

## 7.0 REFERENCES

1. Flottmeyer, Brenda L., "Field Performance of Chemical Admixtures," Master of Science Thesis, South Dakota School of Mines and Technology, 1998.
2. Luciano, John J. and Gregory S. Bobrowski, "Using Statistical Methods to Optimize High-Strength Concrete Performance", *Transportation Research Record 1284*, pp. 60-69.
3. DeMaro, James, Hansen, M.R., and C.L. Haeder, "High Performance Concrete Mixture Proportion Optimization for Precast Concrete Using Statistical Methods," PCI/FHWA International Symposium on High Performance Concrete, New Orleans, October 20-22, 1997.
4. Hansen, M.R. and Paulsen, Robert, "High Performance Concrete for Transportation-Development of Mixture Proportions," International Conference on High Strength Concrete, Kona, Hawaii, July, 1997.

# APPENDICES

# QUESTIONNAIRE
## Admixture/Cement Compatibility Problems

This questionnaire has been sent to your agency in an effort to collect data regarding problems you may have encountered using admixtures on a variety of concrete projects. The information is being used to establish guidelines for use of admixtures for the South Dakota Department of Transportation. Your help in this project is greatly appreciated and will benefit both the concrete/cement industry as well as the admixture manufacturers.

**1. What types of cement is most commonly used for your concrete projects?**

**Type I/II** **Type III** **Type V**

**Sources of Cement:** ______________________________

______________________________________________

______________________________________________

**Comments:** ______________________________________

______________________________________________

______________________________________________

______________________________________________

**2. Which type of High Range Water Reducer is being used, if any?**

**W.R. Grace Products**

**Daracem 19**
**Daracem 100**
**Daracem ML 330**
**Daracem ML 500**

**Master Builders Technologies**

**Rheobuild 1000**
**Rheobuild 2000B**
**Rheobuild 2500**

**Others:** ______________________________________

______________________________________________

3. Which type of Retarder is being used, if any?

| W.R. Grace Products | Master Builders Technologies |
| --- | --- |
| Daratard 17 | Confilm |
| Daratard HC | Pozzolith |
| Daratard 37 | |

Others: ______________________________

4. Which type of Air Entraining Agent is being used, if any?

| W.R. Grace Products | Master Builders Technologies |
| --- | --- |
| Darex AEA | Pave Air |
| Darex II AEA | Pave Air 90 |
| Daravair 1000 | MicroAir |
| Daravair 1400 | MB AE 90 |

Others: ______________________________

5. Have you experienced any problems using certain combinations of cement and admixture?

YES NO

**If yes, please list the combinations below:**

________________________________________

**If yes, can you explain the problems that were occurring and how they were resolved?**

________________________________________

**6. Has any concrete mix design specified by your agency for a project ever exhibited rapid slump loss or premature stiffening as a result of using a chemical admixture?**

**YES** **NO**

**If yes, please explain.** ______________________________

**Please return this questionnaire in the self-addressed envelope. Thank you for your assistance.**

Table A1 - Regional questionnaire results from the six states surrounding South Dakota

QUESTIONNAIRE - Admixture/Cement Compatibility Problems

| Questions | North Dakota | Minnesota | Iowa | Nebraska | Wyoming | Montana |
|---|---|---|---|---|---|---|
| **Question # 1**<br>**What types of cement is most commonly commonly used for your concrete projects?** | I/II | I/II | I/II | I/II<br>III<br>IP | I/II | I/II |
| **Source(s) of Cement** | Inland<br>Holnam<br>Lafarge<br>Ash Grove<br>Dacotah | Lafarge, Exshaw<br>LaFarge, Alpena<br>LaFarge, Daveport<br>LaFarge, Doppa<br>Holnam, St Lawrence<br>Holnam, Clarksville<br>Holnam, Mason City<br>Lehigh Mason City<br>Lehigh, Inland | Ash Grove, Louisville, NE<br>Holnam, Mason City<br>Lafarge, Davenport, IA<br>Lehigh, Mason City | Ash Grove<br>Holnam<br>LaFarge<br>Dacotah | Holnam, La Porte, CO<br>Holnam, Devils Slide, UT<br>Mountain<br>Dacotah | Ash Grove<br>Holnam<br>LaFarge |
| **Comments:** | | | * Type II is used for all paving over 5000 sq yards. | Cement from the above producers comes from a variety of mills. See the attached Approved Products list | I anticipate using more of Holnam's IPF | |
| **Question # 2**<br>**Which type of High Range Water Reducing Admixtures is being used, if any?** | No response | W.R. Grace<br>Daracem 100<br>Daracem ML 500<br>**Master Builders**<br>Rheobuild 2000B | None | W.R. Grace<br>Daracem 100<br>Daracem ML 500<br>**Master Builders**<br>Rheobuild 1000<br>Rheobuild 2000B<br>Rheobuild 2500 | W.R. Grace<br>Daracem 19<br>**Master Builders**<br>Rheobuild 1000 | **W.R. Grace**<br>Daracem 19<br>**Master Builders**<br>Rheobuild 1000 |
| **Others?** | ND DOT does not use HRWRA's | None | None | See attached Approved Products list | None | None |
| **Question # 3**<br>**Which type of Retarder is being used if any?** | None being used | W.R. Grace<br>Daratard 17<br>**Master Builders**<br>Pozzolith 82 | W.R. Grace<br>Daratard 17 | W.R. Grace<br>Daratard 17 | None | **Master Builders**<br>Pozzolith |
| **Others?** | n/a | | | | | |
| **Question # 4**<br>**Which type of Air Entraining Agent is being used, if any?** | W.R. Grace<br>Daravair 1400 | W.R. Grace<br>Darex II AEA<br>Daravair 1000<br>Daravair 1400<br>**Master Builders**<br>MicroAir<br>MB AE 90<br>MBVR Concentrated | W.R. Grace<br>Darex AEA<br>Daravair 1000 | W.R. Grace<br>Darex II AEA<br>Daravair 1000<br>Daravair 1400<br>**Master Builders**<br>Pave Air<br>Pave Air 90<br>MicroAir<br>MB AE 90 | W.R. Grace<br>Daravair 1000<br>**Master Builders**<br>Pave Air<br>Pave Air 90<br>MicroAir<br>MB AE 90 | **Master Builders**<br>MicroAir |
| **Others** | Polychem 400 NC<br>GRT Polychem AE<br>Conchem Air | No response | n/a | See Approved Products list | None | None |
| **Question # 5**<br>**Have you experienced any problems using certain combinations of cement and admixture?** | No | Yes | Yes | No | No | No |
| **If yes, please list the combinations:** | Had trouble reaching air (%) last summer | See # 6 | Lignosulfonate based WR's with cement high in anhydrite and certain class C flyashes | n/a | n/a | n/a |
| **If yes, can you explain the problems that were occurring and how they were resolved.** | n/a | | In some cases changed to a retarder | n/a | n/a | n/a |
| **Question # 6**<br>**Has any concrete mix design specified by your agency for a project ever exhibit rapid slump loss or premature stiffening as a result of using a chemcial admixture?** | No | Yes | No response | Yes | Yes | No |
| **If yes, please explain.** | n/a | Many water reducers lose their effect if not agitate, ie dump truck for paving contractors must know the 'pot life' of their product for various mixes especially different cements | n/a | If superplasticized concrete is not finished soon enough the rapid slump loss is a problem. | On occassion we have exhibited rapid slump loss when using high range water reducer Bob Rothwell WY DOT 307-777-4074 | n/a |

Table B1 - Detailed concrete batch properties and wet and hardened concrete test results

Statistical Mix Design   Updated 4-21-98
File name 33Mix xls

| Mix No. | Five Independent Variables: HRWR (oz/cwt) | W/C | Cement Content (pcy) | (% Type I/II) Blend (%) | Mixing Time (minutes) | Batching Quantities for 2.17 cf: AEA (oz/cwt) | Type I/II Cement (lbs) | Type V Cement (lbs) | Sand (lbs) | Limestone (lbs) | Batch Water (lbs) | Aggregate Water (lbs) | (slump control) Additional Water (lbs) | Total Water (lbs) | Actual W/C | Field Tests: Before HRWR Slump (in.) | After HRWR Slump (in.) | Before HRWR Air (%) | After HRWR Air (%) | Before HRWR Unit Wt. (pcf) | After HRWR Unit Wt. (pcf) | Concrete Temp. °F | Ambient Air Temp. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T 1 | 10 | 0.45 | 658 | 100 | 3.0 | 1.9 | 52.9 | 0 | 91.2 | 140.7 | 19.8 | 4.0 | 0.000 | 23.8 | 0.45 | 2.25 | 11.00 | 4.2 | 6.6 | 145.2 | 140.0 | 84.0 | 75.0 |
| T 2 | 5 | 0.45 | 658 | 100 | 3.5 | 2.2 | 52.9 | 0 | 91.2 | 140.7 | 19.8 | 4.0 | 0.000 | 23.8 | 0.45 | 2.00 | 8.75 | 4.5 | 6.7 | 144.4 | 140.0 | 77.5 | 75.0 |
| T3 | 2.5 | 0.45 | 658 | 100 | 3.0 | 3.0 | 52.9 | 0 | 91.2 | 140.7 | 19.8 | 4.0 | 0.000 | 23.8 | 0.45 | 2.50 | 8.00 | 4.9 | 6.5 | 143.2 | 140.0 | 78.1 | 75.0 |
| 1 | 1.25 | 0.47 | 564 | 75 | 2.0 | 3.0 | 34 | 11.3 | 102 | 148 | 17.3 | 4.1 | 1.102 | 22.5 | 0.50 | 1.25 | 2.25 | 4.6 | 4.7 | 143.2 | 144.4 | 75.2 | 85.0 |
| 2 | 3.75 | 0.43 | 564 | 25 | 4.0 | 3.0 | 11.3 | 34 | 102.4 | 152.5 | 15.5 | 4.1 | 3.858 | 23.5 | 0.52 | 2.25 | 5.50 | 5.5 | 7.6 | 142.8 | 139.6 | 73.5 | 87.0 |
| 3 | 1.25 | 0.47 | 752 | 75 | 4.0 | 3.0 | 45.4 | 15.1 | 87.6 | 130.1 | 25.0 | 3.5 | 0.000 | 28.5 | 0.47 | 8.50 | 9.50 | 8.5 | 9.0 | 134.4 | 135.6 | 71.5 | 87.0 |
| 4 | 3.75 | 0.43 | 752 | 25 | 2 | 3 | 15.1 | 45.4 | 90.1 | 134.2 | 22.5 | 3.6 | 0.000 | 26.1 | 0.43 | 6.50 | 9.25 | 6.9 | 6.4 | 138.8 | 140.0 | 73.1 | 88.0 |
| 5 | 3.75 | 0.43 | 564 | 75 | 2 | 3 | 34 | 11.3 | 102.4 | 152.5 | 15.5 | 4.1 | 0.882 | 20.5 | 0.45 | 0.25 | 1.50 | 3.5 | 4.6 | 147.2 | 146.0 | 77.8 | 80.0 |
| 6 | 1.25 | 0.47 | 564 | 25 | 4 | 3 | 11.3 | 34 | 101.6 | 148.4 | 17.4 | 4.1 | 0.000 | 21.5 | 0.47 | 1.00 | 1.75 | 5.1 | 4.9 | 144.0 | 143.6 | 76.4 | 80.0 |
| 7 | 3.75 | 0.43 | 752 | 75 | 4 | 3 | 45.4 | 15.1 | 90.1 | 134.2 | 22.5 | 3.6 | 0.000 | 26.1 | 0.43 | 3.25 | 8.25 | 4.8 | 6.3 | 141.6 | 139.6 | 76.7 | 80.0 |
| 8 | 1.25 | 0.47 | 752 | 25 | 2 | 3 | 15.1 | 45.4 | 87.6 | 130.1 | 25.0 | 3.5 | 0.000 | 28.5 | 0.47 | 9.00 | 7.75 | 7.6 | 6.7 | 136.0 | 138.8 | 75.8 | 78.0 |
| 9 | 2.5 | 0.45 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 96.5 | 140.3 | 20.0 | 3.8 | 0.000 | 23.8 | 0.45 | 2.00 | 5.50 | 5.7 | 6.8 | 140.8 | 140.0 | 73.1 | 75.0 |
| 10 | 2.5 | 0.45 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 96.5 | 140.3 | 20.0 | 3.8 | 0.000 | 23.8 | 0.45 | 1.75 | 5.00 | 5.7 | 6.2 | 141.6 | 141.2 | 75.8 | 70.0 |
| 11 | 2.5 | 0.45 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 96.5 | 140.5 | 20.0 | 3.8 | 0.000 | 23.8 | 0.45 | 2.00 | 5.50 | 5.9 | 6.5 | 141.6 | 138.8 | 74.5 | 70.0 |
| 12 | 3.75 | 0.47 | 564 | 75 | 4 | 3 | 34 | 11.3 | 101.5 | 148.5 | 18.9 | 2.4 | 1.654 | 23.0 | 0.51 | 1.25 | 4.50 | 5.6 | 7.0 | 142.0 | 141.6 | 72.0 | 58.0 |
| 13 | 1.25 | 0.43 | 564 | 25 | 2 | 3 | 11.3 | 34 | 102.5 | 152.5 | 17.1 | 2.5 | 0.000 | 19.6 | 0.43 | 3.00 | 5.50 | 6.6 | 7.8 | 140.4 | 140.0 | 72.4 | 84.0 |
| 14 | 3.75 | 0.47 | 752 | 75 | 2 | 3 | 45.4 | 15.1 | 87.5 | 130.1 | 26.4 | 2.1 | 0.000 | 28.5 | 0.47 | 8.75 | 10.50 | 8.7 | 8.6 | 134.0 | 136.0 | 69.2 | 59.0 |
| 15 | 1.25 | 0.43 | 752 | 25 | 4 | 3 | 15.1 | 45.4 | 90 | 134.2 | 23.9 | 2.2 | 0.000 | 26.1 | 0.43 | 5.00 | 7.25 | 6.6 | 7.4 | 138.8 | 138.4 | 73.2 | 70.0 |

## Table B1 (continued) - Detailed concrete batch properties and wet and hardened concrete test results

Statistical Mix Design    Updated 4-21-98
File name 33Mix.xls

| Mix No. | Five Independent Variables | | | | | Batching Quantities for 2.17 cf | | | | | | | (slump control) | | | Field Tests | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | Before HRWR | After HRWR | Before HRWR | After HRWR | Before HRWR | After HRWR | | |
| | HRWR (oz/cwt) | W/C | Cement Content (pcy) | (% Type I/II) Blend (%) | Mixing Time (minutes) | AEA (oz/cwt) | Type I/II Cement (lbs) | Type V Cement (lbs) | Sand (lbs) | Limestone (lbs) | Batch Water (lbs) | Aggregate Water (lbs) | Additional Water (lbs) | Total Water (lbs) | Actual W/C | Slump (in.) | Slump (in.) | Air (%) | Air (%) | Unit Wt. (pcf) | Unit Wt. (pcf) | Concrete Temp. °F | Ambient Air Temp. °F |
| 16 | 1.25 | 0.43 | 564 | 75 | 4 | 3 | 34 | 11.3 | 102.5 | 152.5 | 17.1 | 2.5 | 3.858 | 23.4 | 0.52 | 3.50 | 7.25 | 7.6 | 7.8 | 140.8 | 138.0 | 68.2 | 59.0 |
| 17 | 3.75 | 0.47 | 564 | 25 | 2 | 3 | 11.3 | 34 | 101.5 | 148.4 | 18.9 | 2.4 | 0.000 | 21.3 | 0.47 | 2.00 | 5.50 | 8.0 | 8.0 | 140.0 | 140.0 | 72.2 | 72.0 |
| 18 | 1.25 | 0.43 | 752 | 75 | 2 | 3 | 45.5 | 15 | 90 | 134 | 23.9 | 2.2 | 0.000 | 26.1 | 0.43 | 4.25 | 8.25 | 7.2 | 7.1 | 139.2 | 138.8 | 71.2 | 70.0 |
| 19 | 3.75 | 0.47 | 752 | 25 | 4 | 3 | 15 | 45.5 | 87.5 | 130.1 | 26.4 | 2.1 | 0.000 | 28.5 | 0.47 | 9.25 | 9.25 | 9.6 | 7.8 | 133.6 | 137.2 | 70.8 | 61.0 |
| 20 | 2.5 | 0.45 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 96.5 | 140.5 | 18.9 | 2.3 | 0.000 | 21.2 | 0.40 | 4.50 | 8.75 | 7.6 | 8.4 | 140.0 | 139.2 | 72.5 | 80.0 |
| 21 | 2.5 | 0.45 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 96.5 | 140.5 | 18.9 | 2.3 | 0.000 | 21.2 | 0.40 | 5.00 | 7.75 | 8.2 | 8.1 | 136.8 | 137.6 | 70.1 | 59.0 |
| 22 | 2.5 | 0.45 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 96.5 | 140 | 18.9 | 2.3 | 3.307 | 24.5 | 0.46 | 3.25 | 6.25 | 5.2 | 6.4 | 142.4 | 141.2 | 73.9 | 84.0 |
| 23 | 0 | 0.45 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 96.5 | 140.3 | 20.9 | 3.0 | 0.000 | 23.9 | 0.45 | 4.50 | 5.25 | 7.9 | 6.8 | 137.6 | 140.0 | 73.5 | 80.0 |
| 24 | 5 | 0.45 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 96.5 | 140.3 | 20.9 | 3.0 | 0.000 | 23.9 | 0.45 | 3.50 | 8.75 | 6.9 | 9.0 | 140.0 | 136.0 | 69.9 | 60.0 |
| 25 | 2.5 | 0.41 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 98.1 | 144.4 | 18.7 | 3.0 | 1.654 | 23.4 | 0.44 | 2.25 | 4.50 | 4.0 | 5.3 | 144.4 | 142.4 | 69.9 | 65.0 |
| 26 | 2.5 | 0.49 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 92.8 | 138.3 | 23.2 | 2.9 | 0.000 | 26.1 | 0.49 | 8.00 | 10.25 | 10.6 | 9.2 | 132.0 | 135.2 | 73.3 | 78.0 |
| 27 | 2.5 | 0.45 | 658 | 100 | 3 | 3 | 52.9 | 0 | 96.5 | 140.3 | 20.9 | 3.0 | 0.000 | 23.9 | 0.45 | 3.00 | 6.00 | 6.6 | 6.6 | 140.4 | 139.6 | 72.4 | 65.0 |
| 28 | 2.5 | 0.45 | 658 | 0 | 3 | 3 | 0 | 52.9 | 96.5 | 140.3 | 20.9 | 3.0 | 0.551 | 24.4 | 0.46 | 3.25 | 6.50 | 5.5 | 6.5 | 140.8 | 139.6 | 74.7 | 58.0 |
| 29 | 2.5 | 0.45 | 470 | 50 | 3 | 3 | 18.9 | 18.9 | 107.5 | 160.6 | 13.8 | 3.3 | 3.858 | 21.0 | 0.55 | 3.50 | 4.25 | 5.6 | 6.3 | 142.4 | 142.4 | 71.0 | 69.0 |
| 30 | 2.5 | 0.45 | 846 | 50 | 3 | 3 | 34 | 34 | 83.3 | 122 | 28.1 | 2.6 | 0.000 | 30.7 | 0.45 | 9.25 | 10.50 | 6.6 | 6.1 | 136.0 | 138.0 | 70.9 | 65.0 |
| 31 | 2.5 | 0.45 | 658 | 50 | 1 | 3 | 26.5 | 26.5 | 96.5 | 140.3 | 20.9 | 3.0 | 0.000 | 23.9 | 0.45 | 4.00 | 8.50 | 6.4 | 6.3 | 140.0 | 140.8 | 75.0 | 75.0 |
| 32 | 2.5 | 0.45 | 658 | 50 | 5 | 3 | 26.5 | 26.5 | 96.5 | 140.3 | 20.9 | 3.0 | 0.000 | 23.9 | 0.45 | 4.50 | 9.50 | 7.1 | 7.7 | 138.8 | 138.8 | 74.0 | 83.0 |
| 33 | 2.5 | 0.45 | 658 | 50 | 3 | 3 | 26.5 | 26.5 | 96.5 | 140.3 | 20.9 | 3.0 | 0.000 | 23.9 | 0.45 | 4.75 | 8.00 | 7.5 | 7.9 | 138.0 | 137.2 | 71.3 | 63.0 |

Table B1 (continued) - Detailed concrete batch properties and wet and hardened concrete test results

| Mix No. | Humidity % | Theoretical (Design) Values: Air % | Slump (in.) | Fines / (Fines + Coarse) | 28 Day Comp. (psi) | Compressive Strength Results: 1 Day Load (lbs) | 1 Day Strength (psi) | 1 Day Avg Str. (psi) | 3 Day Load (lbs) | 3 Day Strength (psi) | 3 Day Avg Str. (psi) | 7 Day Load (lbs) | 7 Day Strength (psi) | 7 Day Avg. Str. (psi) | 28 Day Load (lbs) | 28 Day Strength (psi) | 28 Day Avg. Str. (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T 1 | - | 5.5 | 2 | 0.39 | 4000 | 25500 | 2029 | 1923 | 42700 | 3398 | 3483 | 66500 | 5292 | 4854 | 78500 | 6247 | 6167 |
| | | | | | | 22500 | 1790 | | 45000 | 3581 | | 58500 | 4655 | | 78000 | 6207 | |
| | | | | | | 24500 | 1950 | | 43600 | 3470 | | 58000 | 4615 | | 76000 | 6048 | |
| T 2 | - | 5.5 | 2 | 0.39 | 4000 | 22600 | 1798 | 1870 | 40800 | 3247 | 3249 | 57500 | 4576 | 4470 | 70000 | 5570 | 5756 |
| | | | | | | 24300 | 1934 | | 39500 | 3143 | | 54500 | 4337 | | 72500 | 5769 | |
| | | | | | | 23600 | 1878 | | 42200 | 3358 | | 56500 | 4496 | | 74500 | 5929 | |
| T3 | - | 5.5 | 2 | 0.39 | 4000 | 23500 | 1870 | 1817 | 38500 | 3064 | 3159 | 53000 | 4218 | 4218 | 65000 | 5173 | 5345 |
| | | | | | | 23400 | 1862 | | 41400 | 3295 | | 55000 | 4377 | | 70500 | 5610 | |
| | | | | | | 21600 | 1719 | | 39200 | 3119 | | 51000 | 4058 | | 66000 | 5252 | |
| 1 | 40 | 5.5 | 2 | 0.41 | 4000 | 23700 | 1886 | 1814 | 38400 | 3056 | 3106 | 51500 | 4098 | 4098 | 61000 | 4854 | 5119 |
| | | | | | | 23700 | 1886 | | 39400 | 3135 | | 50000 | 3979 | | 64500 | 5133 | |
| | | | | | | 21000 | 1671 | | 39300 | 3127 | | 53000 | 4218 | | 67500 | 5371 | |
| 2 | 35 | 5.5 | 2 | 0.40 | 4000 | 19900 | 1584 | 1419 | 32600 | 2594 | 2531 | 44500 | 3541 | 3475 | 55000 | 4377 | 4523 |
| | | | | | | 17000 | 1353 | | 32300 | 2570 | | 42500 | 3382 | | 55000 | 4377 | |
| | | | | | | 16600 | 1321 | | 30500 | 2427 | | 44000 | 3501 | | 60500 | 4814 | |
| 3 | - | 5.5 | 2 | 0.40 | 4000 | 19200 | 1528 | 1448 | 30200 | 2403 | 2355 | 43000 | 3422 | 3329 | 54000 | 4297 | 4218 |
| | | | | | | 19000 | 1512 | | 30000 | 2387 | | 41000 | 3263 | | 54000 | 4297 | |
| | | | | | | 16400 | 1305 | | 28600 | 2276 | | 41500 | 3302 | | 51000 | 4058 | |
| 4 | 40 | 5.5 | 2 | 0.40 | 4000 | 21700 | 1727 | 1934 | 39400 | 3135 | 3093 | 51500 | 4098 | 4058 | 70500 | 5610 | 5637 |
| | | | | | | 25900 | 2061 | | 37800 | 3008 | | 51500 | 4098 | | 69500 | 5531 | |
| | | | | | | 25300 | 2013 | | 39400 | 3135 | | 50000 | 3979 | | 72500 | 5769 | |
| 5 | 33 | 5.5 | 2 | 0.40 | 4000 | 30800 | 2451 | 2393 | 47300 | 3764 | 3783 | 59000 | 4695 | 4655 | 72500 | 5769 | 5716 |
| | | | | | | 29200 | 2324 | | 48000 | 3820 | | 58500 | 4655 | | 72000 | 5730 | |
| | | | | | | 30200 | 2403 | | 47300 | 3764 | | 58000 | 4615 | | 71000 | 5650 | |
| 6 | - | 5.5 | 2 | 0.41 | 4000 | 28400 | 2260 | 2117 | 41700 | 3318 | 3295 | 54000 | 4297 | 4350 | 69500 | 5531 | 5584 |
| | | | | | | 25000 | 1989 | | 40900 | 3255 | | 52000 | 4138 | | 70500 | 5610 | |
| | | | | | | 26400 | 2101 | | 41600 | 3310 | | 58000 | 4615 | | 70500 | 5610 | |
| 7 | - | 5.5 | 2 | 0.40 | 4000 | 29300 | 2332 | 2385 | 34100 | 2714 | 3255 | 57000 | 4536 | 4417 | 71500 | 5690 | 5690 |
| | | | | | | 30900 | 2459 | | 44000 | 3501 | | 55000 | 4377 | | 71000 | 5650 | |
| | | | | | | 29700 | 2363 | | 44600 | 3549 | | 54500 | 4337 | | 72000 | 5730 | |
| 8 | - | 5.5 | 2 | 0.40 | 4000 | 21800 | 1735 | 1732 | 34700 | 2761 | 2785 | 47000 | 3740 | 3634 | 59500 | 4735 | 5013 |
| | | | | | | 21000 | 1671 | | 35700 | 2841 | | 44000 | 3501 | | 65000 | 5173 | |
| | | | | | | 22500 | 1790 | | 34600 | 2753 | | 46000 | 3661 | | 64500 | 5133 | |
| 9 | - | 5.5 | 2 | 0.41 | 4000 | 29000 | 2308 | 2252 | 36800 | 2928 | 3149 | 48000 | 3820 | 4019 | 62500 | 4974 | 4867 |
| | | | | | | 27500 | 2188 | | 40100 | 3191 | | 51000 | 4058 | | 62000 | 4934 | |
| | | | | | | 28400 | 2260 | | 41800 | 3326 | | 52500 | 4178 | | 59000 | 4695 | |
| 10 | - | 5.5 | 2 | 0.41 | 4000 | 28200 | 2244 | 2220 | 41800 | 3326 | 3300 | 54500 | 4337 | 4165 | 69000 | 5491 | 5318 |
| | | | | | | 28000 | 2228 | | 43600 | 3470 | | 48000 | 3820 | | 65000 | 5173 | |
| | | | | | | 27500 | 2188 | | 39000 | 3104 | | 54500 | 4337 | | 66500 | 5292 | |
| 11 | - | 5.5 | 2 | 0.41 | 4000 | 28000 | 2228 | 2212 | 42600 | 3390 | 3316 | 52000 | 4138 | 4337 | 69500 | 5531 | 5305 |
| | | | | | | 27500 | 2188 | | 41400 | 3295 | | 55500 | 4417 | | 69000 | 5491 | |
| | | | | | | 27900 | 2220 | | 41000 | 3263 | | 56000 | 4456 | | 61500 | 4894 | |
| 12 | 30 | 5.5 | 2 | 0.41 | 4000 | 30400 | 2419 | 2180 | 37500 | 2984 | 2976 | 45100 | 3589 | 3812 | 61000 | 4854 | 4947 |
| | | | | | | 24200 | 1926 | | 36800 | 2928 | | 49700 | 3955 | | 63000 | 5013 | |
| | | | | | | 27600 | 2196 | | 37900 | 3016 | | 48900 | 3891 | | 62500 | 4974 | |
| 13 | 21 | 5.5 | 2 | 0.40 | 4000 | 16200 | 1289 | 1265 | 28100 | 2236 | 2141 | 38200 | 3040 | 3077 | 57500 | 4576 | 4417 |
| | | | | | | 16000 | 1273 | | 26500 | 2109 | | 39200 | 3119 | | 53500 | 4257 | |
| | | | | | | 15500 | 1233 | | 26100 | 2077 | | 38600 | 3072 | | 55500 | 4417 | |
| 14 | 50 | 5.5 | 2 | 0.40 | 4000 | 21800 | 1735 | 1724 | 31300 | 2491 | 2668 | 41500 | 3302 | 3350 | 58000 | 4615 | 4456 |
| | | | | | | 19700 | 1568 | | 34200 | 2722 | | 42400 | 3374 | | 52000 | 4138 | |
| | | | | | | 23500 | 1870 | | 35100 | 2793 | | 42400 | 3374 | | 58000 | 4615 | |
| 15 | 35 | 5.5 | 2 | 0.40 | 4000 | 24000 | 1910 | 1878 | 35800 | 2849 | 2889 | 47000 | 3740 | 3873 | 62500 | 4974 | 5199 |
| | | | | | | 23800 | 1894 | | 37400 | 2976 | | 51800 | 4122 | | 67500 | 5371 | |
| | | | | | | 23000 | 1830 | | 35700 | 2841 | | 47200 | 3756 | | 66000 | 5252 | |

Table B1 (continued) - Detailed concrete batch properties and wet and hardened concrete test results

| Mix No. | Humidity % | Theoretical (Design) Values: Air % | Slump (in.) | Fines / (Fines + Coarse) | 28 Day Comp. (psi) | Compressive Strength Results: 1 Day Load (lbs) | 1 Day Strength (psi) | 1 Day Avg Str. (psi) | 3 Day Load (lbs) | 3 Day Strength (psi) | 3 Day Avg Str. (psi) | 7 Day Load (lbs) | 7 Day Strength (psi) | 7 Day Avg. Str. (psi) | 28 Day Load (lbs) | 28 Day Strength (psi) | 28 Day Avg. Str. (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 50 | 5.5 | 2 | 0.40 | 4000 | 17400 | 1385 | 1371 | 30900 | 2459 | 2424 | 37600 | 2992 | 2995 | 50500 | 4019 | 4032 |
| | | | | | | 16800 | 1337 | | 28900 | 2300 | | 37800 | 3008 | | 49500 | 3939 | |
| | | | | | | 17500 | 1393 | | 31600 | 2515 | | 37500 | 2984 | | 52000 | 4138 | |
| 17 | 34 | 5.5 | 2 | 0.41 | 4000 | 17200 | 1369 | 1390 | 30500 | 2427 | 2401 | 41800 | 3326 | 3279 | 55500 | 4417 | 4430 |
| | | | | | | 18200 | 1448 | | 31700 | 2523 | | 40800 | 3247 | | 52000 | 4138 | |
| | | | | | | 17000 | 1353 | | 28300 | 2252 | | 41000 | 3263 | | 59500 | 4735 | |
| 18 | 25 | 5.5 | 2 | 0.40 | 4000 | 26000 | 2069 | 1971 | 39600 | 3151 | 3066 | 47700 | 3796 | 3806 | 63500 | 5053 | 5066 |
| | | | | | | 24700 | 1966 | | 39600 | 3151 | | 47200 | 3756 | | 63500 | 5053 | |
| | | | | | | 23600 | 1878 | | 36400 | 2897 | | 48600 | 3867 | | 64000 | 5093 | |
| 19 | 49 | 5.5 | 2 | 0.40 | 4000 | 20600 | 1639 | 1621 | 27700 | 2204 | 2316 | 41600 | 3310 | 3337 | 61000 | 4854 | 4722 |
| | | | | | | 20700 | 1647 | | 30000 | 2387 | | 42200 | 3358 | | 59000 | 4695 | |
| | | | | | | 19800 | 1576 | | 29600 | 2355 | | 42000 | 3342 | | 58000 | 4615 | |
| 20 | 25 | 5.5 | 2 | 0.41 | 4000 | 21000 | 1671 | 1557 | 31300 | 2491 | 2358 | 42200 | 3358 | 3247 | 55500 | 4417 | 4324 |
| | | | | | | 19000 | 1512 | | 31400 | 2499 | | 40400 | 3215 | | 54500 | 4337 | |
| | | | | | | 18700 | 1488 | | 26200 | 2085 | | 39800 | 3167 | | 53000 | 4218 | |
| 21 | 55 | 5.5 | 2 | 0.41 | 4000 | 20700 | 1647 | 1623 | 34300 | 2730 | 2748 | 43600 | 3470 | 3366 | 57500 | 4576 | 4324 |
| | | | | | | 21600 | 1719 | | 33600 | 2674 | | 41900 | 3334 | | 51500 | 4098 | |
| | | | | | | 18900 | 1504 | | 35700 | 2841 | | 41400 | 3295 | | 54000 | 4297 | |
| 22 | 22 | 5.5 | 2 | 0.41 | 4000 | 24800 | 1974 | 1984 | 40800 | 3247 | 3130 | 50500 | 4019 | 4035 | 67000 | 5332 | 5398 |
| | | | | | | 26600 | 2117 | | 39000 | 3104 | | 50900 | 4050 | | 69000 | 5491 | |
| | | | | | | 23400 | 1862 | | 38200 | 3040 | | 50700 | 4035 | | 67500 | 5371 | |
| 23 | 22 | 5.5 | 2 | 0.41 | 4000 | 20800 | 1655 | 1592 | 32200 | 2562 | 2557 | 42000 | 3342 | 3417 | 58500 | 4655 | 4549 |
| | | | | | | 19200 | 1528 | | 32600 | 2594 | | 44500 | 3541 | | 55500 | 4417 | |
| | | | | | | 20000 | 1592 | | 31600 | 2515 | | 42300 | 3366 | | 57500 | 4576 | |
| 24 | 52 | 5.5 | 2 | 0.41 | 4000 | 25700 | 2045 | 1881 | 32500 | 2586 | 2634 | 43300 | 3446 | 3454 | 57000 | 4536 | 4483 |
| | | | | | | 22000 | 1751 | | 33100 | 2634 | | 44000 | 3501 | | 57500 | 4576 | |
| | | | | | | 23200 | 1846 | | 33700 | 2682 | | 42900 | 3414 | | 54500 | 4337 | |
| 25 | 47 | 5.5 | 2 | 0.40 | 4000 | 28500 | 2268 | 2297 | 40800 | 3247 | 3371 | 54200 | 4313 | 4382 | 73500 | 5849 | 5809 |
| | | | | | | 28400 | 2260 | | 42100 | 3350 | | 53500 | 4257 | | 73500 | 5849 | |
| | | | | | | 29700 | 2363 | | 44200 | 3517 | | 57500 | 4576 | | 72000 | 5730 | |
| 26 | 24 | 5.5 | 2 | 0.40 | 4000 | 16500 | 1313 | 1310 | 26500 | 2109 | 2064 | 33400 | 2658 | 2679 | 46500 | 3700 | 3833 |
| | | | | | | 16400 | 1305 | | 26500 | 2109 | | 30400 | 2419 | | 50000 | 3979 | |
| | | | | | | 16500 | 1313 | | 24800 | 1974 | | 37200 | 2960 | | 48000 | 3820 | |
| 27 | 43 | 5.5 | 2 | 0.41 | 4000 | 27700 | 2204 | 2175 | 39000 | 3104 | 3035 | 46600 | 3708 | 3613 | 55000 | 4377 | 4536 |
| | | | | | | 27200 | 2165 | | 38800 | 3088 | | 45600 | 3629 | | 57000 | 4536 | |
| | | | | | | 27100 | 2157 | | 36600 | 2913 | | 44000 | 3501 | | 59000 | 4695 | |
| 28 | 53 | 5.5 | 2 | 0.41 | 4000 | 22200 | 1767 | 1793 | 37000 | 2944 | 2886 | 48500 | 3860 | 3915 | 66500 | 5292 | 5080 |
| | | | | | | 22900 | 1822 | | 36500 | 2905 | | 49100 | 3907 | | 63500 | 5053 | |
| | | | | | | 22500 | 1790 | | 35300 | 2809 | | 50000 | 3979 | | 61500 | 4894 | |
| 29 | 38 | 5.5 | 2 | 0.40 | 4000 | 14500 | 1154 | 1239 | 26400 | 2101 | 2021 | 37900 | 3016 | 2854 | 46500 | 3700 | 3661 |
| | | | | | | 16800 | 1337 | | 24200 | 1926 | | 35300 | 2809 | | 44000 | 3501 | |
| | | | | | | 15400 | 1225 | | 25600 | 2037 | | 34400 | 2737 | | 47500 | 3780 | |
| 30 | 45 | 5.5 | 2 | 0.41 | 4000 | 26500 | 2109 | 2117 | 38700 | 3080 | 3003 | 48600 | 3867 | 3873 | 66000 | 5252 | 5199 |
| | | | | | | 25300 | 2013 | | 34300 | 2730 | | 49100 | 3907 | | 66000 | 5252 | |
| | | | | | | 28000 | 2228 | | 40200 | 3199 | | 48300 | 3844 | | 64000 | 5093 | |
| 31 | 27 | 5.5 | 2 | 0.41 | 4000 | 22300 | 1775 | 1902 | 36600 | 2913 | 2594 | 49000 | 3899 | 3814 | 61500 | 4894 | 4828 |
| | | | | | | 23800 | 1894 | | 26300 | 2093 | | 49800 | 3963 | | 61000 | 4854 | |
| | | | | | | 25600 | 2037 | | 34900 | 2777 | | 45000 | 3581 | | 59500 | 4735 | |
| 32 | 20 | 5.5 | 2 | 0.41 | 4000 | 19500 | 1552 | 1573 | 32400 | 2578 | 2581 | 44200 | 3517 | 3446 | 56500 | 4496 | 4403 |
| | | | | | | 20200 | 1607 | | 32600 | 2594 | | 42800 | 3406 | | 57500 | 4576 | |
| | | | | | | 19600 | 1560 | | 32300 | 2570 | | 42900 | 3414 | | 52000 | 4138 | |
| 33 | 49 | 5.5 | 2 | 0.41 | 4000 | 21700 | 1727 | 1769 | 32100 | 2554 | 2565 | 43700 | 3478 | 3483 | 57500 | 4576 | 4443 |
| | | | | | | 22900 | 1822 | | 33000 | 2626 | | 43100 | 3430 | | 55000 | 4377 | |
| | | | | | | 22100 | 1759 | | 31600 | 2515 | | 44500 | 3541 | | 55000 | 4377 | |

# USING CHEMICAL ADMIXTURES
# HOW AND WHEN*

**South Dakota Department of Transportation**
**General Guidelines**

**"X" means the admixture could be considered for use.**

| | TYPE OF ADMIXTURE | | | | |
|---|---|---|---|---|---|
| | Water Reducer (WR) | Mid-Range Water Reducer (MRWR) | High-Range Water Reducer (HRWRA) | Retarder | Accelerator |
| **PAVING** | | | | | |
| Slip Form | X | | | X | |
| Forms and Patching | X | X | X | X | X |
| **BATCHING** | | | | | |
| Dry Batch | X | X | X | X | X |
| Central Mix | X | X | X | X | X |
| **ENVIRONMENT** | | | | | |
| Hot Weather (> 80°F) | X | X | X | X | |
| Cold Weather (< 40°F) | X | X | X | | X |
| Long Haul (> 1 hour) | X | X | | X | |
| Short Haul (< 1 hour) | X | X | X | X | X |
| **STRUCTURES** | | | | | |
| Light Reinforcement | X | X | X | | |
| Heavy Reinforcement | X | X | X | | |
| Columns and Piers | X | X | X | X | X |
| Sloped Approaches | X | X | X | X | X |

*General guidelines only. All admixture use must be approved by SDDOT.

Note 1: An air-entraining admixture (AEA) is almost always used in addition to those listed above.

Note 2: A delayed addition of certain admixtures of approximately two minutes at the batch plant, or job site addition, may improve the performance of this admixture. Contact your admixture representative and concrete supplier for further assistance.

file name: guidelines

# USING CHEMICAL ADMIXTURES
# HOW AND WHEN

**South Dakota Department of Transportation**
**General Guidelines**

## General

The general performance of concrete can almost always be improved by the proper use of chemical admixtures. Benefits such as better workability, higher strength, improved durability and cost savings can usually be achieved with the incorporation of admixtures. A good example is entrained air, which has been used for decades to promote freeze-thaw durability.

## New Mixtures

If any person or agency wishes to incorporate the use of chemical admixtures in concrete, it should be encouraged. All parties involved must cooperate to demonstrate and understand the benefits of using the admixtures. Great improvements can be made, but extra effort is required for anything new or different.

## Help Available

The technical representatives (tech-reps) from the admixture companies are the most valuable people available when it comes to using admixtures. Their goal is to demonstrate the advantages of using their product and the resulting performance improvement for the concrete and the cost savings that result. Furthermore, they are the people with the most experience with the local materials and they have the experience of using the products on many previous projects. The chances are that they have already solved a similar problem with their product.

## Trial Batches

It is imperative that laboratory and field trials be done before a new concrete mix is used on a project; unless the proposed supplier has records to show satisfactory past performance of the proposed mix design. The ready-mix concrete provider and the admixture tech-rep should provide historic data regarding the trial batches. Their desire is to provide documentation and data that shows the proven performance of admixtures on past mix designs.

## Approved Admixtures

The South Dakota Department of Transportation (SDDOT) should develop and maintain a pre-approved vendor list. This list should include all vendors and specific admixtures which have been pre-approved by SDDOT