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DETERMINATION OF THE WATER CONTENT OF CONCRETE BY THE MICROWAVE METHOD

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ABSTRACT

This paper presents a rapid (15 minutes or less) method for determining the water content of fresh concrete by using a microwave oven. By combining this information with the cement content used, the water to cement ratio can be obtained. The microwave oven was also used successfully to determine natural moisture content, percent absorbtion (S.S.D.) and bulk specific gravity values of aggregates in a short period of time.

INTRODUCTION

In today's world of modern technology and rapid construction it is becoming more and more important to be able to determine the composition and strength of fresh concrete as soon as possible.

Much of today's construction is very rapid. Usually, by the time we learn that the concrete quality for a project is inferior, it may be too late. If we have been fortunate and the structure hasn't collapsed, we may still find that the inferior concrete is buried deep inside the structure where it is very difficult or practically impossible to replace.

Fortunately some advances have been made in the area of accelerated strength testing [16]+ and three methods have been adopted as ASTM standards[4]. All of these methods require at least 24 hours for results.

It would be ideal to analyze concrete before it is placed in the forms. By analyzing the water-cement ratio (w/c ratio) of the concrete at a

+ See selected Bibliography

very early stage, we could determine whether or not the concrete meets the job specifications. It is well established that the w/c ratio directly affects the concrete strength; and, thus its quality. Therefore, if the w/c ratio is within the specification limits, then the concrete quality is also likely to be within the limits. We could also check the uniformity of the concrete (within or between batches), and possibly estimate the concrete's strength potential. This paper presents a method for determining the water content of fresh concrete rapidly; and by combining this information with known or test result cement content information, the water cement ratio of fresh concrete can be easily determined. The w/c ratio is the key factor in determining the quality of concrete [17]; and at the same time is the most difficult parameter to measure.

There are a handful of methods for analyzing the water-cement ratio of fresh concrete[5,6,7,9,10,11]. Unfortunately, none of these methods are ideal. An ideal method must be accurate (within a 95% confidence level), fast (less than fifteen minutes), simple to perform, inexpensive, independent of ingredient types and fieldworthy.

Popovics[12] and Rhodes[14] have presented a very thorough survey of technical literature concerning the composition analysis of fresh concrete. As Popovics[12] noted, "The importance of determining the composition of fresh concrete is indicated by the fact that numerous principles have been suggested and quite a few test methods have been developed for this purpose."

THE MICROWAVE METHOD

Concrete is normally produced by weighing preselected proportions of cement, aggregate, and water (water may be controlled by a volume meter). Natural moisture in the aggregate must be considered along with other factors such as making sure no water is in the mixer before batching, and that no water is added at any time prior to placing. The natural inclination of those responsible for mixing and placing the concrete is to keep the water content as high as allowable to make their work quicker and easier. Any water in addition to the minimum quantity necessary for hydration is detrimental to the overall concrete quality. It is very important that the water content be carefully controlled. Simple oven or hot-plate drying to determine the water content is unsatisfactory because the heat involved hastens cement hydration which makes a portion of the water non-evaporable. Simple oven or hot-plate drying also takes a substantial amount of time to eliminate all of the water.

Peterson and Leftwich[10] have performed limited laboratory and field tests using the microwave method to determine the water content of fresh concrete. Basically the test consists of weighing a fresh sample of concrete, removing the water through heating in a microwave oven for less than an hour (usually about 15 to 20 minutes), and weighing the dried sample. The difference is the water content of the sample.

EFFECT OF BASIC VARIABLE

Peterson and Leftwich[10] reported that any individual test error for analyzing the water content of a fresh concrete sample was never more

than 0.06 gal (0.0002 m^3) per bag of cement and that the average error was -0.003 gal (-0.00001 m^3) per bag of cement when using the microwave method. This means that the test method is accurate to within ±0.06 gal (0.002 m^3) per bag of cement of the true water content 95% of the time, or to within ±0.08 gal (0.0003 m^3) per bag of cement 99% of the time. Their research included concrete samples with air entrainment, fly ash, and other admixtures.

LABORATORY APPARATUS AND PROCEDURE

The following equipment is required to perform a test for the water content of fresh concrete by the microwave method.

A. 1500 gm (3.3 lb) capacity scale with 0.1 gm (0.0002 lb) readings and accuracy.

B. 30 cm (12 in) microwave resistant glass plate.

C. Microwave oven.

D. 0.002 m^3 (0.5 gal) air tight plastic container.

E. Putty knife to break up and stir sample.

F. Scoop or trowel to place the fresh concrete sample in the container.

Approximately a 1000 gm (2 lb) representative sample of fresh concrete is required to perform the test for the water content. The sample should be placed in an airtight container to help avoid any water loss due to evaporation.

The test is performed in five steps.

1. Level and balance the scale and determine the weight of the glass plate.

2. Measure approximately 1000 gm (2 lb) of fresh concrete onto the microwave resistant glass plate and spread it out evenly.

3. Place the concrete sample and glass plate into the microwave oven and set the desired cooking level.

4. Dry to a constant weight, stopping every few minutes to break-up and stir the sample. This helps to relieve any entrapped water. When the sample appears dry, weigh it after stirring each time to determine constant weight.

5. Subtract the initial and final weights to obtain "water dried out in the microwave oven." This value can be easily converted to percent water content in the sample.

If a 30 cm (12 in) glass plate is not available, a container of similar surface area may be substituted.

MATERIALS AND TEST RESULTS

City of Milwaukee tap water at room temperature was used in the concrete sample batches. Huron brand, Type I, cement was used.

Sand was obtained from Central Ready Mixed Concrete Co. of Milwaukee, WI. Fineness modulus for the sand was determined by ASTM Standard procedure after sieving for ten minutes in an electrically driven sieve shaker. Three tests were run on the sand and the average value was used for mix proportioning. The percent natural moisture values for the sands were obtained by drying three 1500 gm (3.3 lb) samples in its natural state to a constant weight in the microwave oven at full power (generally less than 15 minutes) and averaging the values obtained. Then the samples were allowed to cool in air for 30 minutes and weighed again. The difference between the starting weight and dried weight is the natural moisture in the sample. Natural moisture must be accounted for accurately to determine an accurate water-cement ratio. Bulk specific gravity (saturated surface dry basis) and percent absorption values were obtained by using modified ASTM C-128[3] tests. These tests were performed according to the ASTM standard except for the method of drying. A microwave oven was used instead of a conventional oven to dry the sample to a constant weight at full microwave power. Drying time for a sample was always less than 15 minutes. The samples were then allowed to cool in air for thirty minutes before the final dry weights were obtained. 250-500 gm (0.55-1.10 lb) samples were used in a volumetric flask for specific gravity values. It was found that large variations in absorption values were occurring when using these small samples. Therefore 1400-2600 gm (3.1-5.7 lb) samples were used for obtaining absorption values. The test results were more consistent and specific gravity tests could be run simultaneously.

Maximum size 3/4" (1.9 cm) gravel was obtained from Central Ready Mixed Concrete Co. Dry rodded unit weights for the gravel were obtained by standard procedure. Three tests were run and an average value was obtained. The percent natural moisture value for the gravel was obtained by drying three 1500 gm (3.3 lb) samples of gravel in its natural state to a constant weight in the microwave oven at full power and averaging the values. This generally took less than 15 minutes. Then the samples were allowed to cool in air for thirty minutes and again weighed. The difference between the starting weight and dried weight is the natural moisture in the sample.

Bulk specific gravity (saturated surface dry basis) and percent absorption values were obtained by using modified ASTM C-127[2] tests. The tests were performed using all of the standard's procedures except for the method of obtaining an underwater weight and drying. The underwater weight of the gravel sample was obtained by using the buoyancy principle of Archimedes[8]: "A body wholly or partly immersed in a fluid is buoyed up with a force equal to the weight of the fluid displaced by the body." The saturated surface dry sample was weighed in a container of known volume. The container was then filled with water, stirred to allow any air bubbles to escape, and covered with a plexiglass plate (not allowing any air to remain inside). The constant volume container, water, gravel sample and plexiglass plate are then weighed. This weight less the weight of water that would fill the constant volume container, the container's weight, and the plexiglass plate weight yields the underwater weight of the gravel sample. The water was drained off and the sample of gravel dried in the microwave oven to obtain the sample's dry weight. The Amana microwave oven was used to dry the

sample to a constant weight at full power. Drying time for a 3000 gm-6000 gm (7-13 lb) sample was always less than twenty minutes. The microwave oven was stopped briefly every few minutes and the sample stirred to help release any entrapped moisture. Weights were also recorded to demonstrate the rate at which moisture left the sample. The samples were then allowed to cool in air for thirty minutes before the final dry weights were obtained.

Concrete mix proportions were performed by the Bureau of Reclamation procedure[15]. The amounts of aggregate were calculated by computing the total solid volume of sand and coarse aggregate in the concrete mix and multiplying by the recommended percentage of sand. Approximately 1 kg (2 lb) of concrete was required for performing the microwave test. However 34 kg (75 lb) batches were made to provide for any additional tests to be made (air content[1], etc.) and to provide for a more representative sample.

A tilting drum type mixer was used to mix the concrete. Materials were mixed dry for two minutes and then half the amount of water required was added. Wet mixing was carried out for forty five seconds and then flyash, cement and the remaining water were added. Mixing was continued for two minutes and fifteen seconds. The concrete mixture was then discharged onto a pan and turned over with a shovel before determining the properties of the fresh concrete.

Tests A-1 through A-8 were performed in a room where the room temperature was 23°C ± 2°C (73°F ± 3°F) and the humidity was 49% ± 4%. The mix designs used for tests A-1 through A-8 are shown in Table 1.

A correction for the natural moisture content of the aggregate was made by using the average natural moisture content value obtained earlier. This resulted in "actual" water-cement ratios that were different than the water-cement ratios planned in the mixes of Table 1. This correction was made by calculating the effective water in the mix. The effective water is the water available for hydration, and is simply the total amount of water in the mix minus the amount of water absorbed by the aggregate in the saturated surface dry condition. Test results including the "actual" water-cement ratio are shown in Table 2 for tests A-1 through A-8.

Natural moisture was accounted for in the microwave oven method by calculating the amount of aggregate in the fresh concrete sample and multiplying this weight by the average percent absorption for the aggregate in the saturated surface dry condition. This yielded the

Table 1 -- Base Case Mix Design Data

Test No.	1	2	3	4	5	6	7	8
Water (lb)*	5.69	5.77	5.82	5.92	5.99	6.06	6.12	6.19
Cement (lb)*	16.27	14.43	12.94	11.84	10.88	10.09	9.42	8.84
Sand @ S.S.D. (lb)*	22.36	23.67	24.84	25.84	26.84	27.70	28.64	29.49
Gravel @ S.S.D. (lb)*	30.68	31.13	31.40	31.40	31.29	31.15	30.82	30.48
Total Sample Weight (lb)*	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00

*1 lb = 453.4 gm

Table 2 -- Experimental Test Data

Test No.	Water-Cement Ratio		%
	Actual	Microwave	Error
A-1	0.36	0.46	+(27.8)
A-2	0.41	0.34	-(17.1)
A-3	0.47	0.41	-(12.8)
A-4	0.52	0.44	-(15.4)
A-5	0.57	0.49	-(14.0)
A-6	0.62	0.57	-(8.1)
A-7	0.68	0.73	+(6.8)
A-8	0.73	0.65	-(11.0)

weight of the water absorbed in the aggregate at the saturated surface dry condition. Thus the effective water in the water-cement ratio was obtained by subtracting the weight of the water absorbed in the aggregate at the saturated surface dry condition from the water removed from the fresh concrete sample in the microwave oven.

The microwave oven method results varied from minus seventeen percent to plus twenty eight percent error with an average percent error of fourteen percent.

Controlled tests of the microwave method were performed to determine the reasons for these errors and variations. Fig. 1 shows a flow diagram of the controlled tests performed with the microwave oven. Fig. 2 shows the rate at which water loss occurred with fast drying at full microwave power, and slow drying in the microwave oven's defrost mode.

Table 3 shows the results of the first eight controlled microwave method tests. Sixteen additional controlled microwave tests (Special Test Series AA and BB) were performed to verify some of the patterns developed in the previous eight controlled microwave method tests. Tables 4 and 5 show the mixes used and results obtained. The average percent error for Test Series AA was 0.6% and for Test Series BB was 3.5%.

ANALYSIS OF TEST RESULTS

In reviewing the special tests, (Tables 3, 4 and 5,) all twenty-four tests with hand mixing and exact moisture content knowledge yielded very good results (less than 10% error). Excellent results (less than 5% error) occurred in twenty one out of the twenty four tests. It appears that cement does not appear to be a problem factor. However generally the concrete mixture without any cement did yield more accurate results. Accurate results can be obtained with a representative sample and exact moisture content knowledge of a fresh concrete sample.

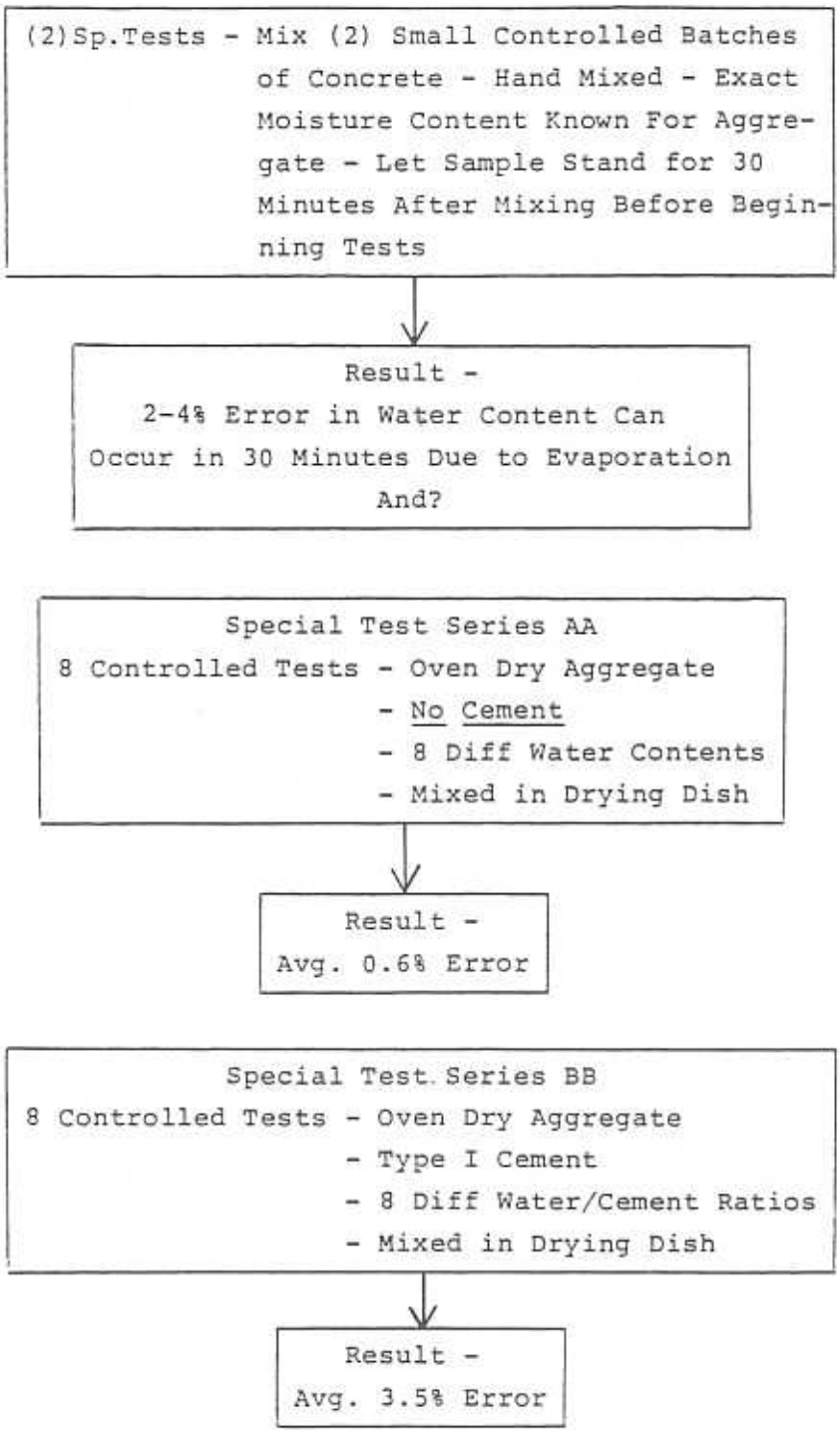

Fig. 1 - Flow Diagram of Special Microwave Oven Tests Performed

Tests were also performed to determine the effect of short waiting periods before running the tests. Samples were allowed to stand for 30 minutes prior to testing and results indicated about 2% to 4% error from known values. Short periods of waiting (less than 30 minutes) do not appear to significantly affect results, however tests should be performed as soon as possible for best accuracy.

It can also be concluded from Fig. 2 that excessive cooking and cooking speed has no effect on results. Once a constant weight is obtained, the sample's water has been removed.

CONCLUSIONS AND RECOMMENDATIONS

In reviewing the laboratory work and research performed several conclusions and recommendations can be made.

A microwave oven can be used successfully to dry aggregates to a constant

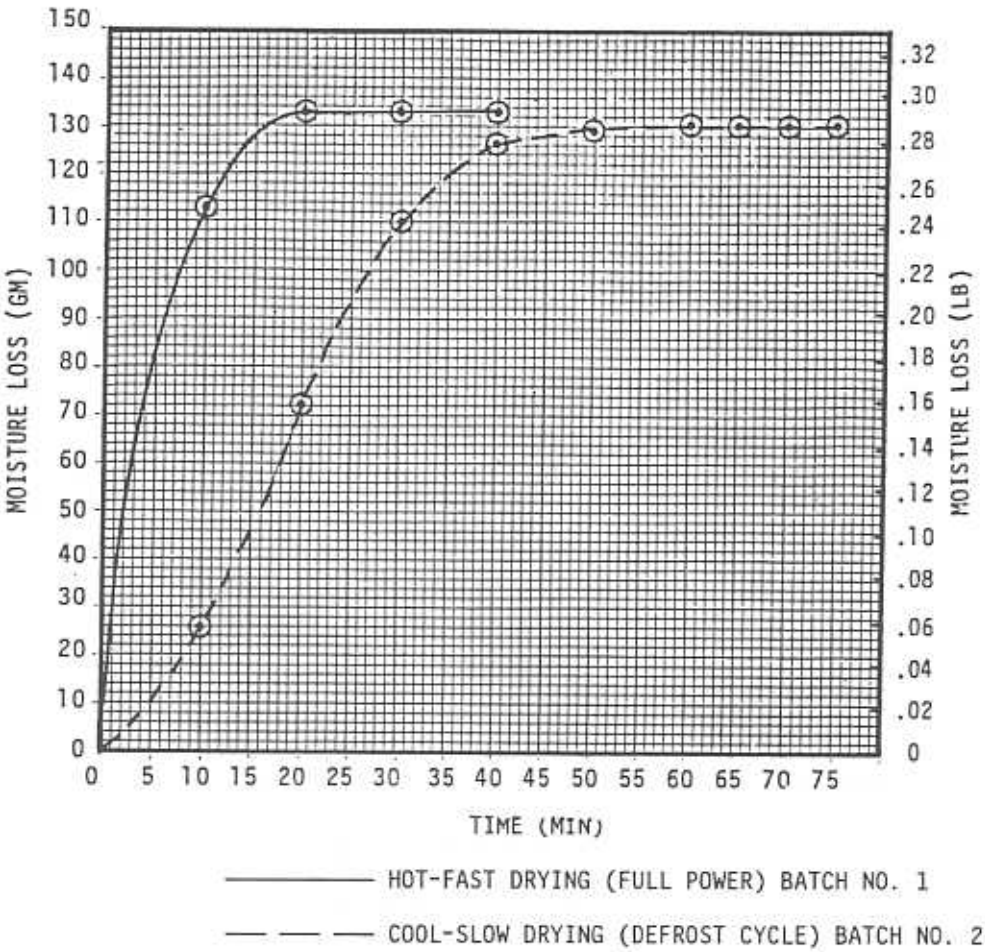

Fig. 2 -- Microwave Oven Moisture Loss Rates
(Special Controlled Test No. 1)

Table 3 -- Controlled Test Results

Controlled Microwave Method Tests

Test No.	Description*	Known Water Content	Water Content by the Microwave Method	Percent Error
1	*	126.0	115.3	-8.5
2	No Cement	132.3	132.4	+0.1
3	Oven Dry Aggregate	113.4	114.8	+1.2
4	Oven Dry Aggregate Slow Drying - Microwave Oven in Defrost Mode	114.9	113.0	-1.7
5	*	130.4	130.5	+0.1
6	Slow Drying - Microwave Oven in Defrost Mode	132.3	130.0	-1.7
	*	126.8	126.7	-0.1
7	Considering 30 Min. Evaporation	124.1	126.7	+2.1
	*	126.9	119.2	-6.1
8	Considering 30 Min. Evaporation	122.1	119.2	-2.4

*Note: A normal controlled test consisted of:

A) Microwave oven cooking at maximum power

B) Concrete sample consisting of water, cement and aggregate in natural states

Exceptions to the normal controlled test are listed in the description column above.

TABLE 4 -- SPECIAL TEST SERIES AA

Test No.	Water Added (gm)*	Sand (gm)*	Gravel (gm)*	Water Removed (gm)*	% Error
AA-1	65.4	373.8	560.8	65.4	0
AA-2	74.1	370.4	555.5	76.0	2.6
AA-3	82.6	367.0	550.4	82.9	0.4
AA-4	90.9	363.6	545.5	91.5	0.7
AA-5	99.1	360.4	540.5	99.1	0
AA-6	107.1	357.1	535.8	108.0	0.8
AA-7	115.0	354.0	531.0	115.0	0
AA-8	122.8	350.9	526.3	123.1	0.2
				Avg. % Error →	0.6

*1 lb = 453.4 gm

TABLE 5 -- SPECIAL TEST SERIES BB

Concrete Mix Microwave-gm*

Test No.	Water (gm)	Cement (gm)	Sand (gm)	Gravel (gm)
BB-1	55.1	157.5	315.0	472.4
BB-2	62.5	156.2	312.5	468.8
BB-3	69.8	155.0	310.1	465.1
BB-4	76.9	153.8	307.7	461.6
BB-5	84.0	152.7	305.3	458.0
BB-6	90.9	151.5	303.0	454.6
BB-7	97.7	150.4	300.8	451.1
BB-8	104.5	149.2	298.5	447.8

Water-Cement Ratio

Test No.	Actual	Microwave	(% Error)
BB-1	0.28	0.30	+7.1%
BB-2	0.33	0.33	+0.0%
BB-3	0.38	0.41	+7.9%
BB-4	0.43	0.42	-2.3%
BB-5	0.48	0.48	+0.0%
BB-6	0.53	0.55	+3.8%
BB-7	0.58	0.57	-1.7%
BB-8	0.63	0.60	-4.8%
		Avg. % Error	3.5%

*1 lb = 453.4 gm

weight in much less time than the standard ASTM oven drying procedure. The microwave method takes less than an hour (usually about 20 minutes), and conventional oven drying takes about twenty four hours. Thus the microwave oven can be used successfully to determine natural moisture contents, percent absorption values and specific gravity values in short periods of time. Results obtained for bulk specific gravity, percent absorption and natural moisture content values were similar to the supplier data for the aggregates analyzed.

Mixed results have been obtained when testing for the water content of fresh concrete using the microwave method. Accuracy reported in prior

research was generally not easily obtainable. However representative samples of hand mixed fresh concrete with exact natural moisture content knowledge yielded excellent results, with less than 5% error.

Microwave oven testing has proved to be very useful in the concrete quality control laboratory both for analyzing the properties of concrete component materials and the water content of fresh concrete. Continued research in this area is highly recommended and should prove rewarding. Two additional areas of research should include job site testing with the microwave oven and sieve analysis of the dried concrete sample to obtain the cement content of the fresh sample.

Successful tests would provide an independent water-cement ratio value very rapidly for a fresh concrete sample.

The research performed demonstrated a pattern of consistently high or low values for sets of water-cement ratio tests. The controlled test sets yielded consistently high values where standard tests A-1 through A-8 yielded consistently low values for the water-cement ratio. Both sets of tests utilized the same specific gravity and percent absorption values. This conflict points to balance inconsistencies, natural moisture differences, the obtaining of a representative sample or a combination of these problems. Further research was performed with extreme accuracy to determine if any patterns do in fact exist. As shown in the Series BB tests, the accuracy was very significantly improved.

The Microwave Method is fast, simple to perform, inexpensive, and field-worthy. Continuing research will verify the accuracy of this ideal method and exhibit its value in quality control and quality assurance.

The obtaining of a value for the water-cement ratio of fresh concrete in fifteen minutes or less is vitally needed and rapidly becoming possible. Further research is necessary to determine the cement content of fresh concrete in a quick and easy manner.

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