MISCELLANEOUS PAPER C-68-1

# EFFECT OF TEMPERATURE ON AIR-ENTRAINING ADMIXTURE DEMAND OF CONCRETE WITH AND WITHOUT POZZOLANS

by

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July 1968

Sponsored by

Office, Chief of Engineers
U. S. Army

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

Miscellaneous Paper C-68-1

# EFFECT OF TEMPERATURE ON AIR-ENTRAINING ADMIXTURE DEMAND OF CONCRETE WITH AND WITHOUT POZZOLANS

## KEY

| Manufacturer | Symbol | Product |
|---|---|---|
| Lone Star Cement Co. Birmingham, Alabama Spocari, Alabama | RC-572 | Portland cement, type II |
| Commonwealth Edison Co. Chicago, Illinois (Procured from Chicago Fly Ash Co., Chicago, Illinois (Fisk Station)) | AD-3(10) | Fly ash I |
| Oregon Portland Cement Co. Oswego, Oregon | AD-140(11) | Calcined shale |
| Consolidated Gas, Electric Light & Power Co. Baltimore, Maryland | AD-9 | Fly ash IV |
| Hunt Process Southern Corp. Ridgeland, Mississippi | AEA-692 | Air-entraining admixture ("Air-In" brand) |
| Vulcan Materials Co. Hermitage Limestone Quarry Nashville, Tennessee | CRD-MS-17(2) | Manufactured limestone fine aggregate |
| | CRD-G-31(3), (4) | Manufactured limestone coarse aggregate |

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
VICKSBURG, MISSISSIPPI 39181

IN REPLY REFER TO: WESAR

4 September 1968

Errata Sheet

No. 1

Miscellaneous Paper C-68-1

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1. On page 11, paragraph 24, fifth line, add "ash" at end of line.

2. In table 1, second column, change "5" to "50" across from $C_3S$, %.

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## FOREWORD

The tests reported herein were authorized by the Office, Chief of Engineers, in first indorsement, dated 27 October 1965, to U. S. Army Engineer Waterways Experiment Station (WES) letter dated 24 September 1965, subject, "Effect of Temperature on Quantity of Air Entrained in Concrete, ES 623." The project is item ES 601.18 and is a part of item ES 601, "Research in Mass Concrete," of the Engineering Studies Program of the Corps of Engineers.

This work was conducted during the period November 1965 to August 1967 at the Concrete Division of WES under the direction of Mr. Bryant Mather and the supervision of Messrs. James M. Polatty, W. O. Tynes, Leonard Pepper, and W. B. Lee. This report was prepared by Mr. Tynes.

COL John R. Oswalt, Jr., and COL Levi A. Brown, CE, were Directors of the WES during this investigation and the preparation and publication of this report. Mr. J. B. Tiffany was Technical Director.

CONTENTS

## CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| inches | 2.54 | centimeters |
| cubic yards | 0.764555 | cubic meters |
| pounds | 0.45359237 | kilograms |
| gallons | 3.78533 | liters |
| pounds per square inch | 0.070307 | kilograms per square centimeter |
| pounds per cubic yard | 0.593 | kilograms per cubic meter |
| Fahrenheit degrees | 5/9 | Celsius or Kelvin degrees* |

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$ . To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.16$ .

## SUMMARY

Mixtures were made with portland cement, blends of portland cement and pozzolan, and pozzolan alone, at temperature ranges of 40-45, 70-80, and 90-100 F to determine whether increasing the temperature of freshly mixed concrete results in an increased requirement for air-entraining admixture in order to maintain a given level of air content in the concrete. The results indicated that the amount of air-entraining admixture (AEA) required in the mixture containing a low-carbon fly ash and no cement was affected very little if at all by temperature; whereas, in all other mixtures, the AEA demand was increased with increasing temperature. The temperature effect was considerable in the mixture containing the pozzolan, calcined shale, between the temperature ranges of 40-45 and 70-80 F. The data also show that the carbon content of fly ash and temperature effects are interrelated. It is believed that the effect of carbon is primarily physical.

## EFFECT OF TEMPERATURE ON AIR-ENTRAINING ADMIXTURE DEMAND OF CONCRETE WITH AND WITHOUT POZZOLANS

## PART I: INTRODUCTION

### Background and Purpose

1. The fact that the quantity of air-entraining admixture (AEA) required to maintain a constant amount of air in concrete increases as the temperature of mixtures containing portland cement or blends of portland cement and fly ash increases is well known. At present, it has not been determined if other pozzolans react to increased temperature in the same way as fly ash; also it is not clear whether the increase in AEA demand is caused by temperature alone or whether other factors influence the increase. The purpose of this investigation was to determine: (a) whether increased mixture temperature itself results in the increased requirement of AEA, (b) if carbon content of fly ash and temperature effects are interrelated, (c) if other pozzolans act the same as fly ash in regard to AEA demand, and (d) the nature of the temperature effect on AEA requirements.

### Scope

2. The first part of this study consisted of the proportioning of two concrete mixtures, one containing portland cement and the other fly ash, at different temperatures, and determining AEA demand. To verify the results of these initial tests and to determine the extent of temperature effect, seven additional mixtures were proportioned, containing (a) portland cement, (b) portland cement plus each of three pozzolans, and (c) each of the three pozzolans alone. Each mixture was mixed and tested for air content and slump at each of three temperature ranges: 40 to 45, 70 to 80, and 90 to 100 F.* To determine the nature (i.e. chemical or physical) of the changes in AEA requirement with temperature, leach water from pastes of five of the test mixtures was chemically analyzed. Other

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* A table of factors for converting British units of measurement to metric units is presented on page ix.

minor tests were conducted, as described in Part III, to aid in interpreting the results of the major tests.

## PART II: MATERIALS, MIXTURES, AND TESTS

### Materials

Portland cement and pozzolans

3. A type II portland cement (RC-572) was used in this investigation. The pozzolans consisted of a high-carbon fly ash (AD-9), a low-carbon fly ash (AD-3(10)), and a calcined shale (AD-140(11)). Chemical and physical properties of the portland cement and pozzolans are given in table 1. Prior to the beginning of the work, sufficient quantities of cement, fly ashes, and shale were blended separately for the complete study.

Aggregates

4. Crushed limestone aggregate from Tennessee, which was graded to comply with applicable Corps of Engineers guide specifications, was used for the coarse and fine aggregates (CRD-G-31(3), (4) and CRD-MS-17(2)). The physical properties and gradings of the aggregates are given in table 2.

Air-entraining admixture

5. A neutralized vinsol resin solution (AEA-692) was used.

### Mixtures

6. For the first part of the study, two mixtures were proportioned, one containing portland cement and the other a low-carbon fly ash. The cement mixture contained 5 bags* of cement per cu yd and 6.5 gal of water per bag of cement. The fly ash mixture contained 5 bags of fly ash (the same volume as the cement mixture) and 5.9 gal of water per bag. Both mixtures were proportioned with 1-1/2-in. maximum-size limestone aggregate. Three batches were made from each mixture, one for each temperature range.

7. For the second part of the study, seven air-entrained concrete mixtures, containing 1-1/2-in. maximum-sized limestone aggregate, were proportioned to have a slump of 2-1/2 ± 1/2 in., and an air content of 5 ± 0.25 percent. For the 70- to 80-F temperature range, 5 bags of cement

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* One bag of cement = 94 lb of cement.

or pozzolans, or blends of cement and pozzolans with a solid volume equal to the volume of 5 bags of cement, were used. Mixture data are given in table 3. For the other temperature ranges, the water-cement ratio was kept constant for all comparable mixtures and only the quantity of air-entraining admixture was varied to provide the required air content. Three batches (rounds) of concrete were made for each mixture for each of the three temperature ranges. The leach water tests were conducted on paste mixtures representing five of the test mixtures.

## Procedures and Tests

8. To obtain the desired temperature ranges of the concrete mixtures, 40-45, 70-80, and 90-100 F, materials were stored and batches were cast in a regulated temperature room with a temperature range of approximately 15 to 150 F. The mixing water was heated to 130 F for the concrete range of 90-100 F. Samples from each batch were tested for slump and air content according to test methods CRD-C 5[1] and CRC-C 41, respectively. The quantity of air-entraining admixture required for an air content of 5 percent was determined, and the water content was observed. Both the ambient and concrete temperatures were recorded. Leach water from the paste mixtures was chemically analyzed to determine the types and amounts of solids present.

## PART III: TEST RESULTS AND DISCUSSION

### Test Results

9. As stated earlier, two mixtures were proportioned for the first part of the study, one containing portland cement and the other a low-carbon fly ash. Results of tests of these two mixtures are given below:

| Desired Temperature Range, °F | Actual Temperature, °F | | AEA ml/batch | Slump in. | Air Content % |
|---|---|---|---|---|---|
| | Ambient | Concrete | | | |
| | | Portland Cement Mixture | | | |
| 40-45 | 47 | 49 | 10 | 2-1/2 | 4.8 |
| 70-80 | 79 | 81 | 18 | 2-1/2 | 5.2 |
| 90-100 | 100* | 95 | 29 | 2-1/2 | 5.2 |
| | | Fly Ash Mixture | | | |
| 40-45 | 47 | 49 | 8.5 | 2-1/2 | 4.9 |
| 70-80 | 87 | 86 | 8.5 | 2-3/4 | 5.0 |
| 90-100 | 102* | 95 | 9.2 | 2-1/2 | 5.0 |

* The temperature of the mixing water was 130 F so that the temperature of the concrete would be 95 F.

This series of tests indicated that temperature has very little, if any, effect on AEA demand when cement has been totally replaced with fly ash.

10. The results of the tests on the seven concrete mixtures of the second part of the study are shown in table 3. The values for slump, air content, temperature, and amount of air-entraining admixture represent an average of three tests.

### Effect of Temperature on Amount of AEA Required

11. The amount of air-entraining admixture needed to entrain the required air increased as the temperature increased for all mixtures with the exception of mixture 2, which contained a low-carbon fly ash. Some of the increases in amount of AEA required from that for the temperature range of 40-45 F to that for the 70-80 F range were substantial, but the

increase for mixtures cast at temperatures between 90 and 100 F was not so pronounced as those for the 70-80 F range (plate 1). A search of records of previous investigations[2] revealed that AEA demand at the 70- to 80-F casting temperature for the portland-cement mixture, the mixture containing 30 percent fly ash replacement (mixture 5), and the mixture containing 30 percent calcined shale replacement (mixture 7) followed the same trend as similar mixtures in other investigations which were cast at comparable temperatures.

12. The motion of water molecules is proportional to the temperature; therefore, as the temperature increases the attraction between molecules is reduced. Consequently, more bubbles break down and go into solution as the temperature increases, which would probably explain why more AEA is required to provide the same air content for the same mixture when the temperature is increased. A publication by Little and Ives[3] states that "the surface tension of a liquid (against air) decreases with rising temperature." It is believed that some of the increase in the AEA demand as the temperature increases is attributable to this surface tension phenomenon.

## Effect of Carbon Content on Amount of AEA Required

13. The temperature did not appear to affect AEA demand of the mixture containing the low-carbon (less than 1.5 percent) fly ash (mixture 2), but did appear to affect that of the mixture containing the fly ash with a carbon content of approximately 7.00 percent (mixture 3). These data suggest that there may be a carbon content level of fly ash at or below which temperature has little or no effect on the AEA demand, but above which temperature has a definite effect. B. Mather[4] states that, in regard to the effect of carbon content of fly ash on AEA demand,

> ...fly ash I, which showed less air-entraining admixture requirement when it was used to replace type II cement, contains 0.43 percent carbon, and fly ash III, which caused the largest increase in air-entraining admixture requirement when it was used, contains 11.13 percent carbon.... It is, therefore, suggested that these data,

> while they do indicate the very marked effect on air-entraining admixture demand as a function of the carbon content of the fly ash, serve also to point up what has been so often emphasized in the past, that very many other factors affect the amount of air-entraining admixture required in concrete.

The fly ash I referred to by Mather was from the same source as fly ash AD-3(10) used in this investigation, but was an earlier shipment.

14. The fineness of the low-carbon fly ash is much higher than that of the high-carbon fly ash. It is known that fineness of materials in a concrete mixture has a considerable effect on AEA demand, i.e., the finer the material passing the No. 100 sieve, the more AEA is required. Therefore, the carbon effect shown in plate 1 has probably been reduced by the fineness effect.

15. Two batches of mortar were made to verify the effect of carbon content on the AEA demand. One batch was made with fly ash AD-3(10) as received (approximately 1.5 percent carbon), and the other batch was made with AD-3(10) with lamp black added to bring the carbon content to 7.22 percent which is about the carbon content of fly ash AD-9. The mixture proportions and results of tests are as follows:

| | As Received | With Carbon Black Added |
|---|---|---|
| Fly ash, g | 274.2 | 274.2 |
| Sand, g | 1400 | 1400 |
| AEA, ml | 0.10 | 4.00 |
| Water, ml | 170 | 210 |
| Flow, % | 91 | 90 |
| Air content, % | 16.7 | 15.0 |

The data indicate that the addition of lamp black definitely has a marked effect on the AEA demand.

16. From the test results as represented in plate 1, starting at the left with mixture 1 which contained cement only, it is apparent that with this product, which had a fineness of the order of 3000 sq cm/g, there was a regular increase in the amount of air-entraining admixture required to produce a given air content as the temperature went up. Mixture 2, which

contained only low-carbon fly ash having a fineness of about 8000 sq cm/g, required only slightly more admixture at the original temperature, 40-45 F, than did the cement mixture and no increase in the admixture demand with increasing temperature. It is possible that at the initial temperature there was an evolution of desorbed gas from the carbon that compensated for the increased fineness that would otherwise have caused an increase in air-entraining admixture demand and that the amount of gas evolved increased with increasing temperature and prevented the increase in air-entraining admixture demand for mixture 2 that was observed with mixture 1. In the case of mixture 3, which contained high-carbon fly ash, it might be assumed that the greater fineness of this product (9500 sq cm/g) was not fully compensated for by gas desorption in the low-temperature case, but that the increase in air-entraining admixture demand was in part compensated for by the gas desorption phenomena; otherwise, the observed increase would be expected to be comparable to that shown by mixture 4, which contained calcined shale of comparable fineness but without significant carbon from which adsorbed gas might be evolved. The activated carbon gas absorption-desorption mechanism has been studied[5] to a limited extent in connection with an examination of an expansive grout composition and also is described in the patent covering the product.

## Effect of Calcined Shale on Amount of AEA Required

17. Mixture 4, containing calcined shale, required more AEA than the two mixtures containing fly ash to produce the same air content. In mixture 4, a large increase in the amount of AEA was required for the temperature range of 70-80 F as compared to that for the 40-45 F range (plate 1). This material was somewhat finer than the two fly ashes, and some of the increase in the AEA was probably due to this fact. Scripture and Litwinowicz[6] state that "entrained air content decreases with increasing cement factor. This effect is most marked in the leaner mixes." Kennedy[7] states that "particles small enough to pass the 100-mesh sieve seem to have a depressive effect on air entrainment." It is reported by ACI Committee 212 that "particular attention should be given to the

unusually high amount of air-entraining admixture often required in concrete containing high early strength (type III) portland cement, portland-pozzolan cements, fly ash, finely divided mineral admixtures such as natural pozzolans, or finely divided coloring admixtures such as untreated carbon black."[8] Tynes[9] states "the amount of air-entraining admixture needed to entrain the required amount of air increased as the amount of pozzolan increased." Scripture, Benedict, and Litwinowicz[10] state "with increasing surface area of the cement the amount of air entrained by air-entraining agents decreases. Without air-entraining agents there are no significant variations in air content with surface area."

## Nature of Temperature Effect on AEA Demand

18. To determine if the temperature effect on the amount of AEA required is chemical, a chemical analysis was made of leach water from five paste mixtures, with and without AEA, at temperatures of 40-45 and 90-100 F. The mixtures represented the following five mixtures used in the basic work: mixtures 1, 2, 4, 5, and 7. The filtered leach waters with no AEA were analyzed for total solids: Si, Al, Fe, Ca, Mg, Na, K, and $SO_3$. Since minor or trace amounts of Si, Al, and Fe were found in these waters, these elements were not determined in the mixtures containing AEA. The results of these tests are shown in table 4.

19. Less total solids as Ca and $SO_3$, and greater amounts of Na and K were leached at 100 F than at 40 F for all mixtures, as shown in plate 2. These changes at these temperatures are normal since $CaSO_4$ decreases in solubility as the temperature increases, whereas Na and K compounds usually increase in solubility as the temperature is increased. The leach water from the shale (mixture 4) contained more Si and appreciably more Mg than the other waters.

20. The Na values of the leach waters from the fly ash mixtures (2 and 5) were considerably higher than those of the other mixtures, while the K values for both the fly ash (mixture 2) and shale (mixture 4) leach waters were much less than for the other mixtures.

21. In order to determine if the large amounts of sodium have any effect on AEA demand, air content was determined on four mortar mixtures, two with and two without sodium, at 100 F. The mixtures and results of the tests were as follows:

| Mixture | Material | Air Content, % |
|---|---|---|
| 1 | Portland cement + AEA | 18.6 |
| 2 | Portland cement + AEA + 450 ppm Na* | 18.8 |
| 3 | Low-carbon fly ash + AEA | 16.1 |
| 4 | Low-carbon fly ash + AEA + 450 ppm Na* | 16.2 |

* This additional sodium was added as sodium hydroxide with the mixture water and the quantity was based on the sodium extracted from the leach tests.

22. The data indicate that the additional sodium had little or no effect on AEA demand of the mixtures. The results of the leach tests do not suggest any plausible explanation for the unusual behavior of the AEA demand in mixture 2, which contained a low-carbon fly ash. It is believed that the temperature effects on the mixtures containing fly ash were influenced to some degree by an activated carbon:gas absorption-desorption mechanism.

# PART IV: SUMMARY OF RESULTS

23. The test results indicated that:

<u>a</u>. The amount of AEA required for mixture 2 (low-carbon fly ash and no cement) was not affected by the temperature in the ranges investigated.

<u>b</u>. Increased temperature did cause an increase in AEA demand of another pozzolan (calcined shale), blends of pozzolans and cement, and even another fly ash which had a higher carbon content.

<u>c</u>. The concrete mixture showing the greatest effect of increased temperature on the AEA demand was mixture 4, which contained calcined shale and no cement. The large increases in AEA requirement generally occurred for the temperature range from 70 to 80 F compared to the AEA required for the range from 40 to 45 F.

24. The data show that the carbon content of the fly ash and temperature effects are interrelated, i.e., temperature had very little effect on mixtures containing fly ash with a low carbon content but had a much greater effect on mixtures containing fly ash with a high carbon content. It is believed that the temperature effects on the mixtures containing fly ash were influenced to some degree by an activated carbon:gas absorption-desorption mechanism.

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8. American Concrete Institute Committee 212, "Admixtures for Concrete," Proceedings, American Concrete Institute, Vol 60, July-Dec 1963, p 1497.

9. Tynes, W. O., "Investigation of Cement-Replacement Materials; Use of Large Amounts of Pozzolans in Lean Mass Concrete," Miscellaneous Paper No. 6-123, Report 10, Aug 1962, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

10. Scripture, E. W., Jr., Benedict, S. W., and Litwinowicz, F. J., "Effect of Temperature and Surface Area of the Cement on Air Entrainment," Journal, American Concrete Institute, Vol 23, No. 3, Nov 1951, pp 205-210.

Table 1

Results of Chemical and Physical Tests of Portland Cement, Fly Ash, and Shale

| Component or Test | Cement | Fly Ash | | Shale |
|---|---|---|---|---|
| | RC-572 | AD-9* | AD-3(10)** | AD-140(11) |
| **Chemical Data** | | | | |
| $SiO_2$, % | 22.7 | 44.9 | | |
| $Al_2O_3$, % | 4.1 | 34.0 | 80.1† | 81.98† |
| $Fe_2O_3$, % | 3.3 | 6.5 | | |
| CaO, % | 64.7 | 2.3 | -- | -- |
| MgO, % | 2.9 | 0.4 | 0.74 | 2.02 |
| $SO_3$, % | 1.5 | 0.34 | 2.00 | 1.04 |
| Loss on ignition, % | 0.85 | 7.9 | 2.10 | 1.40 |
| Insoluble residue, % | 0.14 | 76.8 | -- | -- |
| $Na_2O$, % | 0.19 | 0.30 | -- | -- |
| $K_2O$, % | 0.43 | 1.72 | -- | -- |
| Total alkalies as $Na_2O$, % | 0.47 | 1.43 | -- | -- |
| $C_3S$, % | 50 | -- | -- | -- |
| $C_2S$, % | 27 | -- | -- | -- |
| $C_3A$, % | 5 | -- | -- | -- |
| $C_4AF$, % | 10 | -- | -- | -- |
| Available alkalies at 28 days | | | | |
| $Na_2O$, % | -- | -- | 0.72 | 0.26 |
| $K_3O$, % | -- | -- | 0.65 | 0.43 |
| Total alkalies as $Na_2O$, % | -- | -- | 1.15 | 0.54 |
| Moisture loss, % | -- | 0.26 | 0.31 | 0.20 |
| Heat of hydration, cal/g | | | | |
| 7 days | 72 | -- | -- | -- |
| 28 days | 85 | -- | -- | -- |

| Component or Test | Cement | Fly Ash | | Shale |
|---|---|---|---|---|
| | RC-572 | AD-9 | AD-3(10) | AD-140(11) |
| **Physical Data** | | | | |
| Specific gravity | 3.15 | 2.26 | 2.47 | 2.55 |
| Air permeability (Blaine fineness), sq cm/g | 3320 | -- | -- | -- |
| Air permeability (Blaine fineness), sq cm/cc | -- | 9503 | 7845 | 9185 |
| Water required for normal consistency, % | 24.6 | -- | -- | -- |
| Time of set, Gillmore: | | | | |
| Initial, hr:min | 4:35 | -- | -- | -- |
| Final, hr:min | 6:40 | -- | -- | -- |
| Soundness, autoclave expansion, % | 0.08 | -- | 0.05 | 0.07 |
| Air content of mortar, % | 10.0 | 2.8 | -- | -- |
| Compressive strength, psi | | | | |
| 3 days | 2115 | -- | -- | -- |
| 7 days | 3250 | -- | -- | -- |
| 28 days | 5660 | -- | -- | -- |
| Mean particle diameter, microns | -- | 6.3 | 7.6 | 2.6 |
| Lime-pozzolan strength, psi | -- | -- | 985 | 1405 |
| Water requirement, increase in flow, % | -- | -- | 40 | 29 |
| Pozzolanic strength, % | -- | -- | 89.4 | 84.2 |
| Drying shrinkage of mortar, % | -- | -- | -- | 0.005 |

* High carbon.
** Low carbon.
† $SiO_2 + Al_2O_3 + Fe_2O_3$.

Table 2

Physical Properties and Grading of Crushed Limestone Aggregate

| Test | Fine CRD-MS-17(2) | Coarse No. 4 to 3/4 in. CRD-G-31(4) | Coarse 3/4 to 1-1/2 in. CRD-G-31(3) |
|---|---|---|---|
| **Physical Properties** | | | |
| Bulk specific gravity saturated, surface dry | 2.67 | 2.69 | 2.71 |
| Absorption, % | 1.3 | 0.6 | 0.4 |
| **Percent Passing Standard Sieve** | | | |
| Sieve: | | | |
| 2-in. | | | 100 |
| 1-1/2-in. | | | 97 |
| 1-in. | | 100 | 42 |
| 3/4-in. | | 98 | 6 |
| 1/2-in. | | 70 | 1 |
| 3/8-in. | | 45 | |
| No. 4 | 100 | 4 | |
| No. 8 | 85 | | |
| No. 16 | 68 | | |
| No. 30 | 40 | | |
| No. 50 | 19 | | |
| No. 100 | 9 | | |
| PAN | 6 | | |

Table 3

Mixture Proportions and Effects of Temperature on AEA Demand

| Mixture | Temperature Range, °F | Water-Cement Ratio gal/bag* | Volume** of Cement or Pozzolan/cu yd | Portland Cement lb/cu yd | Pozzolanic Material: Type | Pozzolanic Material: Amount lb/cu yd | Aggregate Weight lb/cu yd: Fine | Aggregate Weight lb/cu yd: Coarse | Total Water Content lb/cu yd | Temperature °F: Amb | Temperature °F: Conc | Amount of AEA ml/cu yd | Slump in. | Air Content % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 40-45 | 6.5 | 2.390 | 470 | None | None | 1133.5 | 2037.5 | 270.75 | 37 | 42 | 120 | 2-3/4 | 5.0 |
| 1 | 70-80 | 6.5 | 2.390 | 470 | None | None | 1133.5 | 2037.5 | 270.75 | 78 | 78 | 240 | 2-1/2 | 5.0 |
| 1 | 90-100 | 6.5 | 2.390 | 470 | None | None | 1133.5 | 2037.5 | 270.75 | 100 | 94 | 290 | 2-1/2 | 5.0 |
| 2 | 40-45 | 5.7 | 2.390 | None | Low-carbon FA† | 368.5 | 1165.0 | 2095.0 | 237.40 | 37 | 41 | 140 | 3 | 5.2 |
| 2 | 70-80 | 5.7 | 2.390 | None | Low-carbon FA | 368.5 | 1165.0 | 2095.0 | 237.40 | 80 | 79 | 140 | 2-1/2 | 5.1 |
| 2 | 90-100 | 5.7 | 2.390 | None | Low-carbon FA | 368.5 | 1165.0 | 2095.0 | 237.40 | 98 | 93 | 140 | 2-1/2 | 5.1 |
| 3 | 40-45 | 6.5 | 2.390 | None | High-carbon FA | 337.0 | 1133.5 | 2037.5 | 270.75 | 38 | 42 | 430 | 2-1/2 | 5.0 |
| 3 | 70-80 | 6.5 | 2.390 | None | High-carbon FA | 337.0 | 1133.5 | 2037.5 | 270.75 | 79 | 78 | 560 | 2-1/4 | 5.0 |
| 3 | 90-100 | 6.5 | 2.390 | None | High-carbon FA | 337.0 | 1133.5 | 2037.5 | 270.75 | 99 | 93 | 580 | 2-1/4 | 5.1 |
| 4 | 40-45 | 6.7 | 2.390 | None | Calcined shale | 374.5 | 1123.5 | 2021.5 | 280.00 | 37 | 41 | 520 | 2-1/2 | 5.0 |
| 4 | 70-80 | 6.7 | 2.390 | None | Calcined shale | 374.5 | 1123.5 | 2021.5 | 280.00 | 80 | 78 | 1600 | 2 | 4.9 |
| 4 | 90-100 | 6.7 | 2.390 | None | Calcined shale | 374.5 | 1123.5 | 2021.5 | 280.00 | 98 | 94 | 1700 | 2-1/4 | 5.0 |
| 5 | 40-45 | 6.2 | 2.390 | 328.5 | Low-carbon FA | 111.0 | 1145.0 | 2058.5 | 258.25 | 37 | 41 | 106 | 2-3/4 | 4.9 |
| 5 | 70-80 | 6.2 | 2.390 | 328.5 | Low-carbon FA | 111.0 | 1145.0 | 2058.5 | 258.25 | 80 | 79 | 234 | 2-1/2 | 5.0 |
| 5 | 90-100 | 6.2 | 2.390 | 328.5 | Low-carbon FA | 111.0 | 1145.0 | 2058.5 | 258.25 | 99 | 94 | 250 | 2-1/4 | 5.0 |
| 6 | 40-45 | 6.4 | 2.390 | 328.5 | High-carbon FA | 101.5 | 1137.0 | 2044.5 | 266.55 | 37 | 42 | 180 | 2-1/2 | 5.0 |
| 6 | 70-80 | 6.4 | 2.390 | 328.5 | High-carbon FA | 101.5 | 1137.0 | 2044.5 | 266.55 | 79 | 79 | 330 | 2-1/4 | 5.0 |
| 6 | 90-100 | 6.4 | 2.390 | 328.5 | High-carbon FA | 101.5 | 1137.0 | 2044.5 | 266.55 | 99 | 94 | 354 | 2 | 4.9 |
| 7 | 40-45 | 6.6 | 2.390 | 328.5 | Calcined shale | 112.5 | 1129.5 | 2030.5 | 274.90 | 37 | 42 | 150 | 2-1/2 | 4.9 |
| 7 | 70-80 | 6.6 | 2.390 | 328.5 | Calcined shale | 112.5 | 1129.5 | 2030.5 | 274.90 | 79 | 79 | 354 | 2-1/4 | 5.0 |
| 7 | 90-100 | 6.6 | 2.390 | 328.5 | Calcined shale | 112.5 | 1129.5 | 2030.5 | 274.90 | 99 | 94 | 380 | 2 | 4.9 |

Note: All mixtures were made with 1-1/2-in. maximum-size coarse aggregate and 36 percent of total aggregate volume as fine aggregate. Values for temperature, amount of air-entraining admixture, slump, and air content are averages of three tests.

* Based on 5 bags of cement/cu yd.

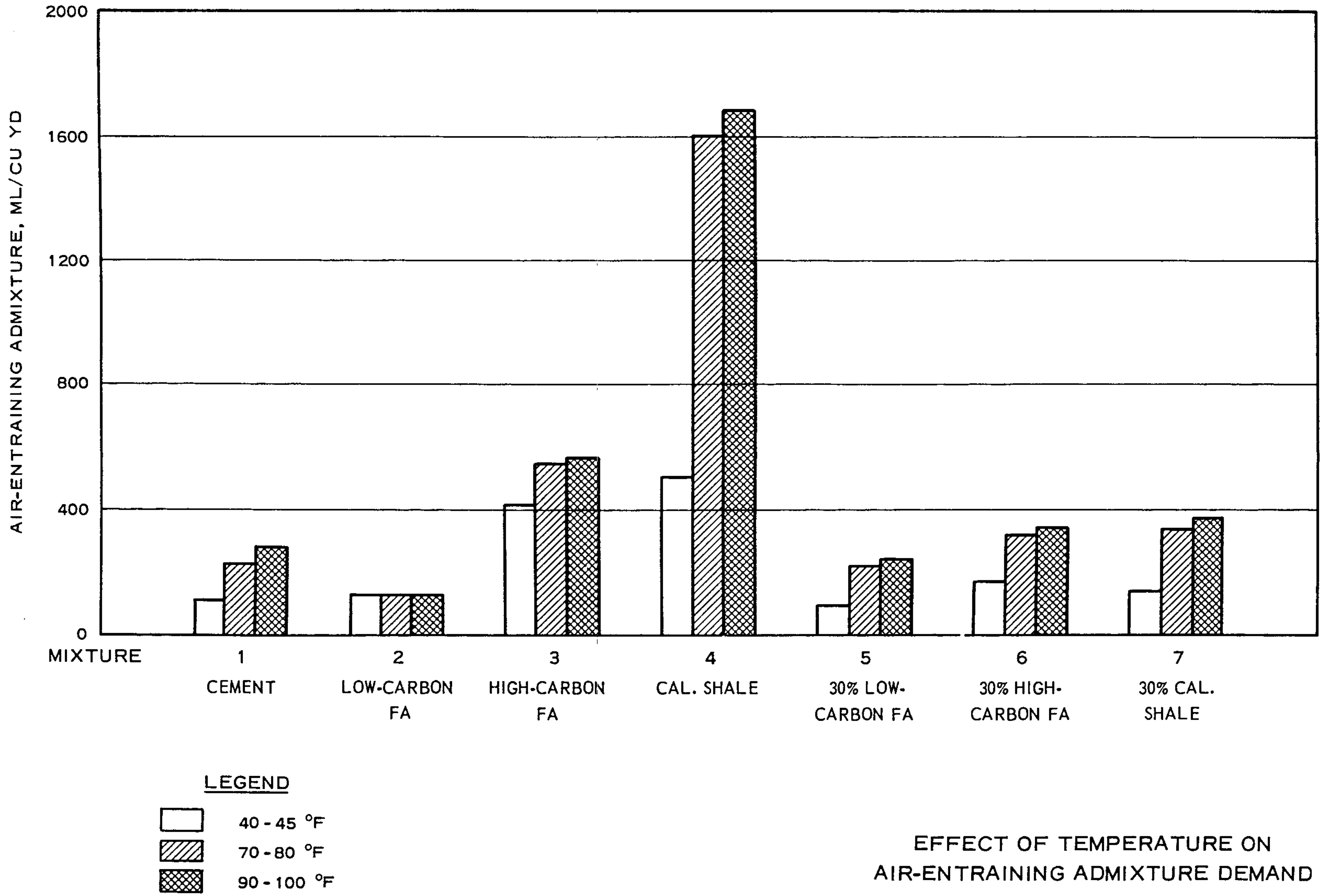
** Based on volume of 5 bags of cement/cu yd.

† FA = fly ash.

Table 4

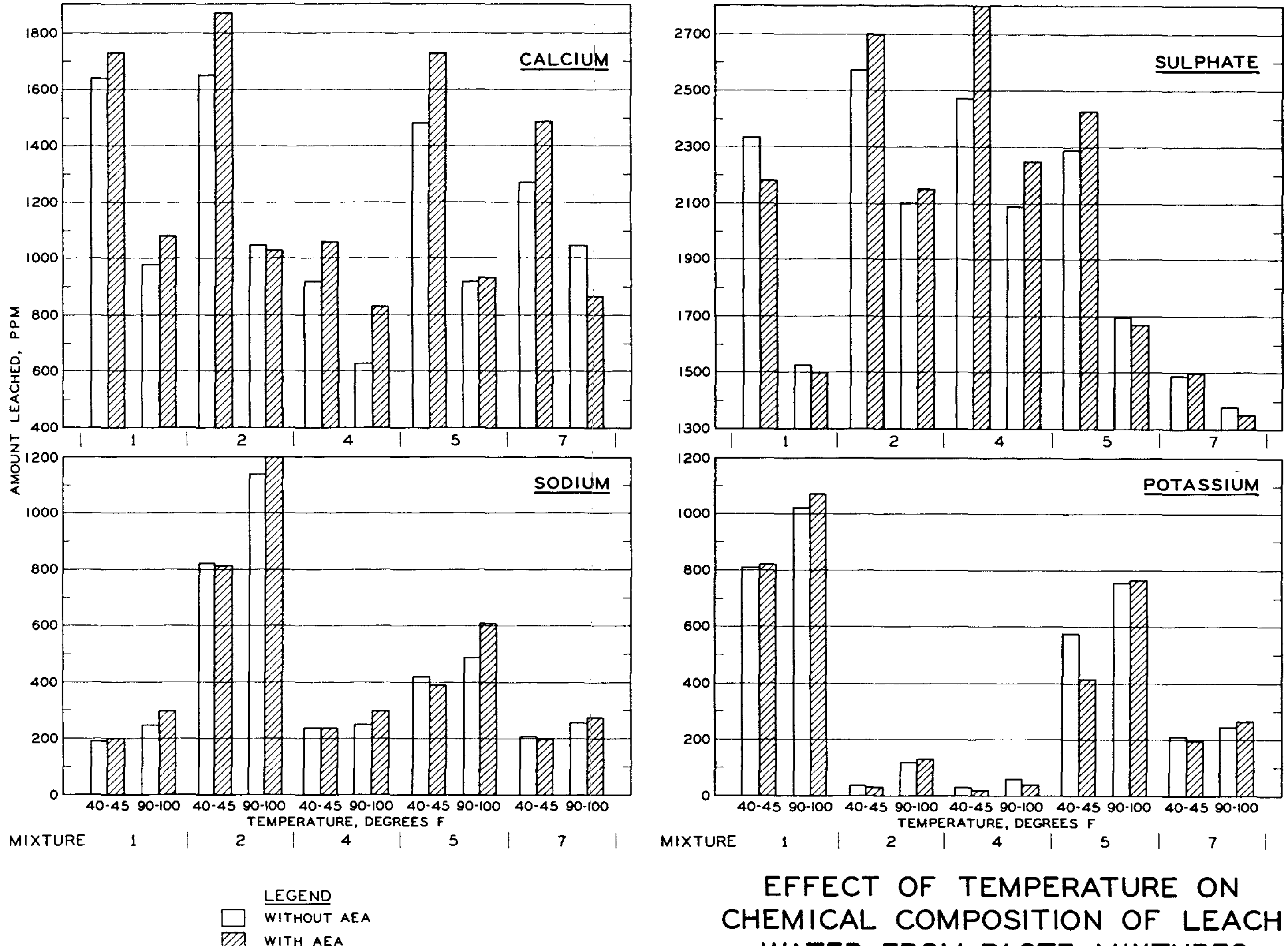
Chemical Data for Leach Water from Paste Mixtures

| | Added AEA | Mixture 1 | | Mixture 2 | | Mixture 4 | | Mixture 5 | | Mixture 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 40 F | 100 F | 40 F | 100 F | 40 F | 100 F | 40 F | 100 F | 40 F | 100 F |
| Total grams leached | No | 117.06 | 143.45 | 174.47 | 159.42 | 139.22 | 129.60 | 131.00 | 152.50 | 120.37 | 127.16 |
| | Yes | 124.82 | 142.32 | 185.89 | 162.02 | 144.21 | 140.93 | 132.51 | 155.89 | 123.62 | 132.26 |
| Total solids, ppm | No | 7075 | 5710 | 7630 | 6995 | 5070 | 4130 | 6650 | 5930 | 5210 | 4910 |
| | Yes | 7055 | 5850 | 7905 | 7310 | 5545 | 4565 | 7010 | 5960 | 5620 | 5045 |
| Si, ppm | No | 2.6 | 1.3 | 1.9 | 2.6 | 14.7 | 26.2 | 2.8 | 1.5 | 1.8 | 0.7 |
| | Yes | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Al, ppm | No | 0 | 0 | 0.5 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 |
| | Yes | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Fe, ppm | No | 0 | 0 | 0 | 0 | 0 | 1.0 | 0 | 0.1 | 0 | 0 |
| | Yes | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Ca, ppm | No | 1650 | 985 | 1650 | 1050 | 925 | 628 | 1480 | 93.0 | 1270 | 1050 |
| | Yes | 1740 | 960 | 1870 | 1030 | 1065 | 835 | 1740 | 1080 | 1480 | 870 |
| Mg, ppm | No | 0.2 | 0.1 | 0.2 | 0.1 | 102 | 69 | 0.2 | 0.1 | 0.2 | 0.1 |
| | Yes | 0.1 | 0.05 | 0.1 | 0.06 | 101 | 68 | 0.1 | 0.05 | 0.1 | 0.04 |
| Na, ppm | No | 199 | 257 | 823 | 1139 | 223 | 249 | 415 | 593 | 208 | 249 |
| | Yes | 197 | 297 | 816 | 1208 | 245 | 297 | 390 | 616 | 197 | 274 |
| K, ppm | No | 814 | 1026 | 46 | 116 | 33 | 46 | 576 | 754 | 428 | 520 |
| | Yes | 822 | 1063 | 37 | 133 | 33 | 56 | 422 | 769 | 357 | 548 |
| $SO_3$ | No | 2330 | 1530 | 2570 | 2100 | 2470 | 2090 | 2290 | 1700 | 1490 | 1370 |
| | Yes | 2180 | 1510 | 2700 | 2150 | 2800 | 2250 | 2430 | 1670 | 1500 | 1350 |




EFFECT OF TEMPERATURE ON AIR-ENTRAINING ADMIXTURE DEMAND

PLATE 2

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**1. ORIGINATING ACTIVITY (Corporate author)**
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

**2a. REPORT SECURITY CLASSIFICATION**
Unclassified

**2b. GROUP**

**3. REPORT TITLE**
EFFECT OF TEMPERATURE ON AIR-ENTRAINING ADMIXTURE DEMAND OF CONCRETE WITH AND WITHOUT POZZOLANS

**4. DESCRIPTIVE NOTES (Type of report and inclusive dates)**
Final report

**5. AUTHOR(S) (First name, middle initial, last name)**
William O. Tynes

**6. REPORT DATE**
July 1968

**7a. TOTAL NO. OF PAGES**
24

**7b. NO. OF REFS**
10

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Mixtures were made with portland cement, blends of portland cement and pozzolan, and pozzolan alone, at temperature ranges of 40-45, 70-80, and 90-100 F to determine whether increasing the temperature of freshly mixed concrete results in an increased requirement for air-entraining admixture in order to maintain a given level of air content in the concrete. The results indicated that the amount of air-entraining admixture (AEA) required in the mixture containing a low-carbon fly ash and no cement was affected very little if at all by temperature; whereas, in all other mixtures, the AEA demand was increased with increasing temperature. The temperature effect was considerable in the mixture containing the pozzolan, calcined shale, between the temperature ranges of 40-45 and 70-80 F. The data also show that the carbon content of fly ash and temperature effects are interrelated. It is believed that the effect of carbon is primarily physical.

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| Concrete--Temperature factors | | | | | | |
| Concrete admixtures | | | | | | |
| Concrete mixtures | | | | | | |
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