FINAL REPORT

DETERMINATION OF THE CEMENT CONTENT OF HARDENED
CONCRETE BY SELECTIVE SOLUTION

by

G. G. Clemeña
Highway Research Analyst

(The opinions, findings, and conclusions expressed in this report are those of the
author and not necessarily those of the sponsoring agencies.)

ABSTRACT

The method of selective solution by methanolic maleic acid, developed by Tabikh et al. for the determination of cement content in hardened concrete, was evaluated. It was found to be relatively simple and inexpensive, and is accurate to within ±1 percentage point cement at the 95% confidence level with the use of calibration curves. Such factors as aggregate and cement compositions, curing time, and water-cement ratio were investigated as to their effects on the method. Among these factors, aggregate composition was the only one found to have a significant effect on the analytical results.

The determination of cement content by the measurement of the specific gravity increase in a methanolic maleic acid solution was also investigated, but was found to have unsatisfactory precision.

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INTRODUCTION

Many millions of dollars are spent each year in highway construction using
portland cement concrete. Because cement content influences many of the important
properties of concrete and because it is often the basis for contractural obligations,
it is important to have available some simple method for the determination of the
cement content of concrete that is reasonably accurate and applicable in field testing.
Such a test would enable determination of compliance to design specifications and of
the uniformity of cement dispersion throughout the concrete mixture. The determi-
nation of the cement content of hardened concrete involves two problems. One is
the extraction of a representative sample from the large mass of concrete in question.
It is of course not always possible to get such a sample, and is a problem common to
all non-in-situ methods. The second problem is to determine accurately and rapidly
the cement content of the sample. It is the second problem with which this project
was concerned.

REVIEW OF CURRENT METHODS FOR THE DETERMINATION OF THE
CEMENT CONTENT OF CONCRETE

Various chemical and nuclear methods have been developed for determining the
cement content of a sample of concrete. However, each of these methods has certain
undesirable features that prevent its wide acceptance.

The ASTM method[1] consists of determining the amount of soluble silica and
calcium oxide in a sample by chemical analysis, and then indirectly calculating the
percentage of cement by assuming or establishing from analyses of the original cement
some definite concentrations of silica and calcium oxide in the cement used. The method
gives reliable results, particularly if samples of original cement and aggregates are
available, but it is time consuming and is not applicable to concrete that contains aggre-
gates that yield simultaneously significant amounts of silica and calcium oxide under the
conditions of the test.

Neutron activation analysis was used by Covault and Poovey[2] to determine cement content. The amount of cement in a radioactivated concrete sample was determined by counting the radioactivity and determining the cement content from a cement content vs. count rate curve. The method, however, requires costly irradiation and counting equipment. Also, it cannot be used with aggregates containing appreciable amounts of calcium.

Iddings and his co-workers[3] investigated the feasibility of some nuclear techniques — activation analysis, stable tracer analysis, natural radioactivity measurement, and isotope dilution — in the determination of cement in concrete. Neutron activation analysis was again found to be rapid, although impaired by errors due to common elements in the concrete components. Also, it requires costly facilities. The other techniques are either applicable only under ideal conditions, or are not economical. Also, it must be mentioned that personnel safety against potential hazards of radiation must be ensured when using radioisotopes. This requirement imposes an extra cost on the analysis.

Kossivas[4] has developed a method in which the cement content of a concrete sample is derived from its sulfate content. This method requires that the sulfate content of the cement be known and that all the sulfates be derived from the cement. Serious errors can result from the use of aggregates which contain appreciable quantities of sulfate.

To summarize, the present chemical methods for determining cement content are laborious, require a prior knowledge of the chemical composition of the cement, and give serious errors if the aggregates contain constituents that interfere with the analysis. On the other hand, the nuclear methods are not widely applicable and require a well equipped laboratory with costly radiation equipment and highly skilled personnel. Consequently, a better method is needed.

DETERMINATION OF THE CEMENT CONTENT BY SELECTIVE SOLUTION

Recently, Tabikh and his co-workers[5] introduced a method which may fill the need for a simple and reliable method of cement content determination.

The method involves washing a dried and crushed concrete sample with a methanolic solution of maleic acid. The hydrated and unhydrated calcium silicates and the hydrated aluminates and ferrites are selectively dissolved by the washing, leaving the unattacked aggregates plus the unhydrated aluminates and ferrites as residue to be separated by filtration. From the weights of the residue, the water combined in hydrated cement, the free water, and the bulk specific gravity of the concrete sample, the cement content is calculated and expressed either in terms of percentage points of cement, or bags per cubic yard of concrete. This selective solution method has several desirable features as follows:

1. Simplicity — The method is simple, since it does not involve any complex chemical procedures. The cement paste is simply separated from the aggregates by washing with the methanolic solution of maleic acid. Because of this feature, a technician can easily perform the analysis once a precedure is developed.

2. Low cost — No expensive and sophisticated equipment is needed. As a matter of fact, only some chemicals, a balance, an oven, and filters are needed. With these first two features, the method can be suitably adapted for use by routine testing laboratories.

3. The method directly determines the cement content — Unlike any of the existing methods that indirectly determine cement content by analyzing for a certain constituent of the cement used, the method directly determines the amount of cement present in a concrete sample. Therefore, no prior knowledge of the chemical composition of the cement, aggregates, or other materials is needed. This means considerable savings in terms of the time needed to perform an analysis.

The method, however, may not be completely without problems. Some anticipated problems are as follows:

1. The methanolic solution of maleic acid dissolves calcium silicates — due to this, the method may give high cement content values if aggregates with high soluble silicate contents are used in a concrete mix.

2. Calcareous aggregates may be dissolved by the acid to some extent — the result would also be a higher apparent cement content when calcareous aggregates are used.

3. The unhydrated aluminate and ferrite phases of the cement are insoluble in the methanolic solution of maleic acid — the apparent cement content of a concrete sample will be inversely affected by the amount of the unhydrated aluminate and ferrite phases present, since these are not dissolved by the acid and will therefore remain with the aggregates as part of the residue.

OBJECTIVE

Inasmuch as this method of selective solution possesses features ideal for a standard testing method, it was considered worthwhile to determine the extent to which the above mentioned problems affect the apparent cement content values. Therefore, the principal objective of this study was to determine the effects of (1) various locally available aggregates, and (2) various factors which are related to the extent of cement hydration on the determination of the cement content of concrete by the method of selective solution with a methanolic solution of maleic acid. As a supplementary study, the relationship between the cement content and the specific gravity of a cement paste solution in alcoholic maleic acid was determined. It was thought that the latter might provide an alternative method by which cement content may be determined more rapidly than by the present version of the selective solution method.

EXPERIMENTAL PROCEDURE

Chemicals

Maleic acid and anhydrous methanol were used to prepare a 20% maleic acid solution. This solution has a shelf life of approximately two weeks.

Apparatus

A 10-cm Buchner funnel fitted with a tared S & S Red Ribbon paper was used for filtration, and a 2,000-ml Erlenmeyer vacuum flask was used to collect the filtrate. Specific gravity measurements were made with an ASTM No. 106H hydrometer with a range of 0.850—0.900. The balance used had a capacity of 1,000 grams, and was sensitive to 0.01 gram.

Cements

Three different cements — Types I, II, and III — were used to prepare the concrete samples. Tables 1 and 2 show the results obtained from some oxide analyses and the potential phase compositions of these cements, respectively.

Table 1

Oxide Compositions of the Three Types of Cement Used

Type	% SiO_2	% Al_2O_3	% Fe_2O_3	% CaO	% SO_3
I	21.06	5.91	2.93	61.61	3.14
II	22.00	4.37	3.19	61.37	2.59
III	20.87	4.62	2.59	61.40	3.36

Table 2

The Calculated Potential Phase Compositions of the Cements Used

Type	% C_3S	% C_2S	% C_3A	% C_4AF	% $CaSO_4$
I	37.8	31.7	10.7	8.9	5.3
II	41.3	31.5	6.2	9.7	4.4
III	47.0	24.3	7.9	7.9	5.7

Aggregates

Unless otherwise stated, the aggregates used were a granite gneiss obtained from Superior Stone Company, Albemarle County, Virginia. The aggregate size was 0.187 to 0.375 inch.

Procedure

In this study, it was decided to express the cement content as percentage points of cement, instead of bags per cubic yard, to eliminate the necessity for determining the bulk specific gravity of the concrete samples. Except for this elimination, the procedure used was essentially that developed by Tabikh and his co-workers[5] and outlined in Figure 1. Each of the concrete samples used in this study weighed about 1,000 grams. In applying this method to field operations, the sample size must be at least three times the size of the largest aggregate used in the concrete mixture, and the bulk specific gravity of the concrete sample should be determined in accordance with ASTM C-642.

The procedure used for the determination of the specific gravity of a cement paste solution in methanolic maleic acid is outlined in Figure 2. The maleic acid solution and extract are kept at 27°C with a water bath.

Calculation

$$\text{Free water, } W_f = \frac{A - C}{A} \times 100$$

where, A = weight in grams of a representative sample, and

C = weight in grams of the sample after 24 hours at $105^{O}C$

$$\text{Combined water, } W_c = \frac{D - E}{D} \times 100$$

where, D = weight in grams of pulverized and 105°-C dried sample, and

E = weight in grams of the same sample after heating at $600^{O}C$ for 4 hours.

$$\% \text{ Residue, } R = \frac{F - G}{G} \times 100$$

where, F = weight in grams of pulverized and 105°-C dried sample, and

G = weight in grams of residue after maleic acid extraction.

$$\% \text{ Cement in concrete, } C = (100 - R - W_c)(1 - W_f/100)$$

$$\text{Specific gravity gradient, } S_i = (S_i - S_o)$$

where, S_o = specific gravity of the maleic acid solution before extraction, and

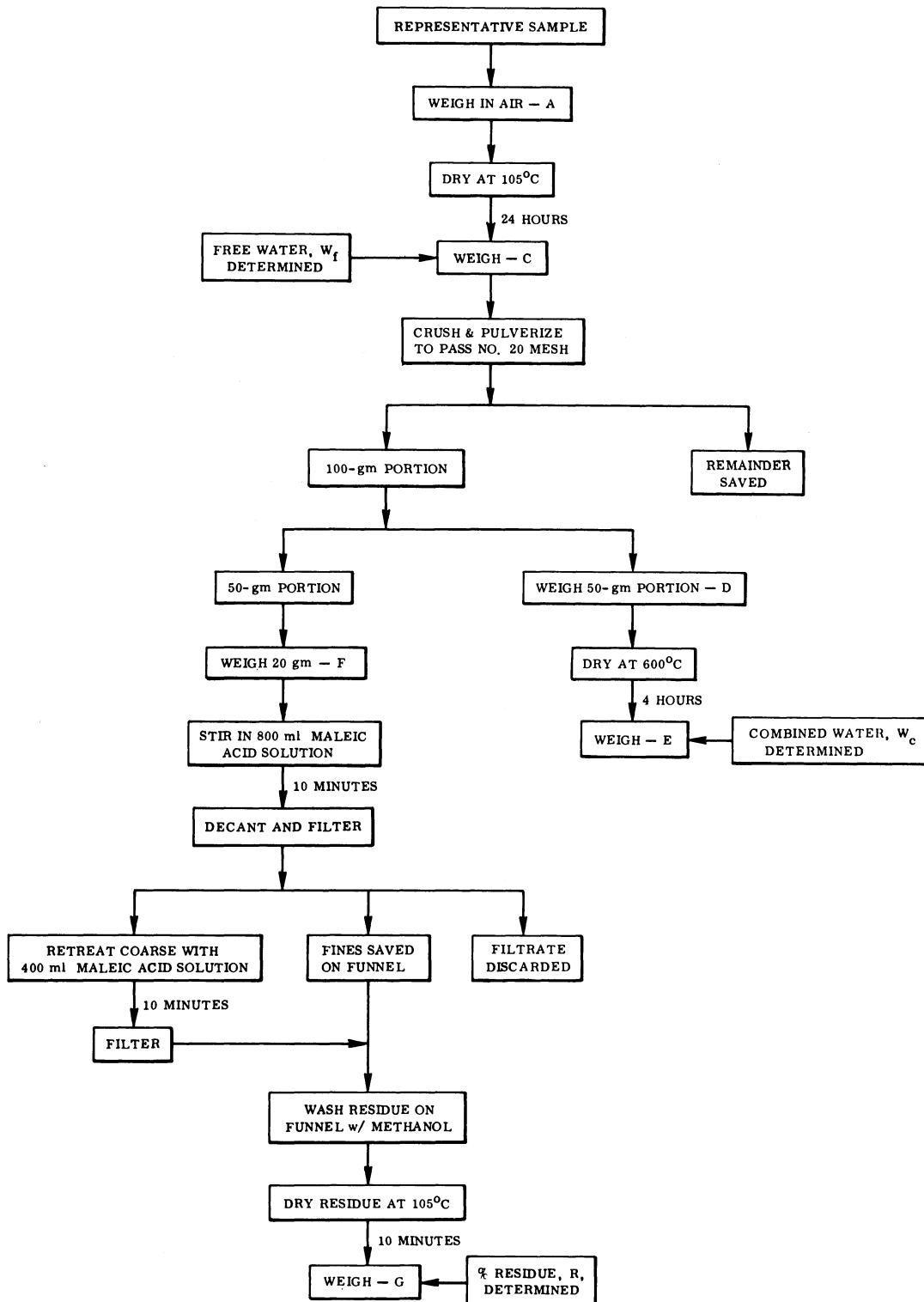S_i = specific gravity of the maleic acid solution after extraction.

Figure 1. Determination of cement content in concrete by maleic acid extraction.
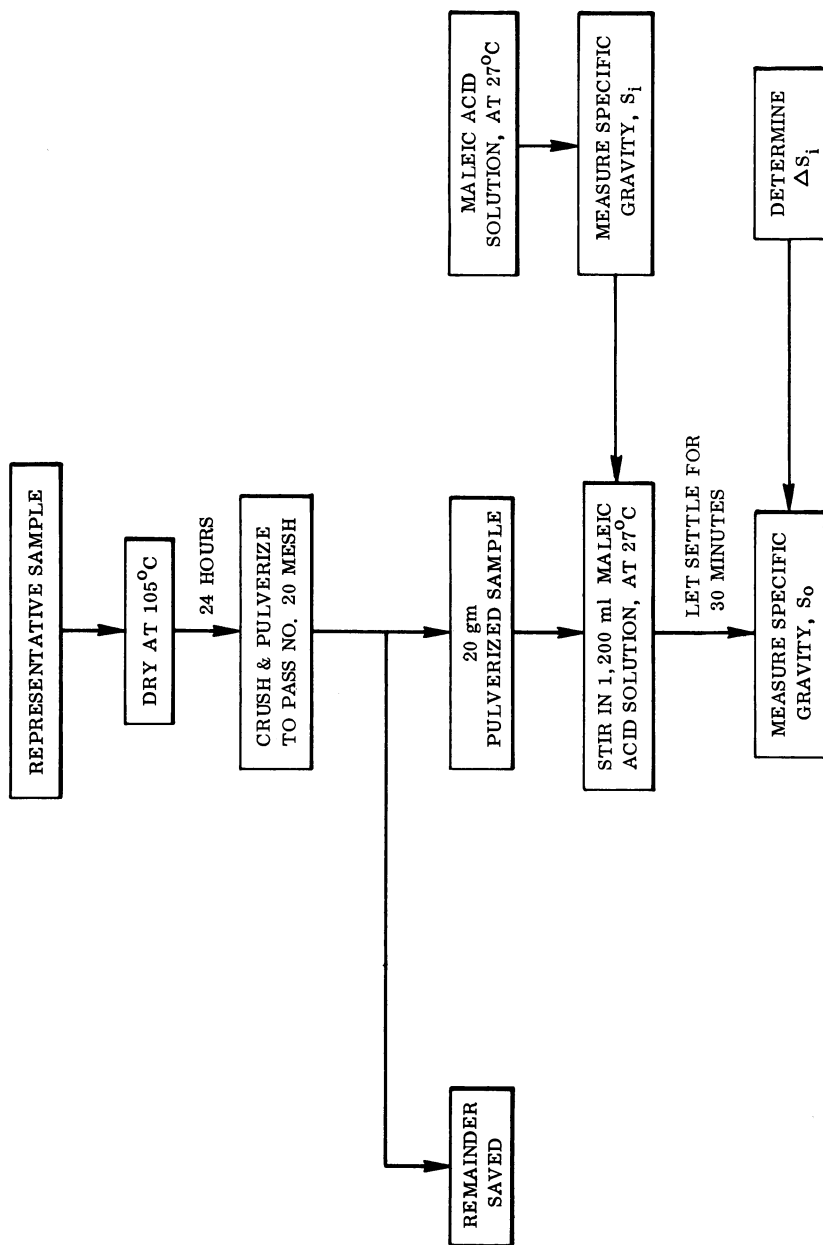
Figure 2. Determination of the specific gravity gradient of a maleic acid solution after dissolution of cement paste.

RESULTS AND DISCUSSION

Accuracy and Precision

Five 150-gram portions of a concrete sample, prepared with the Type II cement and cured for a week in a moisture room, were analyzed for cement content by the procedure outlined in Figure 1. The data, given in Table 3, show that the replicate analyses yield a standard deviation of 0.5 percent cement. The method is accurate to within ±1 percentage point of cement, approximately 0.35 bags/cubic yard, at the 95% confidence level.

The fact that the method failed to detect the unhydrated portion of the cement is manifested in the consistently low results obtained in the replicate analyses.

Table 3

Accuracy and Precision Data

Analysis No.	Percent Cement			Relative Error[a]
	Actual	Measured	Error	
1	15.0	14.0	-1.0	-6.7
2	15.0	14.5	-0.5	-3.3
3	15.0	13.5	-1.5	-10.0
4	15.0	14.9	-0.1	-0.7
5	15.0	14.2	-0.8	-5.3

Mean = 14.2 percent cement

Mean Error = -0.8 percent cement

Mean Relative Error = -5.2 percent

Standard Deviation = 0.5 percent cement

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[a] Expressed as percent of the actual cement content.

Effect of the Aggregates

Although Tabikh, et al., [5] found no effect related to aggregates, it would seem that siliceous and calcareous aggregates would be attacked by a methanolic maleic acid solution, and thereby cause the measured cement content of a concrete sample made from any of these aggregates to be higher than the actual cement content. The error, of course, is directly proportional to the extent of dissolution of the aggregates by the acid. In order to determine the extent to which the organic acid solution will attack aggregates typical of those found in Virginia, eleven different aggregates were subjected to leaching tests. As Table 4 shows, these aggregates can be divided into two groups: (1) The siliceous aggregates (1-7), and (2) the calcareous aggregates (8-11).

Table 4

Aggregates Tested

Aggregate	Quarry	Description
1. Granite (1)	Graham Virginia Quarry Fairfax County	Medium grained, light gray rock composed essentially of quartz, potash feldspar, and biotite with some plagioclase feldspar, muscovite and chlorite.
2. Granite (2)	Superior Stone Co. Albemarle County	Medium grained, light to dark gray, even granular to porphyritic and composed essentially of plagioclase feldspar, quartz, and biotite.
3. Diabase (1)	W. W. Saunders Quarry Fauquier County	Fine grained, dark gray and composed essentially of augite and labradorite.
4. Diabase (2)	Arlington Stone Co. Loudoun County	Medium grained, dark gray and composed essentially of augite and labradorite.
5. Aplite	Dominion Mineral Co. Nelson County	Light colored, fine grained rock composed essentially of orthoclase.
6. Feldspar	Northwestern Feldspar Corp. Bedford County	Light colored, iron stained, coarse grained pegmatite.
7. Kyanite	Kyanite Mining Corp. Buckingham County	Aggregate of kyanite crystals.
8. Marble Schist	Blue Ridge Stone Co. Campbell County	Fine-to medium-grained marble that contains variable amounts of muscovite, biotite, chlorite, and pyrite.
9. Dolomitic Limestone (Beekmantown)	F. K. Betts Quarry Rockingham County	Gray, fine to medium grained with approximately 52% calcium carbonate and 40% magnesium carbonate.
10. Limestone (Lincolnshire)	M. J. Grove Lime Co. Frederick County	A gray black, medium grained thick bedded limestone composed of about 95% calcium carbonate.
11. Limestone (New Market)	M. J. Grove Lime Co. Frederick County	Dominantly a compact thick bedded, dove gray limestone which is 97-98% calcium carbonate.

In the leaching test, 16.0 grams of each aggregate passing the No. 20 mesh were treated with methanolic maleic acid solution using the procedure for the determination of cement content (Figure 1). This particular amount of aggregate is approximately that which will be present in a 20-gram dried and crushed concrete sample of 15% cement and a water-cement ratio of 0.35. In addition to being subjected to the leaching test, each aggregate was used to prepare a concrete sample of the above mentioned composition using Type II cement and cured for a week in a moisture room for analyses of their cement contents.

The results obtained are given in Table 5. It was found that both siliceous and calcareous aggregates dissolve in a maleic acid solution, with the latter dissolving to a slightly higher extent (see the 2nd column in Table 5). From this, it can be expected that for concrete samples of the same actual cement contents, the ones prepared from calcareous aggregates would give higher apparent cement contents than those made of siliceous aggregates. An examination of the measured cement contents (see the 3rd column in Table 5) obtained from analyses of the different concrete samples would confirm this. In Figure 3, the aggregate solubility is plotted against the measured cement content and the corresponding relative error. This graph shows that the siliceous aggregates (1-7) may contribute as much as 3 percent cement to the apparent cement content of a sample, while the calcareous aggregates (8-11) may contribute as much as 5 percent cement. Both of these contributions represent significant errors in the analytical result

Table 5

Aggregate Solutibility in Maleic Acid Solution
and its Effect on the Analytical Result

Aggregate	Solubility (%)[a]	Measured Cement Content (%)[b]	Relative Error (%)
1. Granite (1)	1.57	13.3	-11.3
2. Granite (2)	2.01	14.5	- 3.3
3. Diabase (1)	1.03	14.0	- 6.7
4. Diabase (2)	2.27	14.1	- 6.0
5. Aplite	3.15	15.7	+ 4.7
6. Feldspar	2.33	16.7	+11.3
7. Kyanite	1.88	14.5	- 3.3
8. Marble Schist	3.01	12.9	-14.0
9. Dolomitic Limestone	5.83	18.5	+23.3
10. Limestone (L)	5.45	16.5	+10.0
11. Limestone (N.M.)	6.77	17.0	+13.3

a. Determined by leaching an aggregate sample first with an 800 ml portion of methanolic maleic acid solution followed by a 400 ml portion of the same acid.

b. The actual cement content was 15.0%.

The observed dissolution of siliceous and calcareous aggregates in the maleic acid solution is in contradiction to Tabikh and his co-worker's report, which stated that "the methanolic maleic acid will leave nearly all igneous and calcareous aggregates unaffected."[5]
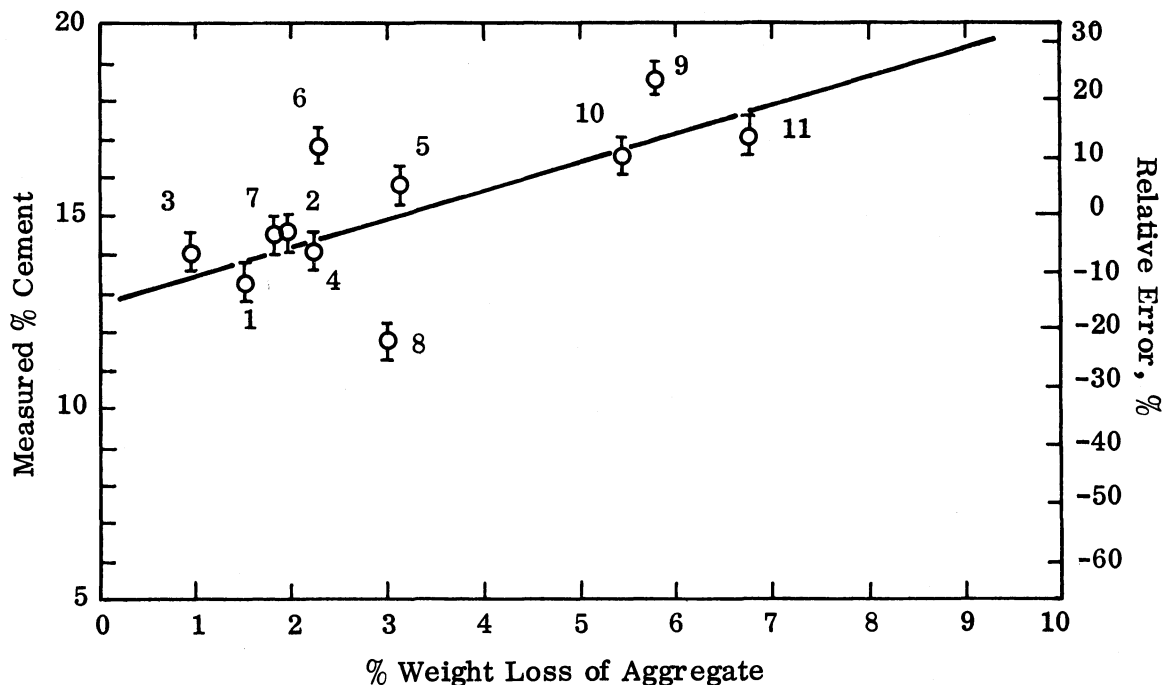

Figure 3. The effect of aggregate solubility in maleic acid solution on the measured cement content. (The error bar is for ± 1 standard deviation calculated from replicate analyses.)

Effects of the Degree of Hydration

Methanolic maleic acid readily dissolves both the hydrated and unhydrated silicates in cement, whereas the unhydrated aluminates and ferrite phases are insoluble. However, the hydration products of the aluminates and the ferrite phases are soluble in the acid. In the presence of water, the aluminates hydrate rapidly, and, therefore, become soluble in the acid. This leaves the ferrite phase to be the only constituent of concern; because of its slower hydration rate, some of the ferrite phase will be unhydrated and remain with the aggregates as part of the residue. The effect is a negative bias on the apparent cement content of a concrete sample, with the bias diminishing as the cement hydrates further. In case of incomplete curing, obviously the unhydrated aluminates will also have the same influence on the analytical results.

There are evidences that the degree of hydration, which determines the amounts of the unhydrated aluminate and ferrite phases in concrete, is dependent upon such factors as the age of the concrete, the composition of the cement, and the water-cement ratio. Therefore, it is expected that the amount of these unhydrated constituents would also depend on these factors. In view of the foregoing discussion, it is necessary to determine to what extent these factors may affect the analytical results.

Effect of Age

A series of concrete samples having the same composition (15% Type II cement and a W/C of 0.35) were prepared and stored in a moisture room. After each curing time — the times ranged from 4 days to 8 months — one of the samples was analyzed for cement content. A plot of the measured cement content versus curing time is shown in Figure 4. There appears to be no definite observable relation between the apparent cement content and the age of the concrete. This is in agreement with the finding of Tabikh and his co-workers,[5] who also reported that no such relation was observed.
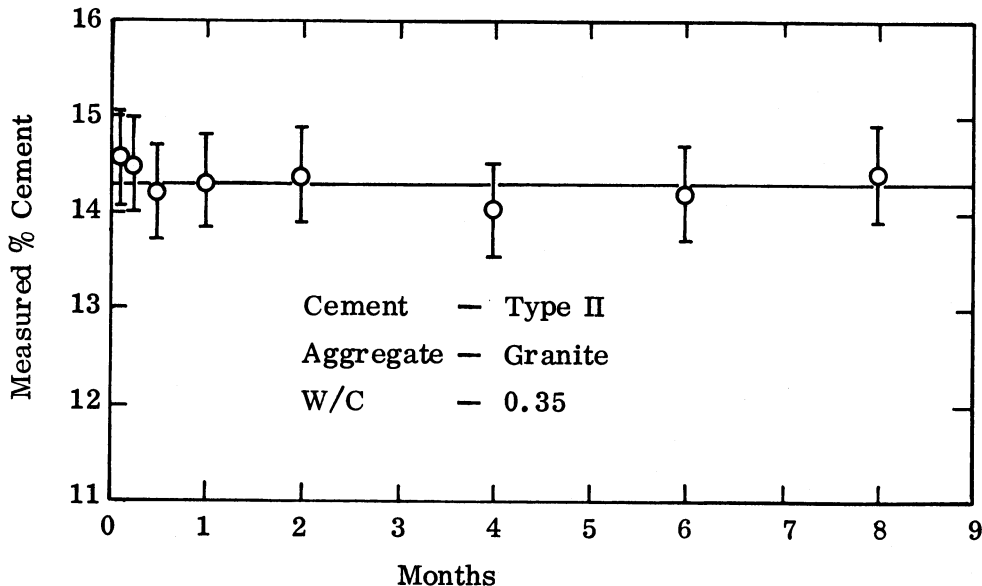

Figure 4. Measured cement contents at various curing periods.

This lack of any apparent effect of curing time on the measured cement content lies in the inability of the method to discern the small differences in the apparent cement contents of concrete as a result of curing time variations. Available information on the percentages of the unhydrated ferrite phase (C_4AF) at certain curing times (see Figure 5) has shown that during the period starting from the 2nd to the 28th day of curing, the maximum increase in the extent of the ferrite phase hydration is only approximately 16%

of the original ferrite phase. The author has estimated that this increase in the extent of ferrite phase hydration would correspond to an increase in the apparent cement content of approximately 0.4 percent cement, i.e., from 14.2 percent for 1 day curing to 14.6 percent for 28 days curing (see Figure 6). Since the method gives results with a standard deviation of 0.5 percent cement this small increase in the apparent cement content as a result of prolonged curing was never observed.
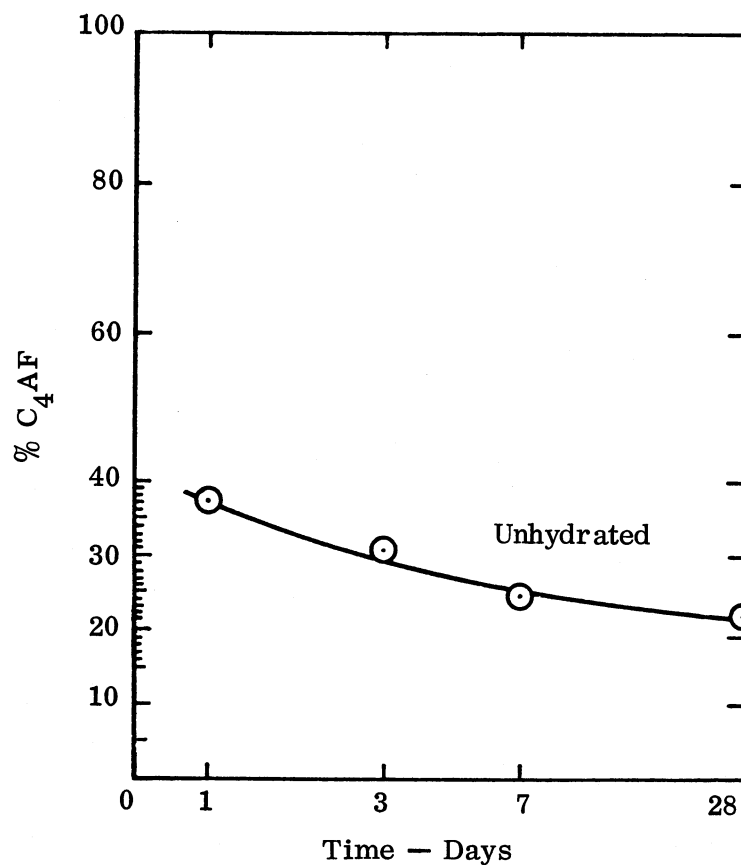

Figure 5. Unhydrated C_4AF as a function of curing time. [5]
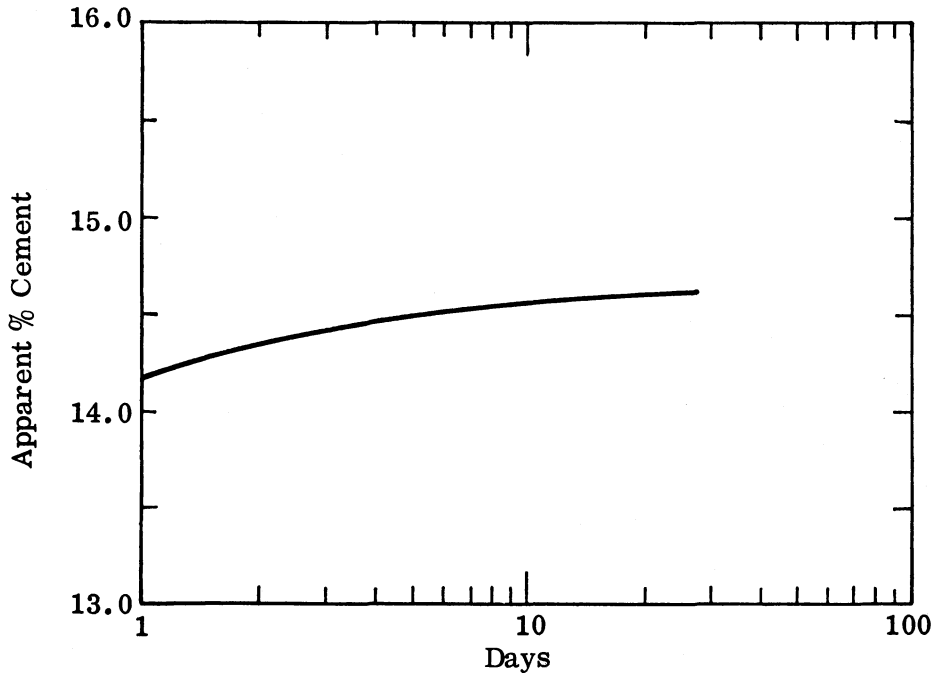
Figure 6. Estimated apparent cement content at different curing periods.

Effect of Cement Composition

This investigation on the effect of cement composition on the apparent cement content was conducted using three different cements — Types I, II and III — whose compositions were shown in Tables 1 and 2. Three series of concrete samples, one for each cement type, were prepared; all series had the same aggregate and water-cement ratio, and cement contents of 10, 15, and 20 percent. After an arbitrarily chosen curing time of one week, the samples were analyzed for cement content.

The amount of combined water, W_c, in a concrete sample is a good indication of the extent of hydration that has been reached. By comparison of the measured W_c values for the three series of concrete samples (Figure 7), it can be seen that the extents of hydration for the different cements is in the order of Type III > Type I > Type II. Since C_4AF hydrates slowly, it tends to lower the overall hydration of a cement; therefore, the above mentioned order of hydration is consistent with the estimated potential C_4AF percentages in the different cements, which is in the order of Type II > Type I > Type III (see Table 2). In view of this, it can be expected that the apparent cement contents of these series of concrete samples would be in the order of Type III > Type I > Type II. However, examination of the results obtained from analyses of the samples (Table 6) shows no discernible differences between the different cement types. In Figure 8, a plot of these results yields a linear relationship with a correlation coefficient of 0.997.
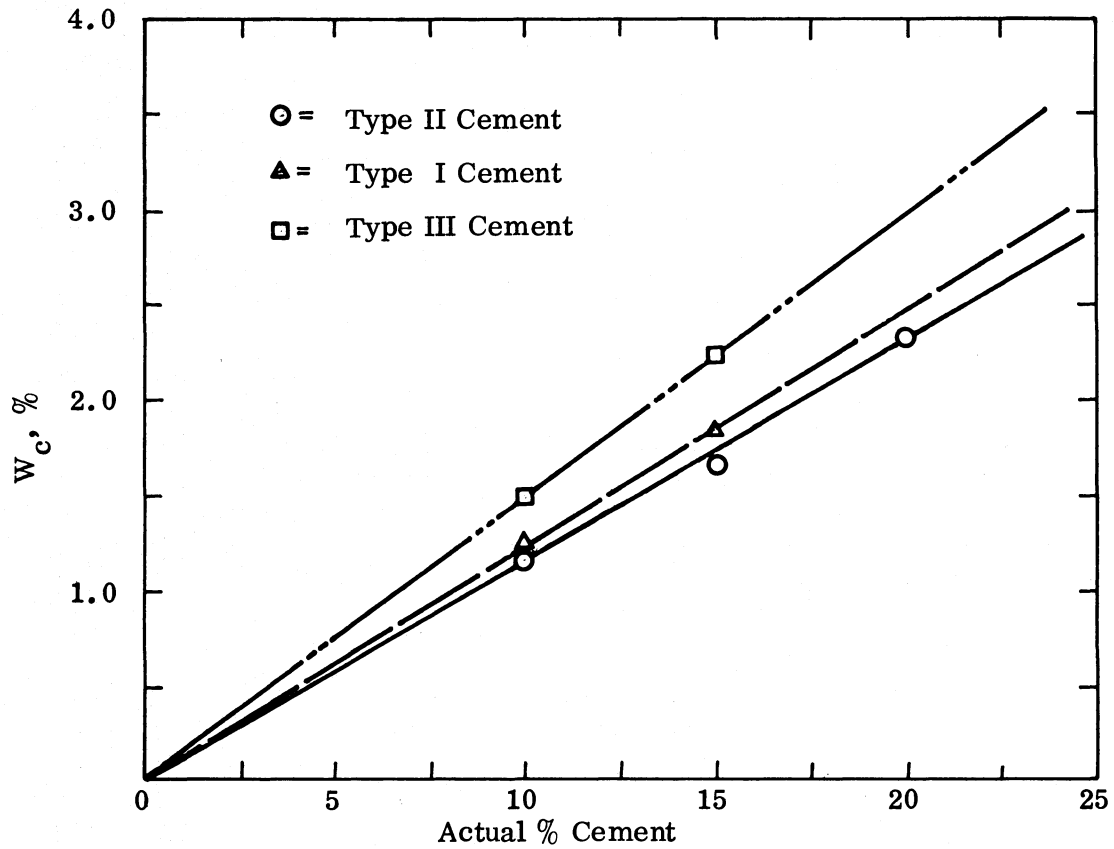
Figure 7. The measured combined water values for concrete of different cement types. (The combined water is expressed in percent by weight of a dried and crushed concrete sample.)

Such good correlation indicates that the differences in the extent of hydration for different cement types are so small as to be negligible when compared to the precision of the method.

Table 6

Comparison of Measured and Actual Cement Contents
in Concrete of Different Cement Types

Cement Type	Cement Content (%)		
	Actual	Measured	Difference
I	10.0	9.8	-0.2
	15.0	14.7	-0.3
	20.0	19.9	-0.1
II	10.0	10.0	0
	15.0	14.2	-0.8
	20.0	19.6	-0.4
III	10.0	9.3	-0.7
	15.0	13.9	-1.1
	20.0	19.8	-0.2
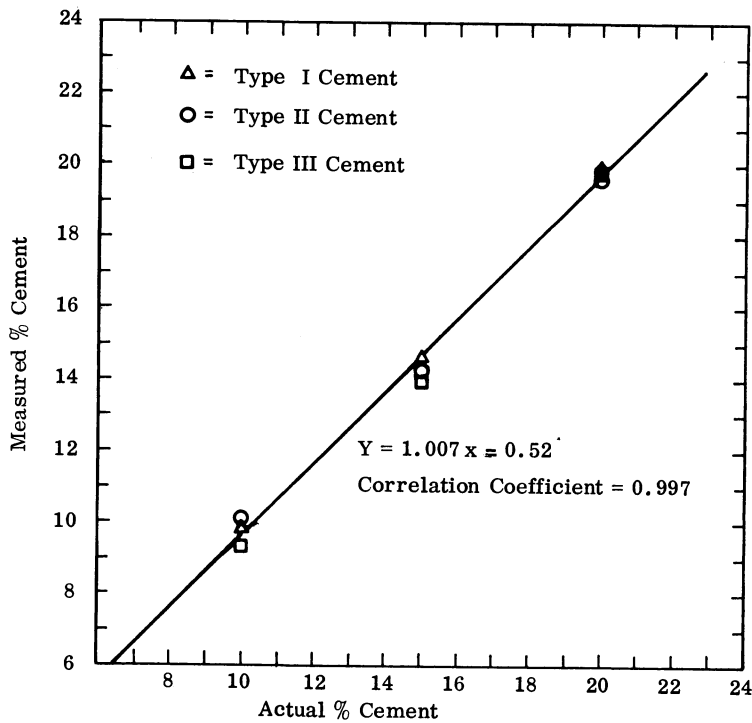
Figure 8. A linear regression line of measured and actual percentages of
cement in concrete samples of different cement types.

Effect of Water-Cement Ratio

Two series of concrete samples were prepared with the same cement (Type II) and aggregates, but with different water-cement ratios: 0.35 and 0.50. These samples were analyzed for their cement contents after a week of curing. The results obtained are given in Table 7. Again, there is no significant difference between the apparent cement contents of the concrete samples to indicate any effect of the water-cement ratios.

Table 7

Comparison of Measured and Actual Cement Contents
in Concrete of Different Water-Cement Ratios

Water-Cement Ratio	Cement Content (%)		
	Actual	Measured	Difference
0.35	10.0	10.0	0
	15.0	14.2	-0.8
	20.0	19.6	-0.4
0.50	10.0	10.0	0
	15.0	14.7	-0.3
	20.0	19.7	-0.3

In the foregoing discussion, it has been seen that the effects of the composition of the cement, the curing time, and the water-cement ratio on the apparent cement content of concrete are insignificant compared to the precision of the method of analysis. As a result, a combined plot of all results (except those results from the study on the aggregate effects) obtained in the study of these effects (Figure 9) yields a linear calibration curve that is expressed by

$$C_m = 0.998 \ C_a - 0.329$$

where C_m and C_a are the measured and actual cement contents, respectively. The correlation coefficient is 0.997, which indicates a good correlation Given a spread of $\pm$ 0.5% (two standard deviations) to the values calculated from this expression, as represented by the shaded band in Figure 10, it can be seen that the expression agrees reasonably with that reported by Tabikh and his co-workers,[5] which is the straight line in the same graph. The slight discrepancies between the two calibration curves at both ends of the concentration range might be due to differences in the aggregates used in these studies; as discussed earlier in this report, different aggregates do contribute differentially to the measured, or apparent, cement content of a concrete sample.
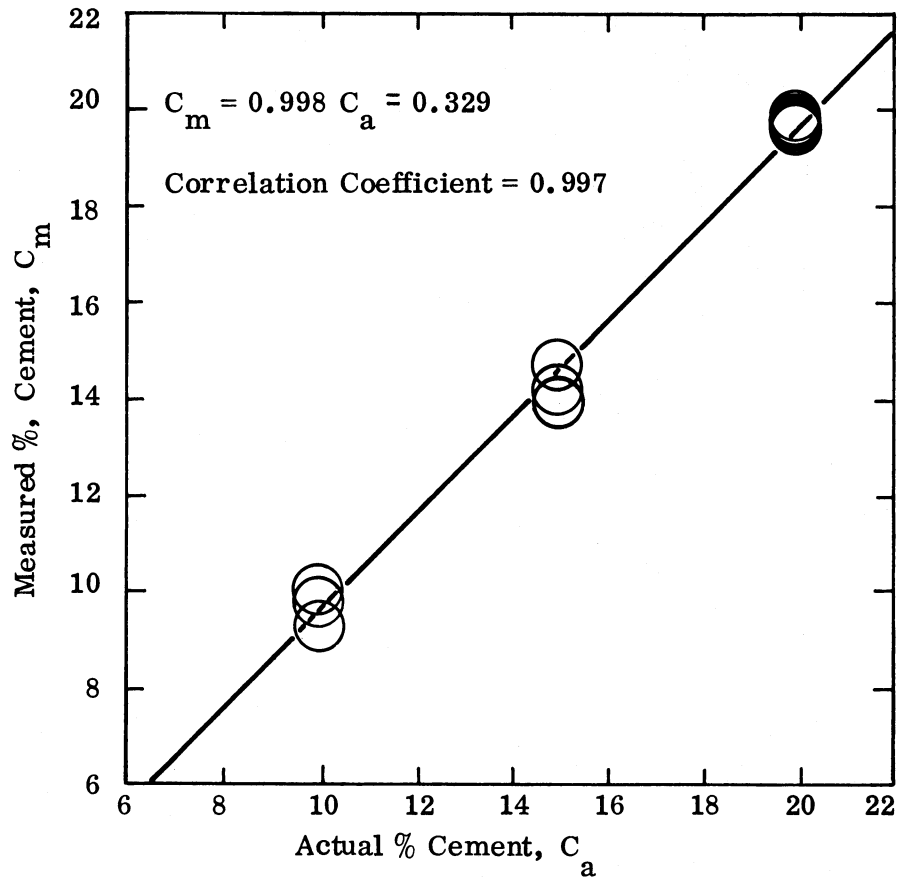
Figure 9. A linear regression line of measured and actual percentages of cement in concrete.

Since granitic aggregates were used in the concrete samples involved in the major portion of the study, the above calibration curve should be applicable to this type of aggregate. When other types of aggregates are involved, it is advisable to prepare calibration curves suitable for them, before using this method for the determination of cement content.
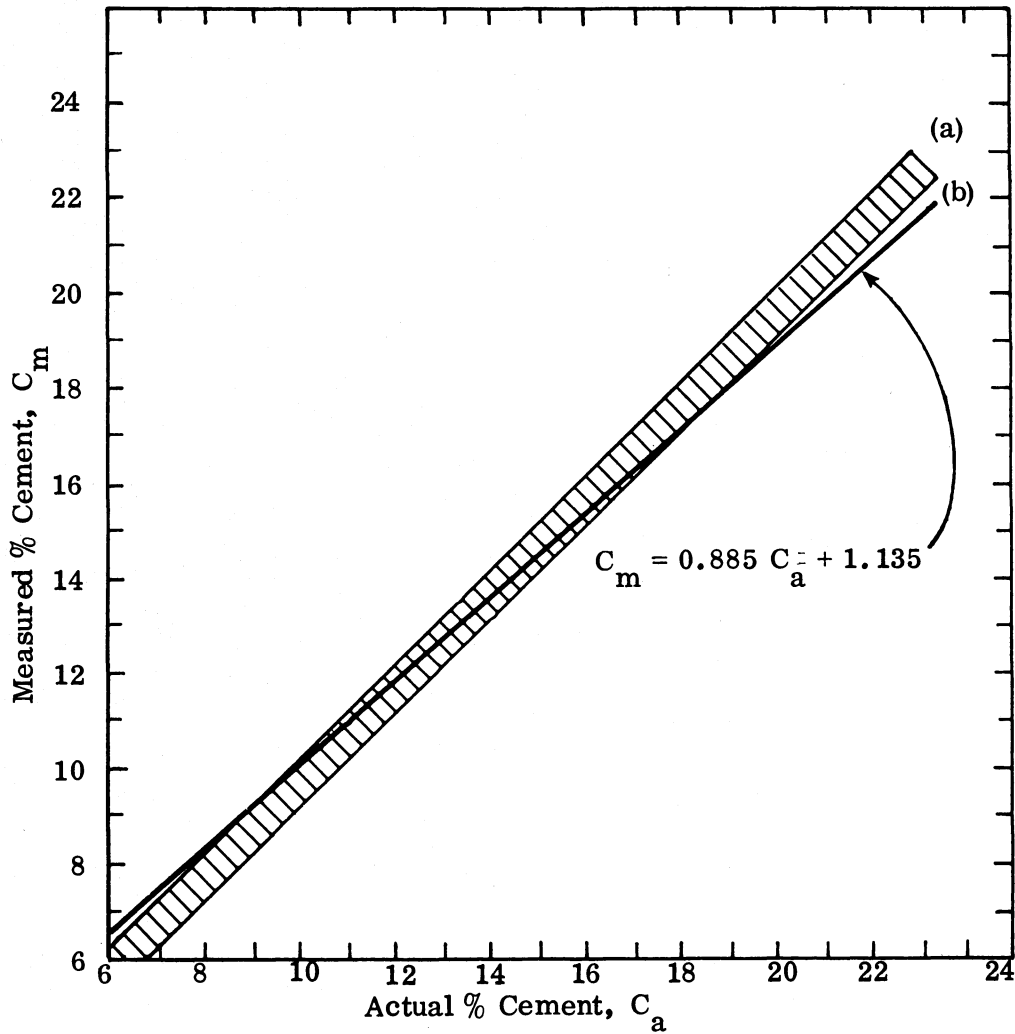
Figure 10. A comparison of linear regression lines: (a) this study — allowing for ± 1 standard deviation; (b) Tabikh et al.

The Specific Gravity of the Maleic Acid Extract of Concrete

As the concentration of a solution increases, its specific gravity also increases, in direct proportionality. Similarly, the increase in the specific gravity of a methanolic maleic acid solution is directly proportional to the amount of hydrated cement dissolved in it, which is a function of the cement content in a concrete sample. Mathematically,

$$\Delta S_i = KC$$

where ΔS_i is the increase in the specific gravity of a mathanolic maleic acid solution, K is a proportionality constant, and C is the cement content of a concrete sample. Such a relationship may provide an even simpler method for the determination of the cement content.

In order to investigate the possibility of such an approach, five concrete samples with cement contents varying from 10 to 50% cement by weights at 10% intervals were prepared. Each sample was treated with methanolic acid and the specific gravity of the resulting extract determined, according to the procedure outlined in Figure 2. This experiment confirmed that the percent cement is directly proportional to the increase in the specific gravity of the maleic acid solution, i.e.,

$$\Delta S_i = 1.64 \times 10^{-4} C$$

as shown in Figure 11. By applying this relationahip, one can determine the percent cement of a concrete indirectly from the measurement of S_i and thereby, further improve the method of analysis.
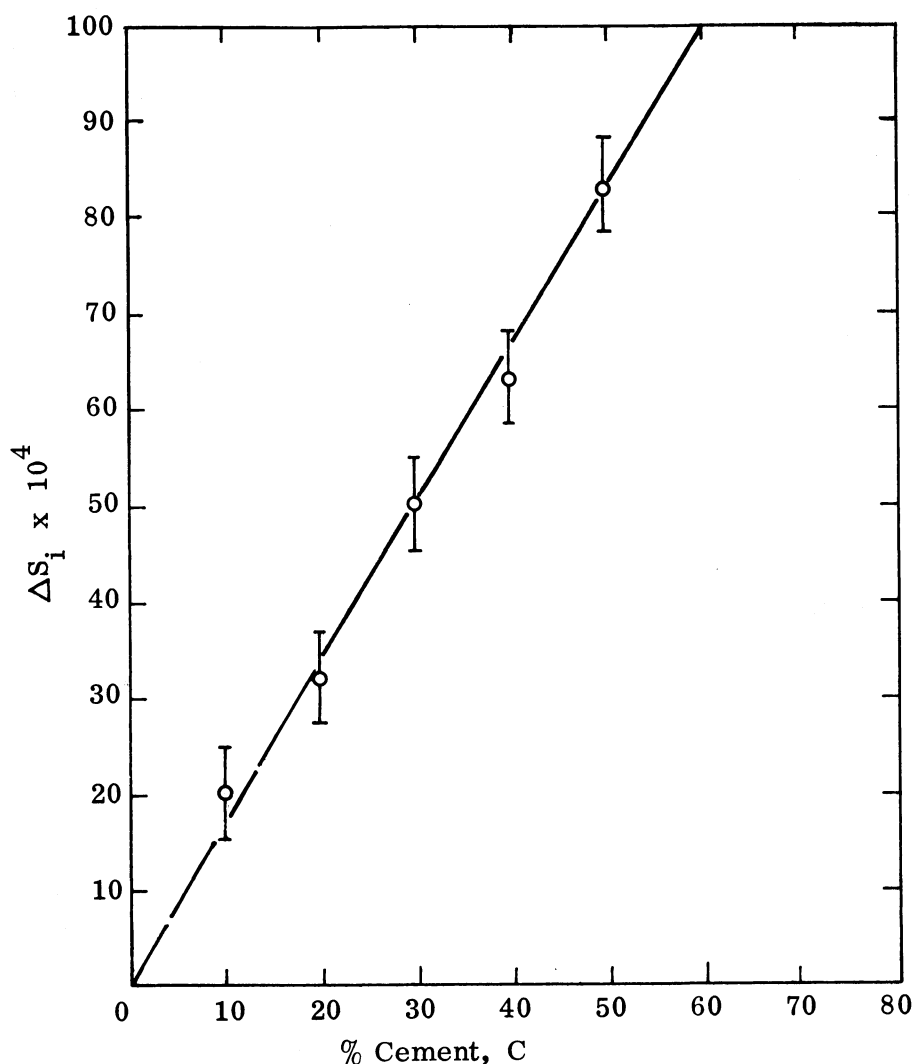

Figure 11. The relationship between specific gravity of maleic acid extract and cement content.

Subsequent experiments, however, revealed that the method has poor reproducibility. Six 20-gram portions of a dried and ground concrete sample, whose cement content was 15 percent, were treated with a maleic acid solution and then the specific gravity measured. The results, shown in Table 8, yield a standard deviation of 5.1×10^{-4}. From the proportionality constant in the above expression, this value corresponds to 3.1 percent cement. It appears that results would be accurate to within only ± 6.1 percent cement at the 95% confidence level, which is unsatisfactory.

Table 8

Reproducibility of the Specific Gravity Method

Trial No.	Measured ΔS_i
1	26×10^{-4}
2	25
3	19
4	25
5	26
6	17

Mean $= 23 \times 10^{-4}$

Standard Deviation $= 5.1 \times 10^{-4}$

CONCLUSIONS

The following conclusions are based on the analyses of the data from this study.

1. The method of selective solution by a methanolic maleic acid solution developed by Tabikh et al. [5] for the determination of the cement content of concrete is simple and easy to perform. Used with calibration curves, it is accurate to ± 1 percentage point of cement, or 0.35 bags/cubic yard, at the 95% confidence level.

2. Siliceous and calcareous aggregates dissolve in a maleic acid solution, with the latter dissolving to slightly higher extents. The dissolution of these aggregates increased the measured cement content of concrete. Since different aggregates contribute differentially to the measured cement content, a calibration curve may have to be prepared for each type of aggregate used.

3. For concrete samples which have been properly cured the effects of curing time, cement composition, and water-cement ratio on the measured cement content are small compared to the precision of the method.

4. The determination of the cement content by measurement of the increase in the specific gravity of a methanolic maleic acid solution does not provide satisfactory accuracy.

RECOMMENDATION

Since the selective solution method gives relatively reliable cement contents for hardened concrete samples, it is recommended that it be used in lieu of ASTM method C-85 for cases involving low-strength concrete samples.

ACKNOWLEDGEMENTS

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