WATER/CEMENT RATIO USING A MICROWAVE OVEN

REPORT 89-3
December 1989

Reporting on Work Plan 87-C-11

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS AND RESEARCH DIVISION

PAUL R. PHILBROOK, SECRETARY OF TRANSPORTATION
ARTHUR J. GOSS, P.E., DIRECTOR OF PLANNING
MILAN W. LAWSON, P.E., MATERIALS AND RESEARCH ENGINEER
CHRISTOPHER C. BENDA, P.E., STRUCTURAL CONCRETE ENGINEER

Prepared By:

Charles R. Abry, Transportation Technician III
&
William L. Meyer, Technician C
Structural Concrete Subdivision

Reviewed By:

M. W. Lawson

M. W. Lawson, P.E.
Materials & Research Engineer

Date: December 19, 1989

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ABSTRACT

Control of the water/cement ratio is one of the most important factors in the production of high quality portland cement concrete. Maintaining precise control of the water/cement ratio is a difficult practice and has led many organizations to search for a rapid method of determining water/cement ratio at the project site. Other researchers indicate the microwave oven can be used successfully for determining the water/cement of portland cement concrete.

This evaluation focused on comparing the results of microwave oven tests with the known water/cement ratio of concrete mixtures. Testing indicates the microwave oven can provide reliable results when used under closely controlled laboratory conditions. When variables normally encountered in field produced concrete are introduced, the accuracy of the test method decreases sharply.

Based on the results obtained in this evaluation, the microwave oven is considered inappropriate for use in determining the water/cement ratio of portland cement concrete mixtures in the field. No further evaluation is planned at this time.

INTRODUCTION

One of the most common causes of poor quality concrete is excessive use of mixing water. Excess mixing water causes segregation, settlement and porosity, low strength and durability, poor wearing and bonding qualities, laitance formation, increased shrinkage and cracking. Measuring and controlling the quantity of mixing water or water/cement ratio is therefore one of the most important factors in the production of high quality portland cement concrete.

The Vermont Agency of Transportation currently determines the water/cement ratio of concrete in the field by conducting aggregate moisture tests at ready mix plants, monitoring the quantity of water added when concrete is batched, and monitoring the quantity of water added by mixer operators at project sites.

Use of the microwave oven for determining water/cement ratio of plastic concrete has been recognized and practiced by a limited number of State and Federal organizations for several years. Considerable research has been conducted and depending on the degree of accuracy desired, some programs have produced excellent results.

Much of the research has been conducted using small samples mixed and tested in a laboratory setting. Occasionally, limited testing has been performed in the field and the results included with laboratory test results.

Following a review of the Agency of Transportation's material sampling and testing procedures by the Federal Highway Administration on July 14,1987, it was recommended by the inspectors that the Agency consider examining use of a microwave oven for determining water/cement ratio of portland cement concrete in the field. In response to this recommendation, the Materials and Research Division embarked on a study to evaluate potential use of a microwave oven on Agency projects.

Prior to initiating physical testing, a literature search was conducted to explore the current "state of the art" as viewed by agencies using the microwave oven to determine water/cement ratio. Operating procedures, sample size and formulas were studied in an effort to avoid many of the problems which confronted other researchers.

This investigation focused on comparing results of microwave oven tests with the known water/cement ratio of concrete at the time of mixing. Field conditions were simulated by delaying the time between mixing and the start of testing, however, all tests were conducted in the laboratory.

The investigation was conducted in two phases. Phase I examined very small batches (1011 grams) of concrete mixed in pyrex dishes, then tested in the microwave oven. Various power levels ranging from 30%

to 60% of maximum microwave power were employed in Phase I. Phase II examined samples obtained from 1 ft^3 batches of concrete mixed and tested in the laboratory. These samples were tested in the microwave oven at 30% power level.

A survey was distributed to transportation agencies in the remaining forty nine states, the District of Columbia, Puerto Rico and Guam to examine how they determine water/cement ratio of concrete in the field and if use of the microwave oven is employed. Survey results are shown in Appendix "A".

MATERIALS & EQUIPMENT

The materials and equipment used in this investigation are as follows:

MATERIALS

Fine Aggregate

TABLE 1
FINE AGGREGATE TEST DATA

Lawrence Sangravco, Guildhall, VT

Sieve Size	% Passing	VAOT Specification Requirements % Passing
3/8"	100	100
# 4	100	95-100
# 8	90	-
# 16	66	50-80
# 30	40	25-60
# 50	18	10-30
#100	7	2-10
Fineness Modulus	2.79	2.60-3.10
Color	<1	2 Max.

TABLE 2
FINE AGGREGATE TEST DATA

A. G. Anderson, Highgate, VT

Sieve Size	% Passing	VAOT Specification Requirements % Passing
3/8"	100	100
# 4	99	95-100
# 8	86	-
# 16	66	50-80
# 30	41	25-60
# 50	13	10-30
#100	3	2-10
Fineness Modulus	2.92	2.60-3.10
Color	1	2 Max.

TABLE 3

FINE AGGREGATE TEST DATA

Lebanon Crushed Stone Inc., W. Lebanon, NH

Sieve Size	% Passing	VAOT Specification Requirements % Passing
3/8"	100	100
# 4	100	95-100
# 8	92	-
# 16	71	50-80
# 30	44	25-60
# 50	16	10-30
#100	5	2-10
Fineness Modulus	2.72	2.60-3.10
Color	<1	2 Max.

TABLE 4

FINE AGGREGATE TEST DATA

S. T. Griswold, Williston, VT

Sieve Size	% Passing	VAOT Specification Requirements % Passing
3/8"	100	100
# 4	99	95-100
# 8	84	-
# 16	66	50-80
# 30	49	25-60
# 50	23	10-30
#100	7	2-10
Fineness Modulus	2.72	2.60-3.10
Color	<1	2 Max.

Coarse Aggregate

TABLE 5
COARSE AGGREGATE TEST DATA

3/4" Crushed Gravel,
Lawrence Sangravco, Guildhall, VT

Sieve Size	% Passing	VAOT Specification Requirements % Passing
1"	100	100
3/4"	98	90-100
3/8"	39	20-55
# 4	5	0-10
# 8	3	0-5
L.A. Abrasion, % loss	23.7	35 Max.
Thin & Elongated Pieces, %	6.9	10 Max.
Fractured Faces, %	78.2	50 Min.

TABLE 6
COARSE AGGREGATE TEST DATA

3/4" Crushed Igneous Stone
Cooley Asphalt Paving Corp., Websterville, VT

Sieve Size	% Passing	VAOT Specification Requirements % Passing
1"	100	100
3/4"	99	90-100
3/8"	42	20-55
# 4	8	0-10
# 8	2	0-5
L.A. Abrasion, % loss	31.4	50 Max.
Thin & Elongated Pieces, %	1.1	10 Max.
Fractured Faces, %	100.0	100 Min.

TABLE 7
COARSE AGGREGATE TEST DATA

3/4" Crushed Stone
Lebanon Crushed Stone, Inc., W. Lebanon, NH

Sieve Size	% Passing	VAOT Specification Requirements % Passing
1"	100	100
3/4"	99	90-100
3/8"	27	20-55
# 4	4	0-10
# 8	1	0-5
L.A. Abrasion, % loss	21.8	35 Max.
Thin & Elongated Pieces, %	4.0	10 Max.
Fractured Faces, %	100.0	100 Min.

TABLE 8
COARSE AGGREGATE TEST DATA

3/4" Crushed Stone
F. W. Whitcomb Construction Corp., Winooski, VT

Sieve Size	% Passing	VAOT Specification Requirements % Passing
1"	100	100
3/4"	100	90-100
3/8"	40	20-55
# 4	3	0-10
# 8	2	0-5
L.A. Abrasion, % loss	17.7	50 Max.
Thin & Elongated Pieces, %	5.6	10 Max.
Fractured Faces, %	100.0	100 Min.

Portland Cement, Type II

Glens Falls Portland Cement Co.
Glens Falls, New York

Northeast Cement Co.
St. Constant, Quebec

Independent Cement Co.
Joliette, Quebec

Air Entraining Admixture

Daravair
W. R. Grace & Co.
Cambridge, Massachusetts

Micro Air
Master Builders
Cleveland, Ohio

Retarding Admixture

Daratard 17
W. R. Grace & Co.
Cambridge, Massachusetts

Pozzolith 100XR
Master Builders
Cleveland, Ohio

High Range Water Reducing Admixture

Daracem 100
W. R. Grace & Co.
Cambridge, Massachusetts

Water Reducing Admixture

WRDA w/Hycol
W. R. Grace & Co.
Cambridge, Massachusetts

Pozzolith 322N
Master Builders
Cleveland, Ohio

EQUIPMENT

Microwave Oven

Sears/Kenmore, Model 99601, 1450 Watt, 1.42 ft^3 capacity

Balance

American Scientific Products, Model Z-12K, 12Kg capacity

Concrete Mixer

Sears, 1.5 ft^3 capacity

Accessory Equipment

8.5" x 8.5" x 2.5" Pyrex glass dishes, 1.0 ml pipettes, large metal spoon, rubber spatula, metal spatula and plastic wrap.

Additional equipment included slump cones, air entrainment meters, etc., necessary to determine the properties of plastic and hardened concrete.

PROCEDURES

This investigation was conducted in the laboratory in two phases. Phase I examined small batches of concrete, mixed and tested in Pyrex glass dishes. Phase II examined samples obtained from 1 ft^3 batches of concrete.

Two formulas were selected for use in calculating the water/cement ratios shown in this report. The North Dakota (1) method employs the concrete unit weight obtained from tests performed on the fresh concrete. The New Hampshire (2) method, utilizes a theoretical or design unit weight in its calculations. While the remainder of the two formulas are similar, the use of theoretical vs. actual weight per $foot^3$ can yield widely differing results. The work sheets used by the North Dakota State Highway Department and the New Hampshire Department of Public Works and Highways are shown in Appendix "B".

Phase I, because of the small overall sample size, shows results calculated using only the New Hampshire formula. Phase II shows water/cement ratio determined using both formulas and permits a comparison of the two methods.

Batch quantities, mixing and testing procedures are as follows:

PHASE I

Aggregates employed in Phase I were oven dried to constant weight, then stored in a dessicator until use. The mix design remained constant for all batches in this application. The materials and batch quantities, shown in Table 9, also remained unchanged.

A total of sixteen batches were tested. Four batches were examined at each of four separate power levels. The power levels selected were 30%, 40%, 50%, and 60% of maximum power.

Testing was further refined by delaying placement into the microwave oven for a period of either thirty minutes or sixty minutes. Two batches were tested for each delay period at each power level.

Mixing and testing procedures are outlined in Table 10.

TABLE 9
MIX DESIGN: PHASE I

Source	Material Used	Design Quantity
Lawrence Sangravco, Guildhall, VT	3/4" Crushed Gravel	438.6 g
Lawrence Sangravco, Guildhall, VT	Fine Aggregate	319.6 g
Glens Falls Portland Cement Co. Glens Falls, NY	Type II Cement	171.1 g
W. R. Grace & Co. Cambridge , MA	Daravair	0.11 ml
W. R. Grace & Co. Cambridge, MA	WRDA w/Hycol	0.45 ml
	Water	81.5 g

TABLE 10
Mixing/Drying Sequence

1. Oven-dry aggregate to constant weight, store in dessicator until use.

2. Weigh aggregate, cement and water.

3. Measure admixtures in pipettes and add to water.

4. Obtain tare weight of pyrex dish.

5. Mix aggregates and cement in a pyrex dish. Add water and admixtures and continue mixing until a homogenous mixture is obtained.

6. Clean all material from the mixing spoon with the rubber spatula and small steel spatula, insuring that all materials are placed in the mixing container.

7. Immediately weigh the mixture, then cover and seal the dish with plastic film for the desired delay period.

8. Prior to placing the mixture into the microwave oven, remove the plastic film and weigh the mixture to determine any loss due to evaporation.

9. Place the pyrex dish with the mixture in the center of the microwave oven and operate the oven at the desired power level. Set the oven timer to operate initially for thirty minutes, then ten minutes. The mixture is weighed immediately following each period of drying. Additional five minute drying periods are utilized until the mixture reaches a constant weight.

PHASE II

Concrete used in Phase II of this investigation was prepared in a 1.5 ft^3 mixer in accordance with AASHTO T126-86. Materials were prepared to produce batches yielding 1 ft^3 of concrete. Mix designs represent Vermont Agency of Transportation Class A concrete from four area concrete suppliers. Three different water/cement ratios were selected for each mix design to reflect concrete characteristics that may be encountered in the field. Material sources and mix designs for Phase II are shown in Tables 11, 12, 13 and 14.

A total of twenty six microwave oven tests were performed in Phase II. Samples were obtained ranging in size from 1000 g to 1500 g. The samples were placed in pyrex dishes and covered to prevent evaporation during a sixty minute delay period prior to being placed in the microwave oven. Drying in the microwave oven was accomplished as outlined in Table 10, no. 9. All testing in Phase II was performed with the microwave oven at the 30% power level.

Other concrete tests performed include; Slump (AASHTO T119-82), Air Content (AASHTO T152-84), Unit Weight (AASHTO T121-82) and Temperature (ASTM C1064-86). Compressive strength tests were performed in accordance with AASHTO T22-86. Compressive strengths were determined at twenty eight days using 4" x 8" cylinders.

TABLE 11
Concrete Mix Design

Materials Sources

Ready Mixed Concrete: S. T. Griswold, Williston, VT
Coarse Aggregate: Whitcomb, Winooski, VT
Fine Aggregate: Hinesburg S&G, Hinesburg, VT
Type II Cement: Northeast, St. Constant, Que.
Air Entraining Admixture: Micro Air, Master Builders, Cleveland, OH
Water Reducing Admixture: Pozzolith 322N
Master Builders, Cleveland, OH
Retarding Admixture: Pozzolith 100XR, Master Builders, Cleveland, OH

Batch Quantities Per Cubic Yard

	Water/Cement Ratio		
	0.40	0.42	0.44
Coarse Aggregate, lbs.	1565	1565	1565
Fine Aggregate, lbs.	1341	1341	1341
Cement, lbs.	660	660	660
Air Entraining Admixture, oz.	5	5	5
Water Reducing Admixture, oz.	33	33	33
Retarding Admixture, oz.	-	16.5	-
Gross Water, lbs.	281.34	294.57	307.80

TABLE 12
Concrete Mix Design

Materials Sources

Ready Mixed Concrete: A. G. Anderson, Berlin, VT
Coarse Aggregate: Cooley, Websterville, VT
Fine Aggregate: Anderson, Highgate, VT
Type II Cement: Northeast, St. Constant, Que.
Air Entraining Admixture: Daravair, W. R. Grace & Co., Cambridge, MA
Water Reducing Admixture: WRDA/Hycol, W. R. Grace & Co., Cambridge, MA
Retarding Admixture: Daratard 17, W. R. Grace & Co. Cambridge, MA

Batch Quantities Per Cubic Yard

	Water/Cement Ratio		
	0.36	0.38	0.40
Coarse Aggregate, lbs.	1589	1589	1589
Fine Aggregate, lbs.	1229	1229	1229
Cement, lbs.	660	660	660
Air Entraining Admixture, oz.	4.5	4.5	4.5
Water Reducing Admixture, oz.	19.8	19.8	19.8
Retarding Admixture, oz.	-	16.5	-
Gross Water, lbs.	266.76	280.00	293.22

TABLE 13
Concrete Mix Design

Materials Sources

Ready Mixed Concrete: Lawrence Sangravco, Woodsville, NH
Coarse Aggregate: Lawrence, Guildhall, VT
Fine Aggregate: Lawrence, Guildhall, VT
Type II Cement: Glens Falls, Glens Falls, NY
Air Entraining Admixture: Daravair, W. R. Grace & Co., Cambridge, MA
Water Reducing Admixture: WRDA/Hycol, W. R. Grace & Co., Cambridge, MA

Batch Quantities Per Cubic Yard

	Water/Cement Ratio		
	0.42	0.44	0.46
Coarse Aggregate, lbs.	1692	1692	1692
Fine Aggregate, lbs.	1233	1233	1233
Cement, lbs.	660	660	660
Air Entraining Admixture, oz.	6.5	6.5	6.5
Water Reducing Admixture, oz.	26.4	26.4	26.4
Gross Water, lbs.	314.55	327.78	340.74

TABLE 14
Concrete Mix Design

Materials Sources

Ready Mixed Concrete: Miller Ready Mix, W. Lebanon, NH
Coarse Aggregate: Lebanon Crushed Stone, W. Lebanon, NH
Fine Aggregate: Lebanon Crushed Stone, W. Lebanon, NH
Type II Cement: Independent, Joliette, Que.
Air Entraining Admixture: Daravair, W. R. Grace & Co., Cambridge, MA
Water Reducing Admixture: WRDA/Hycol, W. R. Grace & Co., Cambridge, MA
High Range Water Reducing Admixture: Daracem 100
W. R. Grace & Co. Cambridge, MA

Batch Quantities Per Cubic Yard

	Water/Cement Ratio		
	0.325	0.35	0.375
Coarse Aggregate, lbs.	1751	1751	1751
Fine Aggregate, lbs.	1468	1468	1468
Cement, lbs.	660	660	660
Air Entraining Admixture, oz.	3	3	3
Water Reducing Admixture, oz.	19.8	19.8	19.8
High Range Water Reducing Admixture, oz.	66	66	66
Gross Water, lbs.	239.49	256.23	272.70

RESULTS & DISCUSSION

PHASE I

Phase I focused primarily on determining the most effective microwave power level for drying plastic concrete. Two criteria were used in this determination; percent error when comparing the water evaporated in the microwave oven to the actual amount of water added to the sample, and the amount of time required to remove all water from the specimens.

Initial tests performed at 40%, 50% and 60% power levels indicated results were closer to actual water added, when the power level was reduced. Testing was then expanded to include the 30% power level.

The overall test error for all power levels was 0.98% and ranged from -0.50% error at 30% power to +1.39% error at 60% power. Average test errors found at each power level were; -0.50% at 30% power, 0.83% at 40% power, +1.05% at 50% power and +1.39% at 60% power. Note that the average percent error was negative (i.e. less water was removed in testing than had been added at the time of mixing) at the 30% power level and positive at the 50% and 60% power levels. The 0.83% overall error at the 40% power level is the average of the absolute values of the numbers and represents the greatest range of results found in Phase I. Individual results were all negative at the 30% power level, a combination of positive and negative at the 40% power level and all positive at the 50% and 60% power levels.

Results reported by North Dakota(1) indicate the problem of weight loss exceeding the quantity of water added, is apparently caused by cement melting. This may explain why the results showed a positive weight loss at the 50% and 60% power levels. Expanding Phase I to include testing at the 30% power level not only improved the accuracy of test results, but also provided a satisfactory solution to the problem of cement melting.

A slight trend was also observed when drying times at the various power levels were compared. Average test completion times were 51 minutes at 30% power, 48 minutes at 40% power, 47 minutes at 50% power and 49 minutes at 60% power.

Considering the properties of plastic concrete and the nature of the test performed, it was decided that a sixty minute time limit be imposed on the test. With greater accuracy and a drying time of 51 minutes at the 30% power level, it was determined the 30% power level would be appropriate for use during Phase II.

Results of microwave oven tests obtained in Phase I are shown in Tables 15 - 22.

TABLE 15
PHASE I-MICROWAVE OVEN DRYING TESTS

30% Power Level - 30 Minute Delay

Test Number	Water Added grams	Weight Loss During Mixing grams	Weight Loss During Delay grams	Weight Loss in Microwave grams	Total Weight Loss grams	Test Error grams	Test Error percent	Drying Time minutes
H30-1	80.5	1.5	0.1	78.6	80.2	-0.3	-0.4	50
H30-2	80.5	1.5	0.2	78.4	80.1	-0.4	-0.5	50

TABLE 16
PHASE I-MICROWAVE OVEN DRYING TESTS

30% Power Level - 60 Minute Delay

Test Number	Water Added grams	Weight Loss During Mixing grams	Weight Loss During Delay grams	Weight Loss in Microwave grams	Total Weight Loss grams	Test Error grams	Test Error percent	Drying Time minutes
H60-1	80.6	1.4	0.2	78.6	80.2	-0.4	-0.5	50
H60-2	80.8	1.4	0.3	78.6	80.3	-0.5	-0.6	55
Average-30% power level[1]							0.5	51

(1) Average % Error, $\bar{x} = \frac{\Sigma|x|}{n}$

TABLE 17
PHASE I-MICROWAVE OVEN DRYING TESTS

40% Power Level - 30 Minute Delay

Test Number	Water Added grams	Weight Loss During Mixing grams	Weight Loss During Delay grams	Weight Loss in Microwave grams	Total Weight Loss grams	Test Error grams	Test Error percent	Drying Time minutes
B30-1	81.5	---	---	----	81.6	+0.1	+0.1	45
B30-2	81.5	---	---	----	82.2	+0.7	+0.9	50
B30-1	81.5	---	---	----	80.2	-1.3	-1.6	45
B30-2	81.5	---	---	----	80.8	-0.7	-0.9	45
G30-1	80.4	1.4	0.1	79.7	81.2	+0.8	+1.0	50
G30-2	80.5	1.2	0.2	79.9	81.3	+0.8	+1.0	45

TABLE 18
PHASE I-MICROWAVE OVEN DRYING TESTS

40% Power Level - 60 Minute Delay

Test Number	Water Added grams	Weight Loss During Mixing grams	Weight Loss During Delay grams	Weight Loss in Microwave grams	Total Weight Loss grams	Test Error grams	Test Error percent	Drying Time minutes
B60-1	81.5	---	---	----	82.2	+0.7	+0.9	50
B60-2	81.5	---	---	----	81.9	+0.4	+0.5	45
B60-1	81.5	---	---	----	81.1	-0.4	-0.5	50
B60-2	81.5	---	---	----	80.7	-0.8	-1.0	45
G60-1	80.2	1.8	0.3	78.6	80.7	+0.5	+0.6	45
G60-2	80.3	1.5	0.1	79.4	81.0	+0.7	+0.9	55
Average-40% power level							0.83	48

TABLE 19
PHASE I-MICROWAVE OVEN DRYING TESTS

50% Power Level - 30 Minute Delay

Test Number	Water Added grams	Weight Loss During Mixing grams	Weight Loss During Delay grams	Weight Loss in Microwave grams	Total Weight Loss grams	Test Error grams	Test Error percent	Drying Time minutes
A30-1	81.5	---	---	----	82.4	+0.9	+1.1	50
A30-2	81.5	---	---	----	82.3	+0.8	+1.0	50
D30-1	80.1	1.7	0.3	78.9	80.9	+0.8	+1.0	45
D30-2	80.5	1.3	0.3	79.9	81.5	+1.0	+1.2	45

TABLE 20
PHASE I-MICROWAVE OVEN DRYING TESTS

50% Power Level - 60 Minute Delay

Test Number	Water Added grams	Weight Loss During Mixing grams	Weight Loss During Delay grams	Weight Loss in Microwave grams	Total Weight Loss grams	Test Error grams	Test Error percent	Drying Time minutes
A60-1	81.5	---	---	----	82.2	+0.7	+0.9	45
A60-2	81.5	---	---	----	82.3	+0.8	+1.0	50
D60-1	79.8	1.7	0.3	78.9	80.9	+1.1	+1.4	45
D60-2	79.7	2.1	0.2	78.0	80.3	+0.6	+0.8	45
Average-50% power level							1.05	47

TABLE 21
PHASE I-MICROWAVE OVEN DRYING TESTS

60% Power Level - 30 Minute Delay

Test Number	Water Added grams	Weight Loss During Mixing grams	Weight Loss During Delay grams	Weight Loss in Microwave grams	Total Weight Loss grams	Test Error grams	Test Error percent	Drying Time minutes
C30-1	81.5	---	---	----	82.7	+1.2	+1.5	50
C30-2	81.5	---	---	----	82.7	+1.2	+1.5	50
F30-1	79.9	1.7	0.3	79.0	81.0	+1.1	+1.4	45
F30-2	80.1	1.6	0.4	79.1	81.1	+1.0	+1.2	45

TABLE 22
PHASE I-MICROWAVE OVEN DRYING TESTS

60% Power Level - 60 Minute Delay

Test Number	Water Added grams	Weight Loss During Mixing grams	Weight Loss During Delay grams	Weight Loss in Microwave grams	Total Weight Loss grams	Test Error grams	Test Error percent	Drying Time minutes
C60-1	81.5	---	---	----	82.6	+1.1	+1.3	50
C60-2	81.5	---	---	----	82.5	+1.0	+1.2	50
F60-1	80.2	1.5	0.3	79.6	81.4	+1.2	+1.5	50
F60-2	80.2	1.7	0.3	79.4	81.4	+1.2	+1.5	50
Average-60% power level							1.39	49

PHASE II

Phase II focused on determining the accuracy of microwave oven test results obtained while simulating field conditions. The aggregates, cements and admixtures represent a cross section of what is encountered throughout Vermont. The sixty minute delay between mixing and start of testing represents a reasonable amount of time for transporting concrete to most projects and obtaining samples for the microwave oven tests. Since the 30% microwave power level produced the most accurate results in Phase I, this power level was used exclusively during Phase II.

With the range of water/cement ratios selected, the air content, slump and unit weight of the various mixes showed considerable variation. Air content ranged from a low of 2.6% to a high of 15.0%. Slump ranged from 1/2 inch to 9 3/4 inches, with both extremes occurring in mixes which contained a High Range Water Reducing Admixture. While it is highly improbable that the extreme results will ever be incorporated into a project, they did provide data for analysis. Results of tests for air content, slump, temperature, unit weight and compressive strength are shown in Appendix "C".

The accuracy of tests in Phase II was again examined by comparing the known water/cement ratio of concrete to results of tests conducted with the microwave oven. Results were reported as percent error, however, two methods were used in the computations; the North Dakota method which uses the measured unit weight of concrete in determining water/cement ratio, and the New Hampshire method which uses the theoretical unit weight. Three of the four concrete sources examined showed greater percent error using the North Dakota method than with the New Hampshire method. Also, all four sources were found to have greater variability i.e. higher standard deviations with the North Dakota method. A comparison of results using the two methods is provided in Tables 23 - 26.

While all mixing and testing was performed in the laboratory, the test error increased sharply when field conditions were simulated. The range of materials, water/cement ratios, air contents, slumps and unit weights had a noticeable effect on the results obtained. Average percent error varied from 2.0% (New Hampshire method) with materials from A. G. Anderson's Berlin, Vermont plant to 6.9% (New Hampshire method) with materials from S. T. Griswold's Williston, Vermont plant. Individual deviations were as high as 11.0% from actual water/cement ratios. The most pronounced deviations occurred principally in mixes having high air content, high slump or both.

A majority of the tests performed in Phase II produced negative results i.e. test results indicated there was less water removed from the concrete than had been added at the time of mixing. Of twenty six batches examined, only six showed more water removed, while twenty batches showed less water removed.

TABLE 23
PHASE II-MICROWAVE OVEN DRYING TESTS
READY MIXED CONCRETE SOURCE: Miller Ready Mix, W. Lebanon, NH

30% Power Level - 60 Minute Delay

Test Number	Sample Size grams	Design Water/ Cement Ratio	W/C N. Dakota Method	% Error N. Dakota Method	W/C New Hampshire Method	% Error New Hampshire Method	Drying time minutes
ML1	1027.8	0.381	0.339	-11.0	0.364	-4.5	45
ML2	1587.9	0.330	0.329	-0.3	0.313	-5.2	55
ML3	1564.2	0.330	0.324	-1.8	0.301	-8.9	60
ML4	1334.2	0.355	0.361	+1.7	0.343	-3.4	60
ML5	1231.1	0.355	0.377	+6.2	0.362	+2.0	55
ML6	1432.1	0.381	0.362	-5.0	0.376	-1.3	60
ML7	1429.2	0.381	0.352	-7.6	0.366	-3.9	55
Average[1]				4.8		4.2	56
Standard Deviation[2]				3.8		2.5	

(1) Average % Error, $\bar{x} = \dfrac{\Sigma|x|}{n}$

(2) Standard Deviation, $S_x = \sqrt{\dfrac{\Sigma x^2 - n\bar{x}^2}{n-1}}$

TABLE 24

PHASE II-MICROWAVE OVEN DRYING TESTS

READY MIXED CONCRETE SOURCE: S. T. Griswold, Williston, VT

30% Power Level - 60 Minute Delay

Test Number	Sample Size grams	Design Water/ Cement Ratio	W/C N. Dakota Method	% Error N. Dakota Method	W/C New Hampshire Method	% Error New Hampshire Method	Drying time minutes
GW2	1117.1	0.423	0.405	-4.3	0.380	-10.2	55
GW3	1110.9	0.403	0.401	-0.5	0.384	-4.7	50
GW4	1360.7	0.423	0.408	-3.5	0.402	-5.0	60
GW5	1295.0	0.403	0.401	-0.5	0.387	-4.0	65
GW6	1260.8	0.423	0.406	-4.0	0.396	-6.4	60
GW7	1327.5	0.444	0.397	-10.6	0.395	-11.0	50
GW8	1318.0	0.444	0.408	-8.1	0.414	-6.8	70
Average				4.5		6.9	59
Standard Deviation				3.7		2.7	

TABLE 25

PHASE II-MICROWAVE OVEN DRYING TESTS

READY MIXED CONCRETE SOURCE: A. G. Anderson, Berlin, VT

30% Power Level - 60 Minute Delay

Test Number	Sample Size grams	Design Water/ Cement Ratio	W/C N. Dakota Method	% Error N. Dakota Method	W/C New Hampshire Method	% Error New Hampshire Method	Drying time minutes
AB1	1407.0	0.383	0.380	-0.8	0.375	-2.1	70
AB2	1225.2	0.383	0.385	+0.5	0.380	-0.8	50
AB3	1257.8	0.363	0.367	+1.1	0.351	-3.3	50
AB4	1161.9	0.363	0.377	+3.9	0.362	-0.3	65
AB5	1254.1	0.403	0.386	-4.2	0.388	-1.5	55
AB6	1347.7	0.403	0.381	-5.5	0.388	-3.7	65
Average				2.7		2.0	59
Standard Deviation				2.1		1.4	

TABLE 26
PHASE II-MICROWAVE OVEN DRYING TESTS
READY MIXED CONCRETE SOURCE: Lawrence Sangravco, Woodsville, NH

30% Power Level - 60 Minute Delay

Test Number	Sample Size grams	Design Water/ Cement Ratio	W/C N. Dakota Method	% Error N. Dakota Method	W/C New Hampshire Method	% Error New Hampshire Method	Drying time minutes
LW1	1416.6	0.422	0.415	-1.7	0.412	-2.4	55
LW2	996.1	0.422	0.427	+1.2	0.424	+0.5	45
LW3	1004.5	0.442	0.418	-5.7	0.423	-4.5	45
LW4	1008.8	0.442	0.423	-4.5	0.432	-2.4	50
LW5	1483.0	0.462	0.423	-8.4	0.435	-5.8	55
LW6	955.5	0.462	0.430	-6.9	0.445	-3.7	50
Average				4.7		3.2	50
Standard Deviation				2.9		1.9	

SURVEY RESPONSE

Response to the survey, distributed to the transportation agencies, was encouraging with forty four of fifty two questionnaires returned to the Materials and Research Division. The survey indicates that while some interest in the use of the microwave oven exists, there is still very limited use of this method for determining water/cement ratio of concrete in the field. Only one respondent claimed to actually be using microwave ovens routinely and one other respondent is currently conducting research. Of the eight transportation agencies which failed to respond to the questionnaire, North Dakota and Oregon(3) have published reports indicating they have conducted research with the microwave oven.

Most agencies indicate that water/cement ratio in the field is determined through use of water meters or weigh batchers at the ready mix plants and the water gauges on truck mixer tanks. A limited number of agencies (three) rely entirely on the slump test as an indicator of water/cement ratio.

A copy of the questionnaire and results of the survey are shown in Appendix "A".

CONCLUSIONS & RECOMMENDATIONS

Apparently, drying plastic concrete in a microwave oven to determine water/cement ratio can provide reliable results under closely controlled laboratory conditions. When variables normally encountered in field produced concrete are introduced, the accuracy of the test method decreases sharply. While the greatest individual percent error in Phase I was 1.6%, the individual percent error jumped to a high of 11.0% in Phase II.

Greater accuracy was experienced using the microwave oven at the 30% power level than at the higher power levels. Average error was reduced from 1.39% at the 60% power level to 0.50% at the 30% power level. At the higher power levels, 50% and 60%, the average percent error was positive i.e. the weight loss experienced was greater than the weight of water added to the mixture. At the 40% power level the results were a combination of positive and negative numbers. At the 30% power all the results were negative.

The 30% power level not only improved the accuracy of the test method, but appeared to eliminate the problem of cement melting while still permitting the test to be completed in a reasonable amount of time.

This project utilized a Sears/Kenmore microwave oven Model 99601 with a power rating of 1450 watts and 1.42 ft^3 of oven space. To standardize this test, the Oregon report(3) stated that microwave power could be converted to power per unit volume or watts per ft^3. Phase I determined that the 30% power level was the most efficient. Conversion of this figure yields a power rating of 306 watts/ft^3. While this particular microwave oven operates at reduced microwave power for operating levels lower than 100%, other microwave ovens may reduce the total energy produced by using alternate on/off cycles while operating at full power. These ovens may require a different power rating to achieve the most effective results.

In three of the four concrete sources examined, the North Dakota method of calculating results produced a greater percent error and showed greater variability of results, as witnessed by the higher standard deviation, than the New Hampshire method.

AASHTO M 157 and ASTM C 94, Standard Specifications for Ready Mixed Concrete both state: "Mixing water shall consist of water added to the batch, ice added to the batch, water occurring as surface moisture on the aggregates, and water introduced in the form of admixtures. The added water shall be measured by weight or volume to an accuracy of 1% of the required total mixing water. Added ice shall be measured by weight. In the case of truck mixers, any wash water retained in the drum for use in the next batch of concrete shall be accurately measured; if this proves impractical or impossible, the wash water shall be discharged prior to loading the next batch of concrete. Total water (including any wash water) shall be measured or weighed to an accuracy of ±3% of the specified total amount." The average percent error obtained with the microwave oven ranged from 2.0% to 6.9% for the four concrete sources examined in Phase II. From the results obtained in this evaluation, it apparently would be inappropriate to use this test method as a quality assurance tool for determining water/cement ratio of concrete in the field.

It is recommended that further testing with the microwave oven be suspended at this time and that the microwave oven not be adopted for use in determining water/cement ratio of portland cement concrete mixtures on Vermont Agency of Transportation projects.

REFERENCES

1. Peterson, R. T. and Leftwich, D., "Determination of Water Content of Plastic Concrete Using a Microwave Oven." North Dakota State Highway Department, Materials and Research Division, Bismark, ND (September 1978)

2. Gress, D. L., "Determining The Water-Cement Ratio Of Plastic Concrete By Microwave Drying." Department of Civil Engineering, University of New Hampshire, in cooperation with the New Hampshire Department of Public Works and Highways

3. Beecroft, D. E. & Dominick, R. L., "Rapid Test Methods For The Evaluation Of Concrete Properties." Oregon State Highway Division, Materials Section (January 1982)

APPENDIX "A"

SURVEY SUMMARY

State Surveyed	Microwave Oven Currently Used Or Under Evaluation	Method Used To Determine W/C Ratio In The Field
Alabama	No	Certified concrete plant
Alaska	No	Batch weights/truck meter
Arizona	No Response	
Arkansas	No	Batch weights/truck meter
California	Yes	Under evaluation
Colorado	No	Water by delivery ticket weights/truck meter
Connecticut	No	Concrete batch weights/water added
Delaware	No	Water content by meter/moisture content
District Of Columbia	No	Documentation by inspectors
Florida	No	Water content by meter
Georgia	No	Batch weights/metered water
Guam	No Response	
Hawaii	No	Batch weights/metered water
Idaho	No	Batch weights/truck meters
Illinois	No	Slump
Indiana	No	Batch weights/truck meters
Iowa	No	Mix design/water measurements/ slump
Kansas	No	Water content read from truck gauge
Kentucky	No	Batch weights/water added
Louisiana	No	Slump/mix design

State Surveyed	Microwave Oven Currently Used Or Under Evaluation	Method Used To Determine W/C Ratio In The Field
Maine	No	Batch weights/truck water gauge
Maryland	No	Batch weights/truck meter
Massachusetts	No	Batch weights/truck meter/slump of plastic concrete
Michigan	No	Water content by meter/moisture content - Bridge decks only
Minnesota	No Response	
Mississippi	No	Slump
Missouri	No	Water meter/moisture content
Montana	No	Water meter/slump
Nebraska	No	Water meter and moisture test
Nevada	No Response	
New Hampshire	Yes	
New Jersey	No	Metered water
New Mexico	No	Actual water and cement in mix
New York	No	Does not control water content in the field by water/cement. Use mix design, slump, air content and temperature.
North Carolina	No	Water content by meter
North Dakota	No Response	
Ohio	No	Water meter/batch weights
Oklahoma	No	Batch weights/truck meter
Oregon	No Response	
Pennsylvania	No	Moisture test/metered water
Puerto Rico	No Response	
Rhode Island	No	Moisture tests/metered water

State Surveyed	Microwave Oven Currently Used Or Under Evaluation	Method Used To Determine W/C Ratio In The Field
South Carolina	No	Moisture tests/metered water
South Dakota	No	Moisture tests/metered water
Tennessee	No	Slump only
Texas	No	Water added is measured
Utah	No	Water content monitored by meter
Virginia	No	Certified plant/mix design
Washington	No Response	
West Virginia	No	Moisture tests/water meters
Wisconsin	No	Batch weights/truck meter
Wyoming	No	Water content monitored by truck meter

V.A.O.T.
Materials & Research Division
01/24/89

W.P. NO: 87-C-11
Microwave Drying
of Concrete

PERSON COMPLETING FORM:

TITLE:

PHONE:

STATE:

1. Has your Agency done research on Rapid Determination of Water Content of Plastic Concrete by microwave drying?

    YES

    NO

2. Does your Agency currently use microwave drying to determine water content of plastic concrete in the field?

    YES

    NO

3. If 'no' to both of the above questions:

    A. What means are used to determine the water content in the field?

    B. Return questionnaire, omitting remaining questions.

LAB TESTING PROCEDURE

4. What model oven was used?

    MAKE:

    MODEL:

    POWER RATING:

5. What power levels were used during the test?

6. If less than full power level was used, what type is employed by the microwave?

    Full power/zero power intervals

    Constant percentage of full power

7. How long did the sample need to be microwaved to bring it to constant weight?

8. What sample size was taken?

9. What batch size was used?

10. What was the time interval between introduction of water and the start of the test?

11. Was the sample covered until the test was run? If YES, with what?

12. What type of dish was used to hold the sample?

13. What time intervals were used to dry the concrete sample to constant weight?

14. Was the sample stirred at intervals during microwaving?

    YES
    NO

15. If so, did this decrease the time it took to run the test?

16. During laboratory testing, was evaporation during mixing considered when comparing the test with design water content?

    YES
    NO

17. Was evaporable water in admixtures taken into account when determining water content?

    YES
    NO

18. Were aggregates used in mixes dried, or was the moisture estimated?

    DRIED
    ESTIMATED

CALCULATIONS

19. What equations are used by your Agency to determine water content and/or water cement ratio with this method?

20. Are the water/cement ratio calculations based on theoretical unit weight or from yield tests of the actual mix?

    THEORETICAL
    ACTUAL

21. What level of accuracy have your tests provided?

22. Has any attempt been made to correlate this test with 28 day compressive strength?

    YES
    NO

RESULTS

23. What controls were imposed on lab testing?

Varying water content

Varying cement content

Varying types of aggregate

Varying types of admixtures

OTHER:

24. Did you find that the accuracy of the test varied when the Mix Design was changed?

YES
NO

a. If yes, what changes were made?

b. How did they affect the accuracy?

25. During Lab testing, was a trend between results obtained with the microwave oven and the actual water content observed?

YES
NO

a. If so, what was it?

b. What was the trend attributed to?

26. Did you find that the age of the sample [from the time water was introduced] had an effect on the accuracy of the test?

YES
NO

27. Did you find that cement particles were "MELTED" by microwaves at high power levels [this phenomenon has been compared to the loss on Ignition Test]?

YES
NO

28. If yes, was this loss enough to significantly alter the accuracy of the test?

YES HOW MUCH [%]? __________
NO

SAFETY

29. Was there ever a problem with the microwave oven overheating?

YES
NO

If yes, what procedure was used to overcome this problem?

30. Was there ever a problem with popping of aggregate particles during heating of the sample?

YES
NO

31. If yes, under what conditions?

32. What safety precautions were taken during testing?

FIELD TESTING PROGRAM

33. If your Agency is currently using a microwave testing program, what is the program's objective?

34. When was the program started?

35. Have test procedures been developed?

YES
NO

36. What procedures are used to ensure the accuracy of the test?

37. What sample size is taken?

38. What method of obtaining a representative sample is employed?

39. Is evaporation during mixing, transport and agitation taken into account when comparing the microwave field test result with the water content based on aggregate moisture, water batched and water added on the project?

YES
NO
NOT DONE

40. What power source is employed to supply power for the microwave in the field?

41. How would you rate the level of available service in the field?

LOW
MEDIUM
HIGH

42. Please include any additional observations or comments you wish to make relating to the determination of water content by microwave drying.

Reports, test procedures, guidelines, results and sample worksheets would be welcomed and appreciated.

Thank you once again for your time and effort in this endeavor.

Charles Abry, Technician III
Vermont Agency of Transportation
Materials and Research Division
133 State St. - State Administration Bldg.
Montpelier, Vermont 05602

APPENDIX "B"

NORTH DAKOTA & NEW HAMPSHIRE WORK SHEETS

NORTH DAKOTA STATE HIGHWAY DEPARTMENT

WATER CONTENT DETERMINATION WORKSHEET FOR PLASTIC CONCRETE

a)	Pan Tare	________g
b)	Wet sample plus pan	________g
c)	Wet sample, b - a	________g
d)	Dried sample plus pan	________g
e)	Water loss, b - d	________g
f)	Cement in percent, $\dfrac{94 \times \_\_\_ \text{sacks/yd}^3}{\text{Unit wt} \_\_\_\_\_\_ \times 27} \times 100$	________g
g)	Weight of cement, $\dfrac{f \times c}{100}$	________g
h)	Water absorbed in aggregate $\dfrac{(c - e - g)}{100} \times$ ____percent absorption	________g
i)	Effective water, e - h	________g
j)	Water - cement ratio, i/g	________
k)	Water in gallons per sack cement, $\dfrac{94 \times j}{8.33}$	________gals/sack

Job: ____________
Date: ________ BR# ____

W/C RATIO

BY

MICROWAVE OVEN

N.H. D.P.W.&H.

M.&R. DIV.

MD= MOISTURE CONTENT, DRY BASIS ____________

N= AGGREGATE TO CEMENT RATIO ____________

FA= FINE AGGREGATE CONTENT (%) ____________

AB_{CA}= ABSORPTION OF COARSE AGGREGATE ____________

AB_{FA}= ABSORPTION OF FINE AGGREGATE ____________

$$W/C = (N=1) \quad MD-N \left[AB_{CA} \quad (1-FA) \quad - \quad AB_{FA} \quad (FA) \right]$$

W/C= ______________________________

APPENDIX "C"

PHASE II - CONCRETE TEST RESULTS

READY MIXED CONCRETE SOURCE: Miller Ready Mix, W. Lebanon, NH

Batch Ident.	ML1	ML2	ML3	ML4	ML5	ML6	ML7
Water/cement ratio	0.381	0.330	0.330	0.355	0.355	0.381	0.381
Air Content, %	15.0	5.5	4.6	4.2	4.9	9.5	7.6
Slump, inches	9.75	.50	.50	1.75	2.00	9.50	8.50
Temperature, ^{o}F	75	79	76	73	74	73	70
Unit wgt, lb/ft^3	137.68	154.58	157.93	154.86	154.22	142.82	142.14
Compressive strength, psi							
28 days	4910	4520	5150	2606	5690	5630	6390
28 days	4970	5470	5570	2984	5290	5020	6110
Average	4940	4995	5360	2790	5490	5325	6250

PHASE II - CONCRETE TEST RESULTS

READY MIXED CONCRETE SOURCE: S. T. Griswold, Williston, VT

Batch Ident.	GW2	GW3	GW4	GW5	GW6	GW7	GW8
Water/cement ratio	0.423	0.403	0.423	0.403	0.423	0.444	0.444
Air Content, %	2.6	4.6	6.6	5.1	5.9	7.3	8.1
Slump, inches	3.00	2.00	3.75	2.00	3.50	5.50	5.50
Temperature, ^{o}F	74	74	75	77	79	80	75
Unit wgt, lb/ft^3	149.08	146.27	142.86	145.43	144.14	141.05	138.80
Compressive strength, psi							
28 days	7260	6290	4810	6230	5610	5630	4950
28 days	7540	5450	5210	6640	5690	5670	4730
Average	7400	5870	5010	6435	5650	5650	4840

PHASE II - CONCRETE TEST RESULTS

READY MIXED CONCRETE SOURCE: A. G. Anderson, Berlin, VT

Batch Ident.	AB1	AB2	AB3	AB4	AB5	AB6
Water/cement ratio	0.383	0.383	0.363	0.363	0.403	0.403
Air Content, %	7.2	7.4	5.0	5.3	10.0	9.5
Slump, inches	2.75	3.00	1.25	1.50	6.00	6.50
Temperature, ^{o}F	74	73	75	78	72	72
Unit wgt, lb/ft^3	140.93	140.81	144.83	144.66	135.83	136.80
Compressive strength, psi						
28 days	5850	5550	6860	6920	5210	5250
28 days	5490	5390	6430	----	4930	5090
Average	5670	5470	6645	6920	5070	5170

PHASE II - CONCRETE TEST RESULTS

READY MIXED CONCRETE SOURCE: Lawrence Sangravco Woodsville, NH

Batch Ident.	LW1	LW2	LW3	LW4	LW5	LW6
Water/cement ratio	0.422	0.422	0.442	0.442	0.462	0.462
Air Content, %	6.8	6.5	7.9	8.6	8.7	9.3
Slump, inches	4.00	3.25	6.00	7.00	7.25	7.75
Temperature, ^{o}F	78	74	74	75	76	72
Unit wgt, lb/ft^3	141.03	145.43	143.02	141.73	141.15	140.29
Compressive strength, psi						
28 days	4580	4640	4020	3980	3960	3520
28 days	4580	4870	4140	3680	3760	3640
Average	4580	4755	4080	3830	3860	3580

TA 565 Rev. 4/79

Prepared By: W. L. Meyer
Date: 12/18/87 WLM
Sheet 1 of 1

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH DIVISION

RESEARCH INVESTIGATION

Work Plan No. 87-C-11

Subject Evaluation of Water Content of Plastic Concrete Using a Microwave Oven

Investigation Requested By Structural Concrete Engineer CWR Date 12/18/87

Date Information Required April 1, 1988

Purpose of Investigation 1. To evaluate laboratory test results for water content of plastic concrete, using a microwave oven.

2. To establish procedures for using a microwave oven for determining the water content of plastic concrete, in the field.

Proposed Tests or Evaluation Procedure Prepare 24 batches of Class A concrete, using several water cement ratios and various combinations of aggregates, cements and admixtures (air entraining, retarding, water reducing and high range water reducing). Determine the water content of each batch of plastic concrete, using a microwave oven. Conduct tests of each batch to determine: slump, air content, unit weight, temperature and 28 day compressive strength, using 4"X8" cylinders.

NOTE: One additional 4"X8" cylinder will be prepared from each batch to be used for preparing standard specimens for microscopic examination.

Proposal Discussed With [signature] Projected Manpower Requirements 28 man days

Investigation To Be Conducted By Structural Concrete Subdivision

Proposed Starting Date ASAP Estimated Completion Date April 1, 1988

Approval/Disapproval by Materials & Research Engineer [signature]

Comments by Materials & Research Engineer

Materials & Research Division
Agency of Transportation
Date Typed: December 21, 1987