HIGH-STRENGTH CONCRETE FOR PEACEKEEPER FACILITIES(U)
ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS
STRUCTURES LAB K L SAUCIER MAR 84 WES/MP/SL-84-3
CTIAC-70
UNCLASSIFIED
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NL
HIGH-STRENGTH CONCRETE
FOR PEACEKEEPER FACILITIES

by

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Structures Laboratory
U. S. Army Engineer Waterways Experiment Station
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March 1984
Final Report

Approved For Public Release; Distribution Unlimited

Prepared for U. S. Army Corps of Engineers
Missile Construction Office
Norton AFB, San Bernardino, Calif. 92409

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**Title:** High-Strength Concrete for Peacekeeper Facilities

**Authors:** Kenneth L. Saucier

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**Report Date:** March 1984

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**Abstract:**

An investigation is described which was conducted to determine the processes and techniques required to produce portland-cement concrete with a compressive strength of 15,000 psi or greater using conventional concreting methods and equipment, and to develop physical property data on the mixtures. It was permitted that special materials and admixtures be used, but a requirement was set that the aggregates and cements be selected from those available in the Cheyenne, Wyoming, area.

(Continued)
20. ABSTRACT (Continued)

Results indicated that it is feasible to achieve the 15,000-psi compressive strengths but that workability may decrease over a 2-hour period, and this latter development should be studied under job conditions. It is recommended that (a) all materials and procedures to be used on a specific project be tested in the laboratory for basic property information, and (b) selected mixtures be tested in the field under expected environmental conditions prior to actual job use.
Preface

The investigation described in this report was conducted for the U. S. Army Corps of Engineers Missile Construction Office, Norton AFB, California, by the Concrete Technology Division (CTD) of the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES). Authorization for the investigation was given in DA Form 2544, No. E87 83-7165, dated 21 March 1983.

The investigation was performed under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. John M. Scanlon, Chief, CTD, and under the direct supervision of Mr. Kenneth L. Saucier, Principal Investigator. Mr. Donald M. Walley, CTD, proportioned the concrete mixtures. This report was prepared by Mr. Saucier.

Funds for publication of this report were provided from those made available for operation of the Concrete Technology Information Analysis Center (CTIAC). This is CTIAC Report No. 70.

Commander and Director of WES during the investigation and the preparation and publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.
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<th>Page</th>
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<tr>
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Conversion Factors, Non-SI to SI (Metric)

Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

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<td>kilograms</td>
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<tr>
<td>pounds (mass) per cubic yard</td>
<td>0.5932764</td>
<td>kilograms per cubic metre</td>
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</table>
HIGH-STRENGTH CONCRETE FOR PEACEKEEPER FACILITIES

Background, Purpose, and Scope

Background

1. Previous work has indicated that concrete with a compressive strength of 10,000 psi* is achievable with present-day technology and materials. Quality materials, use of a low water-cement ratio (W/C), and admixtures are required. More recently the use of more effective admixtures, known as high-range water-reducing admixtures (HRWRA), and a very fine silicon-dioxide powder, known as silica fume, have shown promise for increasing the compressive strength of portland-cement concrete above 10,000 psi.

Purpose

2. The purposes of this program were (a) to conduct a study of the processes and techniques required to produce portland-cement concrete with a compressive strength of 15,000 psi or greater using conventional concreting methods and equipment, and (b) to develop physical property data on the mixtures. Special materials and admixtures were permitted, but the aggregates and cements were selected from those available in the Cheyenne, Wyoming, area.

Scope

3. The study consisted of the necessary investigation of materials and methods to produce 15,000-psi concrete. The slump was allowed to vary between 2 and 8 in. Tests included compressive strength at different ages, tensile strength, elastic properties, resistance to freezing and thawing, shrinkage, creep, and loss of slump with time.

Materials, Mixtures, and Tests

Materials

4. One granite coarse aggregate, designated OM 19 G-1, one limestone aggregate, designated OM 19 G-2, and one limestone sand, designated OM 19 S-1, were received for use in the study. Both project coarse aggregates were washed prior to use. The granite was also screened over a 1-in. sieve to remove

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.
oversize material. In addition, a laboratory rock was used in a number of mix-
tures when it became apparent that the large number of trial batches required
would exhaust the supply of project aggregate before all the physical property
tests could be conducted. A local chert aggregate and a local lightweight ag-
gregate were used in several trial mixtures. Aggregate property data on the
project aggregates and the laboratory limestone aggregate are given in
Tables 1-4.

5. The portland cement was a Type II from Wyoming. Information on the
cement is given in Table 5. Results of tests of a Class F fly ash, a Class C
fly ash, and the silica fume used in the study are given in Tables 6A, 6B, and
7, respectively.

6. A naphthalene-based HRWRA and a melamine-based HRWRA were used in the
study. An air-entraining admixture was used in selected admixtures. Fibers
were incorporated in three mixtures on a trial basis.

Mixtures

7. Seventy-six mixtures were proportioned. Results are given in Table 8.
In addition to the mixtures given, many batches were discarded when they were
found to be harsh or unworkable. The first five mixtures were based on previous
experience applied to project material and using the recommended dosage of ad-
mixture. Subsequent mixtures introduced the materials and proportions required
to provide a comprehensive study of all reasonable combinations. Pertinent
information on the mixtures is given in the remarks column of Table 8. Mixing
was done according to ASTM C 192-81.

Tests

8. Tests were conducted according to the following ASTM standards:
   a. Slump - C 143-78.
   c. Splitting tensile strength - C 496-79.
   d. Modulus of elasticity and Poisson's ratio - C 469-81.
   e. Resistance to freezing and thawing - C 666-80.
   f. Length change on drying - C 157-80.
   g. Creep - C 512-82.

9. The compressive strength specimens were 3-in.-diameter by 6-in.-long
cylinders cured in water until time of test. Due to the very high test strength,
compressive specimens were ground to tolerance on a surface grinder rather than
being capped. Electrical resistance strain gages were used to record stress-
strain data for calculation of modulus of elasticity and Poisson's ratio.
Results

Proportioning

10. The proportioning work, Table 8, indicated that it is indeed possible to achieve workable, low W/C concrete with various combinations of the selected materials. Slumps in the range up to 8 in. were secured with water-cementitious ratios approximating 0.25 and without segregation or harshness in most instances. During the proportioning study, however, it became apparent that a slight reduction in W/C or slight increase in admixture dosage could instantly change the workability of a mixture. A decrease of 0.01 in W/C could make a mixture very sticky or an increase of 0.1 percent in admixture dosage could result in a harsh mixture. Apparently, these changes are the result of working near the critical minimum amount of water (W/C = 0.25) and the critical maximum dosage of admixture (1.0 percent of cement). The slump test is not a good indicator of workability under these circumstances. A high-slump mixture may consolidate satisfactorily yet be sticky and hard to move. A high-slump mixture may even "flow" during the slump test, but be very harsh. It is not possible to relate the characteristics of the mixture developed herein directly to a field situation due to variations of materials, the chemistry of the cement and admixtures, and the differences in mixing actions and temperature. These mixtures could, however, be used as a basis for field mixtures to be tried under actual job conditions with job equipment.

11. Slump loss tests were conducted on three mixtures, Nos. 38, 48, and 58, to determine loss of workability with time. An initial slump test was conducted immediately after mixing. The concrete was then allowed to be at rest for 25 min, at which time it was remixed for 5 min. This cycle was repeated until the end of the test. Results are given in Table 9. Indications are that some workability will be lost over a period of 2 hr, but the concrete will remain placeable for 2 hr. Redosing with admixture is a viable option for restoring workability, but redosing tests were not conducted in this study. Again, the importance of these tests is to indicate that extended workability is possible to achieve with these mixtures; field tests should be conducted under actual project conditions.
Compressive strength

12. Compressive strength results are given in Table 10. The tests were conducted on 3- by 6-in. cylinders (3 x 6) unless otherwise noted. Indications are that:

a. Compressive strengths of approximately 10,000 psi may be attained at 7-days age with the materials used and the slump specified.
b. Compressive strengths of 12,000 psi may be achieved at 28-days age.
c. Compressive strengths of 15,000 psi may be attained at 90-days age.
d. Compressive strengths of 20,000 psi may be attained with selected mixtures at extended ages.
e. The use of high-range water-reducing admixtures is necessary to achieve the desired strengths at the required slumps.
f. Fly ash and silica fume enhance the potential for increased compressive strength.
g. High-strength, air-entrained concrete containing silica fume is feasible.
h. Fibers may be used in high-strength concrete; however, a significant loss in workability results.
i. Lightweight high-strength (10,000-psi) concrete could not be attained with the materials and techniques used herein.

13. To facilitate comparison of the two project aggregates, strength results are given in Tables 11 and 12 for limestone and granite coarse aggregates, respectively. A cursory examination of the results reveals that the granite aggregate produced slightly higher strengths for comparable mixtures. However, it is obvious that 15,000-psi concrete may be attained with either of the coarse aggregates and selected cementitious materials and admixtures used in the program.

Splitting tensile strength

14. Splitting tensile strength results are given in Table 13. Tensile strengths of approximately 1200 psi were achieved on several mixtures. Thus, the tensile strength is approximately 9 percent of the comparable compressive strength. This compares to the normally accepted value of 10 percent used for conventional concrete.

Elastic properties

15. Stress-strain curves for 18 specimens tested in compression to failure are given in Figures 1-18. The curves for vertical strain are essentially linear to failure. Some nonlinearity is apparent in the horizontal or
circumferential strain. Young's modulus of elasticity and Poisson's ratio results are given in Table 13. Young's modulus for the representative samples tested approximated $6.0 \times 10^6$ psi. This is twice the normally accepted value for conventional concrete. Poisson's ratio varied somewhat depending on the curvature of the horizontal strain curve and at what stress level the ratio was computed. Actual values ranged between 0.20 and 0.25.

**Drying shrinkage tests**

16. Results of length change tests, conducted on mixtures No. 22 and 35, are given in Tables 14-17. All specimens were cured in water in accordance with ASTM C 157. For the control tests, Tables 14 and 16, cement was substituted for silica fume on a weight basis. Thus, the total amount of water and the W/C remained constant for all four mixtures. On the 1-in. unrestrained bars expansion was noted in all mixtures. However, significantly more expansion was noted on the mixtures without silica fume. Approximately 0.004 percent shrinkage was noted with the 3-in. bars on the mixtures containing silica fume at 100-days age.

**Resistance to freezing and thawing**

17. Tests for resistance to freezing and thawing were conducted on three mixtures; one air-entrained limestone coarse aggregate mixture, one air-entrained granite aggregate mixture, and one nonair-entrained granite mixture. Results are given in Tables 18, 19, and 20. After 300 cycles of freezing and thawing all mixtures had a relative modulus (E) of at least 80 percent. At approximately 350 cycles both granite mixtures (air- and nonair-entrained) had a modulus of about 85 percent but the air-entrained limestone mixture had dropped to approximately 70 percent. At approximately 400 cycles the granite mixtures still had a modulus of approximately 80 percent, but the limestone mixture had dropped to 50 percent. All testing was terminated when the modulus decreased to 50 percent on each of the three mixtures. Apparently, the combination of a very dense rock (granite) and a very low W/C provided excellent resistance to freezing and thawing. It would appear that the nonair-entrained concrete did not achieve critical saturation with water under the test conditions used.
Creep tests

18. Creep tests were conducted on specimens from mixture No. 22 with and without silica fume in accordance with ASTM C 512-82. The creep load was 2000 psi. Results for total strain, creep strain, and specific creep up to 3-months age are given in Figures 19-24. At 90-days age indications are that (a) creep is essentially equal for mixtures with and without silica fume, (b) total strain approximated 500 millionths, (c) creep strain approximated 200 millionths, and (d) specific creep was approximately 0.1 millionth per psi.

Conclusions

19. The results of this investigation indicate the following:
   a. It is feasible to achieve 15,000-psi compressive strength concrete with selected cementitious materials and aggregates from the Wyoming area.
   b. Some workability may be lost over a time period of 2 hr; thus, this phenomenon should be investigated under job conditions.
   c. Tensile strengths approximating 1200 psi were achieved. Modulus of elasticity was approximately 6.0 x 10^6 psi and Poisson's ratio was approximately 0.20.
   d. Shrinkage of typical high-strength concrete containing silica fume was indicated to be on the order of 0.004 percent at 100 days in water.
   e. Freeze-thaw-resistant concrete was achieved with both project aggregates in an air-entrained mixture. In addition, a nonair-entrained mixture with the granite aggregate developed significant freeze-thaw resistance.
   f. Creep was essentially equal for mixtures with and without silica fume, approximating 200 millionths of strain at 3-months age under 2000 psi of stress.

Recommendations

20. It is recommended that (a) all materials and procedures to be used on a specific project be tested in the laboratory for basic property information, and (b) selected mixtures be tested in the field under expected environmental conditions prior to actual job use.
**Table 1**

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<th>TEST RESULTS</th>
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<td>6 IN.</td>
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<td>3 IN.</td>
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<td>12 IN.</td>
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**OCURRENCE:**
- **LOCATION:** Granite Canyon, Wyoming
- **PRODUCER:** Omaha District
- **SAMPLED BY:** Omaha District
- **TESTED FOR:**
- **USES AT:**
- **PROCESSING BEFORE TESTING:**
- **GEOLOGICAL FORMATION AND AGE:**

**AGGREGATE DATA SHEET**

| LAB SYMBOL NO. | OM19 G-1 |
| TOTAL VOLUME | 4.00 |
| TYPE OF MATERIAL | Granite No. 4 to 1 in. |
| DATE | 29 April 1983 |

**LABORATORY SYMBOI NO.**

**REMARKS:**

**PETROGRAPHIC DATA (CRD-C 127):**

**MORTAR-MAKING PROPERTIES (CRD-C 116):**

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**SOUNDNESS IN CONCRETE (CRD-C 40, 116):**

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<tr>
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<td>12 MO.</td>
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**PETROGRAPHIC DATA (CRD-C 127):**

**REMARKS:**
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| GRADING (ICRD-C 103) (CUM. % PASSING): | TEST RESULTS |
|-----|-----|-----|-----|-----|
| SIEVE | 3-4 | 1-3 | 1-1 | 4E-1 |
|       | FINE AGG. | BULK SP GR. | S.S.O. | (ICRD-C 107, 108) |
| 6 IN.  |       | 2.69 |     |     |
| 5 IN.  |       |     | 0.44 |     |
| 4 IN.  |       |     |     |     |
| 3 IN.  |       |     |     |     |
| 2 IN.  |       |     |     |     |
| 1 IN.  |       |     |     |     |
| 1/2 IN. | 100 |     |     |     |
| 1/2 IN.. | 99 |     |     |     |
| 1/4 IN. | 64 |     |     |     |
| 1/4 IN. | 27 |     |     |     |
| NO. 4  | 14 |     |     |     |
| NO. 8  | 1  |     |     |     |
| NO. 16 |     |     |     |     |
| NO. 30 |     |     |     |     |
| NO. 100 |     |     |     |     |
| NO. 200 |     |     |     |     |
| -200/1 |     |     |     |     |
| F.M.T. |     |     |     |     |
| MORTAR-MAKING PROPERTIES (ICRD-C 116) | TYPE CEMENT, RATIO: DAYS, % |
| MORTAR-BAR EXPANSION AT 100F, % (ICRD-C 121) | FINE AGG. COARSE AGG. |
| SOUNDNESS IN CONCRETE (ICRD-C 40, 116) | FINE AGG. COARSE AGG. |
| PETROGRAPHIC DATA (ICRD-C 127) | REMARKS |

Remarks:
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<th>Table 3</th>
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**STATE**

**INDEX NO.**

**AGGREGATE DATA SHEET**

**LAB SYMBOL NO.**

**LONG**

**TYPE OF MATERIAL**

**LOCATION**

**OM19 S-1**

Granite Canyon, Wyoming

**PRODUCER**

Omaha District

**SAMPLED BY**

Omaha District

**TESTED FOR**

**USED AT**

**PROCESSING BEFORE TESTING**

**GEOLOGICAL FORMATION AND AGE**

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**TEST RESULTS**

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**FINER FRACTION**

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<tr>
<td>100</td>
<td></td>
<td></td>
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**MORTAR-MAKING PROPERTIES (CRD-C 116):**

<table>
<thead>
<tr>
<th>NO. 16</th>
<th>NO. 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>5</td>
</tr>
</tbody>
</table>

**MORTAR-BAR EXPANSION AT 100F. (CRD-C 123):**

<table>
<thead>
<tr>
<th>FINE AGG.</th>
<th>COARSE AGG.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PETROGRAPHIC DATA (CRD-C 127):**

<table>
<thead>
<tr>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>
Table 4

<table>
<thead>
<tr>
<th>SIEVE</th>
<th>3/8&quot;</th>
<th>1/4&quot;</th>
<th>1/2&quot;</th>
<th>%4.1 FINE AGG.</th>
<th>3/8&quot;</th>
<th>1/4&quot;</th>
<th>1/2&quot;</th>
<th>%4.1 FINE AGG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 IN.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 IN.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 IN.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3 IN.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 IN.</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>1 1/4 IN.</td>
<td>100</td>
<td></td>
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</tr>
<tr>
<td>1 IN.</td>
<td>96</td>
<td></td>
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</tr>
<tr>
<td>3/4 IN.</td>
<td>47</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1/2 IN.</td>
<td>19</td>
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<td>NO. 4</td>
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<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO. 50</td>
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<td></td>
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<tr>
<td>NO. 100</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>NO. 200</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-200 (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PROCESSING BEFORE TESTING**

**GEOLOGICAL FORMATION AND AGE**

**TEST RESULTS**

| BULK SP. GR. S.S.D. (CRD-C 107, 108) | 2.69 |
| ABSORPTION, % (CRD-C 107, 108) | 0.5 |
| ORGANIC IMPURITIES, FIG. NO. (CRD-C 121) |      |
| SOFT PARTICLES, % (CRD-C 120) |      |
| LIGHTER THAN SP GR (CRD-C 122) |      |
| FLAT AND ELONGATED (CRD-C 119, 120) |      |
| WT AV - LOSS, 5 CYC MGO (CRD-C 115) |      |
| L.A. ABRASION LOSS, % (CRD-C 117, 145) GRADING |      |
| UNIT WT, LB CFT (CRD-C 106) |      |
| FRIABLE PARTICLES, % (CRD-C 142) |      |
| SPEC. HEAT, BTU/LB/DEG F. (CRD-C 124) |      |
| REACTIVITY WITH NaOH S, CRM L |      |
| MORTAR-MAKING PROPERTIES (CRD-C 118) |      |
| CEMENT, RATIO |      |
| DAYS |      |
| 3 IN. |      |
| 6 IN. |      |
| 9 IN. |      |
| 12 IN. |      |
| 3 MO. |      |
| 6 MO. |      |
| 9 MO. |      |
| 12 MO. |      |
| LINEAR THERMAL EXPANSION, MILLIONTHS-DEG F. (CRD-C 129, 126) |      |
| ROCK TYPE |      |
| PARALLEL |      |
| ACROSS |      |
| AVERAGE |      |
| MORTAR |      |

**MORTAR-BAR Expansion at 100°F.** (CRD-C 123)

<table>
<thead>
<tr>
<th>FINE AGGREGATE</th>
<th>COARSE AGGREGATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 MO. 6 MO. 9 MO. 12 MO.</td>
<td>2 MO. 6 MO. 9 MO. 12 MO.</td>
</tr>
<tr>
<td>LOW-ALK. CEMENT</td>
<td></td>
</tr>
<tr>
<td>HIGH-ALK. CEMENT</td>
<td></td>
</tr>
<tr>
<td>SOUNDERNESS IN CONCRETE (CRD-C 60, 114)</td>
<td></td>
</tr>
<tr>
<td>FINE AGG</td>
<td></td>
</tr>
<tr>
<td>COARSE AGG</td>
<td></td>
</tr>
<tr>
<td>FINE AGG</td>
<td></td>
</tr>
<tr>
<td>COARSE AGG</td>
<td></td>
</tr>
<tr>
<td>PETROGRAPHIC DATA (CRD-C 127)</td>
<td></td>
</tr>
</tbody>
</table>

**REMARKS:**

**LAB SYMIBOL NO.**

<table>
<thead>
<tr>
<th>LAB SYMBOL NO.</th>
<th>CL-2 G-1, Ms-1</th>
</tr>
</thead>
</table>

**TYPE OF MATERIAL:**

Limestone

**PRODUCER:**

Vulcan Materials Co., Birmingham, Ala.

**SAMPLED BY:**

USAEWES

**TESTED FOR:**

Laboratory Stock

**USED AT:**

USAEWES

**LOCATION:**

Sec. 8, T 22 S, R 2 W, 1-1/2 miles NW of Calera, Ala. (Calera Quarry)

**STATE:**

Ala.

**INDEX NO.:**

6 (Suppl 7)

**AGGREGATE DATA SHEET:**

**TESTED BY:**

USAEWES

**DATE:**

3 Feb 1975
# Table 5

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1</th>
<th>20.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.O.</td>
<td></td>
<td>4.3</td>
</tr>
<tr>
<td>P.O.</td>
<td></td>
<td>3.2</td>
</tr>
<tr>
<td>M.O.</td>
<td></td>
<td>0.9</td>
</tr>
<tr>
<td>S.O.</td>
<td></td>
<td>2.8</td>
</tr>
<tr>
<td>Loss on Ignition</td>
<td></td>
<td>2.3</td>
</tr>
<tr>
<td>Total Alkalies</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>N.H.</td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>S.I.</td>
<td></td>
<td>0.35</td>
</tr>
<tr>
<td>Insoluble Residue</td>
<td></td>
<td>0.32</td>
</tr>
<tr>
<td>C.O.</td>
<td></td>
<td>64.5</td>
</tr>
<tr>
<td>C.3</td>
<td></td>
<td>65</td>
</tr>
<tr>
<td>C.2</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>C.1</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>C.4</td>
<td></td>
<td>71</td>
</tr>
<tr>
<td>C.8</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>3.0 + 3.1</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>Heat of Hydration, 24 Hr, cal/g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat of Hydration, 28 D, cal/g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface Area to CO2 (g per g)</td>
<td>4030</td>
<td></td>
</tr>
<tr>
<td>Air Content</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Comp. Strength 30 D, psi</td>
<td>3600</td>
<td></td>
</tr>
<tr>
<td>Comp. Strength 7 D, psi</td>
<td>4770</td>
<td></td>
</tr>
<tr>
<td>Comp. Strength 28 D, psi</td>
<td>6090</td>
<td></td>
</tr>
<tr>
<td>False Set-Prel. F.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Auto.Clave Exp.</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Initial Set, HR/MIN</td>
<td>2:45</td>
<td></td>
</tr>
<tr>
<td>Final Set, HR/MIN</td>
<td>4:25</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:** High Strength Concrete Program - Ken Saucier

**cc:** Don Walley

---

The information given in this report shall not be used in advertising or sales promotion to indicate either explicitly or implicitly endorsement of this product by the U.S. Government.

---

R. E. REINHOLD
Chief, Cement & Pozzolan Unit
<table>
<thead>
<tr>
<th>Table 6A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LABORATORY:</strong> Structures Laboratory USAE Waterways Exp St</td>
</tr>
<tr>
<td><strong>ATTN:</strong> Cem &amp; Pozz Test Br</td>
</tr>
<tr>
<td><strong>P.O. Box 631</strong></td>
</tr>
<tr>
<td>Vicksburg, MS 39180</td>
</tr>
<tr>
<td><strong>CLASS (F):</strong></td>
</tr>
<tr>
<td><strong>KIND OF POZZOLAN:</strong> Fly Ash</td>
</tr>
<tr>
<td><strong>SOURCE:</strong> Williams Bros., Atlanta, GA</td>
</tr>
<tr>
<td><strong>BRAND:</strong></td>
</tr>
<tr>
<td><strong>TEST RESULTS OF THIS SAMPLE LOT [ ] COMPLY [X] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS):</strong></td>
</tr>
<tr>
<td><strong>FOR USE AT:</strong></td>
</tr>
<tr>
<td><strong>DISTRICT(S):</strong></td>
</tr>
<tr>
<td><strong>SAMPLED BY:</strong> Cem &amp; Pozz Testing Branch</td>
</tr>
<tr>
<td><strong>TESTED BY:</strong> Cem &amp; Pozz Testing Branch</td>
</tr>
<tr>
<td><strong>CAR NO.:</strong></td>
</tr>
<tr>
<td><strong>DATE RE CEIVED:</strong></td>
</tr>
<tr>
<td><strong>TESTED ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW</strong></td>
</tr>
<tr>
<td><strong>TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>POZZOLAN</strong></td>
</tr>
<tr>
<td><strong>SOURCE:</strong></td>
</tr>
<tr>
<td><strong>FIRE &amp; ALKALIES</strong></td>
</tr>
<tr>
<td><strong>AVAILA BLE ALKALIES</strong></td>
</tr>
<tr>
<td><strong>SIO2 + AL2O3 + Fe2O3</strong></td>
</tr>
<tr>
<td><strong>w/o</strong></td>
</tr>
<tr>
<td><strong>%</strong></td>
</tr>
<tr>
<td><strong>SO3</strong></td>
</tr>
<tr>
<td><strong>%</strong></td>
</tr>
<tr>
<td><strong>POZZOLAN STRENGTH % CONTROL</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>INCREASE IN SHrinkage</strong></td>
</tr>
<tr>
<td><strong>%</strong></td>
</tr>
<tr>
<td><strong>AUTOCLAVE EXPANSION</strong></td>
</tr>
<tr>
<td><strong>%</strong></td>
</tr>
<tr>
<td><strong>REDUCTION IN EXPANSION</strong></td>
</tr>
</tbody>
</table>

| **REMARKS:** | **APPLICABLE ONLY TO CLASS N** |
| | **LABORATORY CEMENT USED** |
| | **ALPHA, BIRMINGHAM, AL, WES-215-79** |
| **ALUMINUM**: | **CHESMARONE** |
| **APPLICATIONS:** | **OPPERATIONAL REQUIREMENTS** |
| **NOTES:** | **LAbORATORY USE** |
| **SPECIFICATION REQUIREMENTS:** | **W. G. MILLER** |
| **28 DAY TEST REPORT** | **CHEMIST** |
| **MEETS/7 DAY SPECIFICATION REQUIREMENTS** | **CHIEF, CEMENT & POZZOLAN TEST BRANCH** |

**NOTE:** THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLIED ENDORSEMENT OF THIS PRODUCT BY THE U.S. GOVERNMENT.
# Table 6B

<table>
<thead>
<tr>
<th>SIO₂</th>
<th>K₂O</th>
<th>MgO</th>
<th>K₂O</th>
<th>ALKALIES</th>
<th>POZZOLAN STRENGTH</th>
<th>POZZOLAN STRENGTH</th>
<th>AUTOCLAVE EXPANSION</th>
<th>REDUCTION IN Mg₁₀ALKALIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.0</td>
<td>5.5</td>
<td>3.2</td>
<td>1 * 105</td>
<td>-0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>MOISTURE CONTENT</th>
<th>LOSS ON IGNITION</th>
<th>LIME FROM POZZOLAN</th>
<th>POZZOLAN STRENGTH</th>
<th>WATER REQUIREMENT</th>
<th>SPECIFIC GRAVITY</th>
<th>SP OR VARIATION</th>
<th>SP OR VARIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>0.2</td>
<td>12</td>
<td>2</td>
<td>1830</td>
<td>98</td>
<td>2.75</td>
<td>2</td>
</tr>
</tbody>
</table>

| CaO %: | 25.0 |

### Remarks
Meets 7 day specification requirements, *28 day test results*

R. E. REINHOLD  
Chief, Cement & Pozzolan Unit

**NOTE:** The information given in this report shall not be used in advertising or sales promotion to indicate either explicitly or implicitly endorsement of this product by the U.S. Government.
### Table 7
CORRECTED 12 APRIL 1983

<table>
<thead>
<tr>
<th>CLASS</th>
<th>KIND OF POZZOLAN</th>
<th>SOURCE</th>
<th>BRAND</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Silica Fume</td>
<td>Reynolds Metals, Sheffield, Ala</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>REPORT NO.</th>
<th>WES-435-83</th>
</tr>
</thead>
<tbody>
<tr>
<td>REPORT OF TESTS ON POZZOLAN</td>
<td>AD 536(S5)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DATE</th>
<th>23 February 1983</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHEET OF</td>
<td>2</td>
</tr>
</tbody>
</table>

**LABORATORY REPORT NO., Structures Laboratory**

**WES-435-83**

**Wa terways Exp Station**

**ATTN: Cem & Pozz Unit**

**P. O. Box 631**

**Vicksburg, MS 39180**

**Laboratory Test Results**

- **Fineness (AP) m²/kg:**
  - 2584, e=0.727
  - 3806, e=0.700
  - 4783, e=0.678
- **Extrapolated m²/kg:**
  - 12780, e=0.500, Correlation Coefficient: -1

**Date Sampled:** 10 Feb 83

**Field Sample No.:**

**Lab Sample No.:**

**Date Received:** 11 Feb 83

**Lab Job No.:**

**Sampled by:** Cem & Pozz Unit

**Checked by:**

**Tests on Composites of the 150-Ton Samples Listed Below**

<table>
<thead>
<tr>
<th>Source</th>
<th>Field Sample No.</th>
<th>Lab Sample No.</th>
<th>Date Received</th>
<th>Tested by</th>
<th>Checked by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica Fume</td>
<td>1</td>
<td>11 Feb 83</td>
<td></td>
<td>Cem &amp; Pozz Unit</td>
<td></td>
</tr>
</tbody>
</table>

**Tests on Composite of the 150-Ton Samples Listed Below**

| Test Results | 109 | -0.14 |

**Tests on Samples Representing 100 Tons or Less**

- **Fineness %:** 325 Mesh var from 102000 psi
  - % of Retained: 10
    - Control

**Available Alkalis**

<table>
<thead>
<tr>
<th>Na₂O</th>
<th>K₂O</th>
<th>MgO</th>
<th>CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.50</td>
<td>0.50</td>
<td>5.00</td>
<td>15.00</td>
</tr>
</tbody>
</table>

**Requirements**

<table>
<thead>
<tr>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.50</td>
<td>5.00</td>
</tr>
</tbody>
</table>

**Tests Results**

- **Heat of Hydration**
  - **Portland Cement, RC 883(4):**
    - W/C: 0.27, W/C: 0.40
    - 7 days: 56, 75cal/m²
    - 28 days: 62, 83
  - **RC883(4), 85g + AD536(S5), 15g + H₂ range WRA.4g:**
    - 7 days: 50, 53
    - 28 days: 48, 61

**AVERAGE**

- **W/C: 0.40**
  - 7 days: 56, 75cal/m²
  - 28 days: 62, 83

**Remarks**

- *Fails water requirement.

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

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<table>
<thead>
<tr>
<th>Mix-</th>
<th>Rock</th>
<th>Cement/</th>
<th>W/C</th>
<th>% HRWR</th>
<th>Slump</th>
<th>S/A</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>ture</td>
<td>Type</td>
<td>Sil. Fume/</td>
<td>By wt</td>
<td>per 100 #</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td></td>
<td>Fly Ash/</td>
<td>cmt mtls</td>
<td>cmt mtls</td>
<td>in.</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>lb/cu yd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>LS</td>
<td>940</td>
<td>0.27</td>
<td>0.5</td>
<td>1/2</td>
<td>38</td>
<td>Slump too low; used D-19 HRWR admixture.</td>
</tr>
<tr>
<td>2</td>
<td>LS</td>
<td>940</td>
<td>0.28</td>
<td>0.5</td>
<td>2-3/4</td>
<td>38</td>
<td>Upped the W/C for more slump.</td>
</tr>
<tr>
<td>3</td>
<td>LS</td>
<td>940</td>
<td>0.30</td>
<td>0.5</td>
<td>2</td>
<td>38</td>
<td>Upped the W/C again.</td>
</tr>
<tr>
<td>4</td>
<td>LS</td>
<td>940</td>
<td>0.32</td>
<td>0.5</td>
<td>5-1/2</td>
<td>38</td>
<td>Upped the W/C again. Increased slump.</td>
</tr>
<tr>
<td>5</td>
<td>LS</td>
<td>940</td>
<td>0.32</td>
<td>0.5</td>
<td>6-1/2</td>
<td>40</td>
<td>Upped the S/A. Got the slump.</td>
</tr>
<tr>
<td>6</td>
<td>WES</td>
<td>940</td>
<td>0.28</td>
<td>0.5</td>
<td>1</td>
<td>38</td>
<td>Concerned about high W/C and strength. Lowered S/A. Used WES rock.</td>
</tr>
<tr>
<td>7</td>
<td>LS</td>
<td>799/141</td>
<td>0.30</td>
<td>0.5-0.8</td>
<td>1 to 6</td>
<td>38</td>
<td>First fume mix (15%). Increase to 0.8 HRWR makes big slump diff.</td>
</tr>
<tr>
<td>8</td>
<td>WES</td>
<td>799/141</td>
<td>0.30</td>
<td>0.5</td>
<td>1-1/4</td>
<td>38</td>
<td>Repeat of last mix using WES rock and 0.5 HRWR.</td>
</tr>
<tr>
<td>9</td>
<td>WES</td>
<td>799/141</td>
<td>0.28</td>
<td>0.7-0.8</td>
<td>1-1/2</td>
<td>38</td>
<td>Repeat of last mix lowering W/C, upping HRWR using WES rock.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6-1/2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>WES</td>
<td>799/141</td>
<td>0.26</td>
<td>0.8</td>
<td>1-1/2</td>
<td>38</td>
<td>Repeat of last mix lowering W/C even more and upping HRWR to 0.8.</td>
</tr>
<tr>
<td>11</td>
<td>WES</td>
<td>799/141</td>
<td>0.30</td>
<td>0.8</td>
<td>6-3/4</td>
<td>40</td>
<td>Repeat of No. 8 increasing HRWR to 0.8 and S/A to 40% or workability.</td>
</tr>
<tr>
<td>12</td>
<td>LS</td>
<td>799/141</td>
<td>0.28</td>
<td>0.8</td>
<td>1</td>
<td>38</td>
<td>Too stiff.</td>
</tr>
<tr>
<td>13</td>
<td>LS</td>
<td>799/141</td>
<td>0.28</td>
<td>0.8</td>
<td>2</td>
<td>38</td>
<td>Modification of No. 7 decreasing the W/C and using 0.8 HRWR.</td>
</tr>
<tr>
<td>14</td>
<td>LS</td>
<td>799/141</td>
<td>0.30</td>
<td>0.8</td>
<td>6</td>
<td>38</td>
<td>Repeat of last one using 0.28 W/C at the beginning. Acceptable.</td>
</tr>
<tr>
<td>15</td>
<td>WES</td>
<td>859/139</td>
<td>0.24</td>
<td>1.86</td>
<td>9-1/2</td>
<td>40</td>
<td>Upped W/C; still concerned that W/C of 0.30 too high.</td>
</tr>
<tr>
<td>16</td>
<td>WES</td>
<td>859/139</td>
<td>0.24</td>
<td>1.16</td>
<td>8</td>
<td>40</td>
<td>Upped HRWR, upped S/A, lowered W/C; error increased CMT and decreased fume.</td>
</tr>
<tr>
<td>17</td>
<td>WES</td>
<td>859/139</td>
<td>0.24</td>
<td>0.93</td>
<td>2-1/2</td>
<td>40</td>
<td>Lowered HRWR and slump just fell inside criteria.</td>
</tr>
<tr>
<td>18</td>
<td>WES</td>
<td>799/141</td>
<td>0.24</td>
<td>1.25</td>
<td>3-1/4</td>
<td>40</td>
<td>Brought HRWR down some more, slump came down with it. O.K.</td>
</tr>
<tr>
<td>19</td>
<td>WES</td>
<td>799/141</td>
<td>0.26</td>
<td>1.0-1.25</td>
<td>3 to 9</td>
<td>40</td>
<td>Just to see what No. 15 would look like using right CMT &amp; fume. O.K.</td>
</tr>
<tr>
<td>20</td>
<td>WES</td>
<td>658/141/</td>
<td>0.24</td>
<td>1.0</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>141</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>LS</td>
<td>799/141</td>
<td>0.24</td>
<td>1.0</td>
<td>3</td>
<td>40</td>
<td>First fume-fly ash mixture (15% each by weight). Looked good.</td>
</tr>
<tr>
<td>22</td>
<td>LS</td>
<td>959/169</td>
<td>0.24</td>
<td>1.0</td>
<td>7-3/4</td>
<td>40</td>
<td>Slightly harsh; vibrated O.K.</td>
</tr>
<tr>
<td>23</td>
<td>LS</td>
<td>959/169</td>
<td>0.22</td>
<td>1.0</td>
<td>3-1/2</td>
<td>40</td>
<td>Better looking than 21; less harsh; vibrated well.</td>
</tr>
<tr>
<td>24</td>
<td>G</td>
<td>940</td>
<td>0.24</td>
<td>1.0</td>
<td>8</td>
<td>40</td>
<td>Lowered W/C; same as 22; looked good.</td>
</tr>
<tr>
<td>25</td>
<td>G</td>
<td>940</td>
<td>0.22</td>
<td>1.0</td>
<td>3</td>
<td>40</td>
<td>Sticky; vibrated, but hard to work with.</td>
</tr>
<tr>
<td>26</td>
<td>G</td>
<td>799/141</td>
<td>0.24</td>
<td>1.0</td>
<td>3-1/2</td>
<td>40</td>
<td>Very sticky; balled up; added 0.2% HRWR to make placeable.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Remarks**

- Slump too low; used D-19 HRWR admixture.
- Upped the W/C for more slump.
- Upped the W/C again.
- Upped the W/C again. Increased slump.
- Upped the S/A. Got the slump.
- Concerned about high W/C and strength. Lowered S/A. Used WES rock.
- First fume mix (15%). Increase to 0.8 HRWR makes big slump diff.
- Repeat of last mix using WES rock and 0.5 HRWR.
- Repeat of last mix lowering W/C, upping HRWR using WES rock.
- Repeat of last mix lowering W/C even more and upping HRWR to 0.8.
- Repeat of No. 8 increasing HRWR to 0.8 and S/A to 40% or workability.
- Too stiff.
- Modification of No. 7 decreasing the W/C and using 0.8 HRWR.
- Repeat of last one using 0.28 W/C at the beginning. Acceptable.
- Upped W/C; still concerned that W/C of 0.30 too high.
- Upped HRWR, upped S/A, lowered W/C; error increased CMT and decreased fume.
- Lowered HRWR and slump just fell inside criteria.
- Brought HRWR down some more, slump came down with it. O.K.
- Just to see what No. 15 would look like using right CMT & fume. O.K.
- Upped the W/C to See if 1.0 HRWR would compare to 1.25 at 0.24 W/C. It did.

**TABLE 8 HIGH-STRENGTH MIXTURES**
<table>
<thead>
<tr>
<th>Mixt. No.</th>
<th>Rock Type</th>
<th>Cement/Sil. Fume/ Fly Ash/ By wt</th>
<th>W/C</th>
<th>% HRWR per 100 # cmmt mtls</th>
<th>Slump in.</th>
<th>S/A % Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>G</td>
<td>799/141</td>
<td>0.26</td>
<td>1.0</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>28</td>
<td>LS</td>
<td>799/141</td>
<td>0.24</td>
<td>1.0</td>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td>29</td>
<td>G</td>
<td>799/0/141</td>
<td>0.24</td>
<td>1.0</td>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>30</td>
<td>LS</td>
<td>799/0/141</td>
<td>0.24</td>
<td>1.0</td>
<td>2-1/2</td>
<td>40</td>
</tr>
<tr>
<td>31</td>
<td>G</td>
<td>902/226</td>
<td>0.20</td>
<td>1.0</td>
<td>2-3/4</td>
<td>40</td>
</tr>
<tr>
<td>32</td>
<td>LS</td>
<td>658/141/0</td>
<td>0.24</td>
<td>1.0</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>33</td>
<td>LS</td>
<td>658/141/1</td>
<td>0.24</td>
<td>1.0</td>
<td>3-1/2</td>
<td>40</td>
</tr>
<tr>
<td>34</td>
<td>G</td>
<td>658/141/141</td>
<td>0.24</td>
<td>1.0</td>
<td>3-1/2</td>
<td>40</td>
</tr>
<tr>
<td>35</td>
<td>G</td>
<td>959/169</td>
<td>0.24</td>
<td>1.0</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>36</td>
<td>G</td>
<td>799/141</td>
<td>0.26</td>
<td>1.0</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>37</td>
<td>LS</td>
<td>658/141/141</td>
<td>0.24</td>
<td>1.0</td>
<td>6-1/2</td>
<td>40</td>
</tr>
<tr>
<td>38</td>
<td>WES</td>
<td>799/141</td>
<td>0.30</td>
<td>30 oz.</td>
<td>9</td>
<td>40</td>
</tr>
<tr>
<td>39</td>
<td>WES</td>
<td>799/141</td>
<td>0.28</td>
<td>0.8</td>
<td>6-3/4</td>
<td>40</td>
</tr>
<tr>
<td>40</td>
<td>WES</td>
<td>799/141</td>
<td>0.30</td>
<td>40 oz.</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>41</td>
<td>WES</td>
<td>799/141</td>
<td>0.26</td>
<td>40 oz.</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>42</td>
<td>WES</td>
<td>799/141</td>
<td>0.24</td>
<td>25.5 oz.</td>
<td>1-3/4</td>
<td>40</td>
</tr>
<tr>
<td>43</td>
<td>WES</td>
<td>898/100</td>
<td>0.24</td>
<td>1.16</td>
<td>3-1/2</td>
<td>40</td>
</tr>
<tr>
<td>44</td>
<td>WES</td>
<td>799/141</td>
<td>0.24</td>
<td>1.16</td>
<td>5</td>
<td>40</td>
</tr>
</tbody>
</table>
### TABLE 8 (CONCLUDED)

<table>
<thead>
<tr>
<th>Mixture No.</th>
<th>Cement Type</th>
<th>Sil. Fume/ Fly Ash/</th>
<th>W/C</th>
<th>% HRWR per 100#</th>
<th>Slump in.</th>
<th>S/A %</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>51</td>
<td>WES</td>
<td>752/188</td>
<td>0.24</td>
<td>1.00</td>
<td>9-1/4</td>
<td>40</td>
<td>20% by weight cementitious materials substituted with Class C fly ash.</td>
</tr>
<tr>
<td>52</td>
<td>WES</td>
<td>658/282</td>
<td>0.24</td>
<td>1.00</td>
<td>8-1/4</td>
<td>40</td>
<td>30% by weight cementitious materials substituted with Class C fly ash.</td>
</tr>
<tr>
<td>53</td>
<td>Chert</td>
<td>798/200</td>
<td>0.42</td>
<td>1.16</td>
<td>10</td>
<td>40</td>
<td>Mix with special cement; unsuccessful.</td>
</tr>
<tr>
<td>54</td>
<td>Chert</td>
<td>799/141</td>
<td>0.29</td>
<td>1.00</td>
<td>5-1/2</td>
<td>40</td>
<td>Good mix; vibrated well.</td>
</tr>
<tr>
<td>55</td>
<td>WES</td>
<td>658/141</td>
<td>0.24</td>
<td>1.16</td>
<td>8</td>
<td>40</td>
<td>Control for mix 57; used Melgran.</td>
</tr>
<tr>
<td>56</td>
<td>Chert</td>
<td>780/160/0</td>
<td>0.24</td>
<td>2.00</td>
<td></td>
<td>40</td>
<td>2% calcium chloride used; very stiff; no slump test.</td>
</tr>
<tr>
<td>57</td>
<td>Chert</td>
<td>780/160/0</td>
<td>0.24</td>
<td>2.00</td>
<td></td>
<td>40</td>
<td>Repeat of mix 16 using 1-in. fiberglass fibers = 14.8#/cu yd.</td>
</tr>
<tr>
<td>58</td>
<td>WES</td>
<td>799/141/0</td>
<td>0.24</td>
<td>1.25</td>
<td>8-1/2</td>
<td>40</td>
<td>Repeat of mix 16 using fiberglass fibers = 24.3#/cu yd.</td>
</tr>
<tr>
<td>59</td>
<td>WES</td>
<td>859/139/0</td>
<td>0.24</td>
<td>1.16</td>
<td>1/4</td>
<td>40</td>
<td>Repeat of mix 16 using polypropylene fibers = 14.8#/cu yd.</td>
</tr>
<tr>
<td>60</td>
<td>WES</td>
<td>859/139/0</td>
<td>0.24</td>
<td>1.16</td>
<td>1/2</td>
<td>40</td>
<td>Attempt to entrain air; batch discarded.</td>
</tr>
<tr>
<td>61</td>
<td>WES</td>
<td>859/139/0</td>
<td>0.24</td>
<td>1.16</td>
<td>1/2</td>
<td>40</td>
<td>Not cast.</td>
</tr>
<tr>
<td>62</td>
<td>WES</td>
<td>799/141</td>
<td>0.24</td>
<td>1.25</td>
<td>8-1/2</td>
<td>40</td>
<td>Air entrained for freeze/thaw beams (4.6%).</td>
</tr>
<tr>
<td>63</td>
<td>WES</td>
<td>799/141</td>
<td>0.24</td>
<td>1.25</td>
<td>9-1/4</td>
<td>40</td>
<td>Non-air-entrained; control for mix 64.</td>
</tr>
<tr>
<td>64</td>
<td>LS</td>
<td>799/141</td>
<td>0/24</td>
<td>1/25</td>
<td>8-1/2</td>
<td>40</td>
<td>Air entrained for freeze/thaw beams (4.0%).</td>
</tr>
<tr>
<td>65</td>
<td>G</td>
<td>799/141/0</td>
<td>0.24</td>
<td>1.24</td>
<td>8-1/2</td>
<td>40</td>
<td>Air entrained at 2.5%; added AEA to get 5.8%.</td>
</tr>
<tr>
<td>66</td>
<td>G</td>
<td>799/141/0</td>
<td>0.24</td>
<td>1.25</td>
<td>9</td>
<td>40</td>
<td>Control for mix 67.</td>
</tr>
<tr>
<td>67</td>
<td>LS</td>
<td>846/96/0</td>
<td>0.24</td>
<td>1.25</td>
<td>7</td>
<td>40</td>
<td>3/8-in. expanded clay lightweight coarse aggregate (119.7#/cu ft).</td>
</tr>
<tr>
<td>68</td>
<td>G</td>
<td>799/141/0</td>
<td>0.24</td>
<td>1.25</td>
<td>2</td>
<td>39.5</td>
<td>3/8-in. expanded clay lightweight coarse aggregate (116.9#/cu ft).</td>
</tr>
<tr>
<td>69</td>
<td>LS</td>
<td>859/169/0</td>
<td>0.22</td>
<td>1.25</td>
<td>11</td>
<td>45</td>
<td>Lightweight aggregate. Wet unit weight = 121.2#/cu ft; 4.0% air.</td>
</tr>
<tr>
<td>70</td>
<td>G</td>
<td>799/169/0</td>
<td>0.22</td>
<td>1.25</td>
<td>10-1/2</td>
<td>45</td>
<td>Repeat of mix 22; cast creep and shrinkage specimens.</td>
</tr>
<tr>
<td>71</td>
<td>G</td>
<td>859/69/0</td>
<td>0.24</td>
<td>1.10</td>
<td>10</td>
<td>7</td>
<td>Repeat of mix 22 without silica fume. Cast shrinkage specimens.</td>
</tr>
<tr>
<td>72</td>
<td>G</td>
<td>859/69/0</td>
<td>0.24</td>
<td>1.10</td>
<td>8</td>
<td>40</td>
<td>Repeat of mix 35. Cast creep and shrinkage specimens.</td>
</tr>
<tr>
<td>73</td>
<td>G</td>
<td>1128/0/0</td>
<td>0.24</td>
<td>1.10</td>
<td>8</td>
<td>40</td>
<td>Repeat of mix 35 without silica fume. Cast shrinkage specimens.</td>
</tr>
</tbody>
</table>

**NOTE:** Aggregates:  
- LS - Project Limestone  
- WES - Laboratory Limestone  
- G - Project Granite  
- LTW - Lightweight
Table 9
Slump Loss Tests

Mixture No. 38

<table>
<thead>
<tr>
<th>Time, hours</th>
<th>Slump, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>0.5</td>
<td>7-3/4</td>
</tr>
<tr>
<td>1.0</td>
<td>7-3/4</td>
</tr>
<tr>
<td>1.5</td>
<td>7-3/4</td>
</tr>
<tr>
<td>2.0</td>
<td>7-1/2</td>
</tr>
<tr>
<td>2.5</td>
<td>5-1/2</td>
</tr>
</tbody>
</table>

Mixture No. 48

<table>
<thead>
<tr>
<th>Time, hours</th>
<th>Slump, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3-1/4</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Mixture No. 58

<table>
<thead>
<tr>
<th>Time, hours</th>
<th>Slump, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8-1/2</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Mixture No.</td>
<td>W/C Ratio</td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
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Table 10 (Continued)

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Table 10 (Concluded)

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Note: Strength data for mixes 73-76 are from 4 by 8 cylinders.
### Table 11

**Mixtures with Project Limestone Coarse Aggregate**

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ELASTIC PROPERTY RESULTS

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**Remarks:** TEST MIXTURE

- TYPE II CEMENT 958.8 LBS/YD³
- SILICA FUME 169.2 LBS/YD³
- WATER 270.7 LBS/YD³
- W/C 0.24

### 1-IN. UNRESTRAINED

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# Table 16

## Expansion Data Sheet

**Project:** High Strength Concrete  
**Mix Design:** No. 35 Without Silica Fume  
**Source of Data:** Laboratory  
**Remarks:** Control Mixture  
ASTM C 490 & ASTM C 157  
Material for 1-in. prisms passed the No. 4 sieve.

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<td>0.011</td>
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<td>0.1279</td>
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### 3-in. Unrestrained

<table>
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<tr>
<th>Date</th>
<th>Bar 1</th>
<th>% Exp</th>
<th>Bar 2</th>
<th>% Exp</th>
<th>Average</th>
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<tr>
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</tr>
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<td>0.024</td>
<td>0.1279</td>
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<td>0.025</td>
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</table>
### Table 17

#### EXPANSION DATA SHEET

**PROJECT:** HIGH STRENGTH CONCRETE  
**MIX DESIGN:** NO. 35 WITH SILICA FUME

**Source Of Data:** LABORATORY  
ASTM C 490 & ASTM C 157  
MATERIAL FOR 1-IN. PRISMS PASSED THE NO. 4 SIEVE

**DATE CAST:** 30 SEP 83  
**DATE DEMOLDED:** 1 OCT 83 at 24 HRS Age

**Remarks:** TEST MIXTURE  
TYPE II CEMENT 958.8 LBS/YD³  
SILICA FUME 169.2 LBS/YD³  
WATER 270.0 LBS/YD³  
W/C 0.24

#### 1-III, 1'1' RESTRAINED

<table>
<thead>
<tr>
<th>DATE</th>
<th>AGE (DAYS)</th>
<th>BAR 1</th>
<th>% EXP</th>
<th>BAR 2</th>
<th>% EXP</th>
<th>AVERAGE</th>
<th>BAR 1</th>
<th>% EXP</th>
<th>BAR 2</th>
<th>% EXP</th>
<th>AVERAGE</th>
</tr>
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<tbody>
<tr>
<td>Oct 1</td>
<td>2 Initial</td>
<td>0.2658</td>
<td>-----</td>
<td>0.3052</td>
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<td>0.1318</td>
<td>-----</td>
<td>0.1300</td>
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### Table 18

**DATA SHEET FOR HARDENED CONCRETE SPECIMENS**

<table>
<thead>
<tr>
<th>SYMBOL:</th>
<th>JOB NO.: 441-S591</th>
<th>MEMO NO.</th>
<th>DATE: 8-5-83</th>
<th>INITIALS: FWK</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT:</td>
<td>HIGH STR.</td>
<td>SPECIMEN TYPE: 3-1/2 X 9-1/2 X 16 in.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DATE PLACED:</td>
<td>8/8/83</td>
<td>DATE CORED:</td>
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<td></td>
</tr>
<tr>
<td>FINE AGG.:</td>
<td>Limestone OM 19 S-1</td>
<td>CURING: TYPE: Inundated Hot Room</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEMENT: RC (894(1))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AIR T TOTAL:</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TH. W.V. LB./CU. FT:</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>TESTS:</td>
<td>F &amp; T BEAMS (C14-C13-C13-C13)</td>
<td>F &amp; T 10&quot; CORES (C47-C47-C47-C47)</td>
<td>SPEC. HEAT (F95, 124-C40)</td>
<td>HWCD (C40)</td>
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<tr>
<td>BEGIN DATE:</td>
<td>97-93</td>
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<td>INT. FREQ.</td>
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<tr>
<td>REMARKS</td>
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#### TEST RESULTS

![Graph showing test results](attachment:graph.png)

#### LAB TRIAL MIXT NO. 66 (TEST MIXT: NO CONTROL)

<table>
<thead>
<tr>
<th>SPEC. NO.</th>
<th>RELATIVE E AT NO. OF CYCLES SHOWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycles</td>
<td>0</td>
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<tr>
<td>9781</td>
<td>100</td>
</tr>
<tr>
<td>9782</td>
<td>100</td>
</tr>
<tr>
<td>9783</td>
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</table>

#### REPORT OF EXAMINATION AFTER TEST

Relative E at No. of Cycles Shown

<table>
<thead>
<tr>
<th>Cycles</th>
<th>380</th>
<th>430</th>
</tr>
</thead>
<tbody>
<tr>
<td>9781</td>
<td>64</td>
<td>45</td>
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<tr>
<td>9782</td>
<td>43</td>
<td>49</td>
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<tr>
<td>9783</td>
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#### REMARKS

W. R. Grace HRWR DAXAD 19 (dry) 1-1/4% by wt cmt mtls (cmt+fume)

AEA AMEX 210 6 fl oz per cwt cmt mtls (cmt+fume)
Table 19

**DATA SHEET FOR HARDENED CONCRETE SPECIMENS**

(CRD-C 13, 25, 40, 47, 114, 38, 36, 37, 35, 124)

<table>
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<tr>
<th>SYMBOL</th>
<th>JOB NO: 441-8592</th>
<th>MEMO NO: 200</th>
<th>DATE: 8-9-83</th>
<th>INITIALS: DMW</th>
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<tbody>
<tr>
<td>PROJECT</td>
<td>HIGH S TR. CONC.</td>
<td>SPECIMEN TYPE: 3-1/2 x 4-1/2 x 16-in.</td>
<td>INHIBITED PLG ROOM</td>
<td>DURATION: 28 D</td>
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<tr>
<td>DATE PLACED</td>
<td>8/31/83</td>
<td>DATE CORDED</td>
<td>CURING TYPE</td>
<td>MAX.1-1/2</td>
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<tr>
<td>FINE AGG</td>
<td>Limestone ON 19 S-1</td>
<td>COARSE AGG</td>
<td>Granite ON 19 G-1</td>
<td>MAX.1-1/2</td>
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<tr>
<td>CEMENT</td>
<td>RC 894 (2)</td>
<td>ACT. C.F. B/CY</td>
<td>940 cmt+fume</td>
<td>S/A 1 VOL: 40</td>
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<tr>
<td>AIR I 5</td>
<td>1/2</td>
<td>IN-1/2</td>
<td>W/C GPB</td>
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<td>DURATON</td>
<td>28 D</td>
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<td>ACT. U.W. (PLASTIC)</td>
<td>ADMS</td>
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**TEST RESULTS**

<table>
<thead>
<tr>
<th>(A)</th>
<th>(B)</th>
<th>NO. OF CYCLES (A)</th>
<th>TIME HR (C)</th>
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<tbody>
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<td>50</td>
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**LAB TRIAL MIXT NO. 67 (TEST MIXT)**

<table>
<thead>
<tr>
<th>SPEC. NO</th>
<th>RELATIVE E AT NO. OF CYCLES SHOWN</th>
<th>DATE TEST COMPLETED</th>
<th>INITIALS</th>
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<tbody>
<tr>
<td>Cycles 0</td>
<td>58 119 165 200 246 307 346</td>
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</tr>
<tr>
<td>9784 100 99 97 97 96 96 89 81</td>
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<td>9785 100 97 97 97 96 96 90 82</td>
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<td>9786 100 97 96 96 96 95 95 94</td>
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**REPORT OF EXAMINATION AFTER TEST**

<table>
<thead>
<tr>
<th>Cycles</th>
<th>395 437</th>
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</thead>
<tbody>
<tr>
<td>9784</td>
<td>77 31</td>
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<td>9785</td>
<td>79 29</td>
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<tr>
<td>9786</td>
<td>93 27</td>
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**REMARKS:**

- W. R. Grace HRWR DAX49-19(dry) 1-1/4% by wt cmt mts (cmt+fume)
- AEA AMEX 210 8 fl oz per cwt cmt mts (cmt+sil fume)

*FES FORM 534*

*REV. MARI 30*
### Table 20

**DATA SHEET FOR HARDENED CONCRETE SPECIMENS**

**SYMBOL:** 441-S592  **MEMO NO:**  **DATE:** 8-9-83  **INITIALS:** DM

**PROJECT:** HIGH STR CONC  **SPECIMEN TYPE:** 3-1/2 x 4-1/2 x 16 in  **FIRE NO:**

**DATE PLACED:** 8/9/83  **DATE CORED:**  **CURING TYPE:** Inundated Fog Room  **DURATION:** 28 D

**FINE AGG:** Limestone OM 19 S-1  **COARSE AGG:** Granite 19 G-1  **MAX. 1-1/2 in.

**CEMENT:** RC 894(2)  **TH. C.F. B/CY:**  **ACT. C.F. B/CY:** 940 cmt+silfume  **S/A VOL:** 40

**AIR % TOTAL:** 0.8  **IN-1/2:**  **W/C GPB:** 0.24  **SLUMP IN. (-1/2):** 9  **TH. U.W. LB/CU. FT:**

**SPECIMEN TYPE:** 3-1/2 x 4-1/2 x 16 in  **DATE PLACED:** 8/9/83  **DATE CORED:**

**CURING TYPE:** Inundated Fog Room  **DURATION:** 28 D

**TESTS:** F & T BEAMS C140 C13  **F & T 30° CORES** C47  **SPEC. HEAT C35.124 C40**  **HWCD C40**  **SHRINKAGE C40**  **HEAT RISE C40**  **DIFFUSIVE C40**  **OTHER**  **SEE REMARKS**

**BEGIN DATE:**  **SPEC. NO.:** 97-87  **(A) FOR 3 1/2 X4 1/2 X W.N BEAMS**  **INITIALS:______**

**NOTE:** This table contains data for hardened concrete specimens, including symbols, project details, specimen type, and various test results. It also includes a graph showing relative heat at different cycles and a report of examination after the test. The table concludes with remarks about the mixture and entrapped air.

**Remarks:**

W. R. Grace HRWR DAXAD-19 (dry) 1-1/4% by wt cmt mts (cmt + fume) Control Mixture - No AEA used - the 0.8% is entrapped air.
FIGURE 2
Mixture No. 39
Specimen No. 1

\[ \epsilon = 1.3720 \times 10^6 \text{ psi} \]

\[ \epsilon = 6.49 \times 10^6 \text{ psi} \]
Figure 7:
Mixture No. 1, Specimen No. 1
σ = 11,150 psi
--- Horizontal Strain
--- Vertical strain
E = 5.75 x 10^6 psi
ν = 0.248

Stress (psi) vs. Strain

STRAIN: Gr. 71 x 10^{-6}
Figure 10

Mixture No. 65
Specimen No. 2

σ = 2,720 psi

Horizontal strain

Vertical strain

H = 4.45 x 10^-6 psi

ν = 0.25

Horizontal 250 500 750 1000 1250

Vertical 0 500 1000 1500 2000 2500

STRAIN 10^-5/10^-6 x 10^-6
FIGURE 12
Mixture 88
Specimen No. 2
\( \sigma = 14150 \text{ psi} \)
- horizontal strain
- vertical strain
\( E = 6.65 \times 10^6 \text{ psi} \)
\( \nu = 0.286 \)

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<thead>
<tr>
<th>Vertical</th>
<th>0</th>
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<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
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<tbody>
<tr>
<td>Horizontal</td>
<td>0</td>
<td>150</td>
<td>300</td>
<td>450</td>
<td>600</td>
<td>750</td>
</tr>
</tbody>
</table>

\( \text{STRAIN: in./in.} \times 10^{-6} \)
FIGURE 16

Specimen No. 2

$\sigma = 16610$ psi

- Horizontal strain
- Vertical strain

$E = 6.91 \times 206$ psi

$\nu = 0.215$

<table>
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<th>Vertical</th>
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<tbody>
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<td>750</td>
<td>1000</td>
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</table>
FIGURE 15
Mixture 68
Specimen No. 1
- o = 1600 psi
- Horizontal strain
- Vertical strain
\( \varepsilon = 0.17 \times 10^{-4} \text{ psi} \)
\( \nu = 0.205 \)
Figure 19. Total strain during loading period for mixture 22 with silica fume
Figure 20. Total strain during loading period for mixture 22 without silica fume.
Figure 21. Corrected creep strain for mixture 22 with silica fume; loaded to 2000 psi at 14-day age (unconfined)
Figure 22. Corrected creep strain for mixture 22 without silica fume; loaded to 2000 psi at 14-day age (unconfined)
Figure 23. Specific creep for mixture 22 with silica fume; loaded to 2000 psi at 14-day age (unconfined)
Figure 24. Specific creep for mixture 22 without silica fume; loaded to 2000 psi at 14-day age (unconfined)