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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/VA-R23		

4. Title and Subtitle	5. Report Date
Comparison of Air Void Content Measurements in Fresh versus Hardened Concretes	March 1990
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Celik Ozyildirim	VTRC 90-R23
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Virginia Transportation Research Council P. O. Box 3817, University Station Charlottesville, Virginia 22903	11. Contract or Grant No. HPR 2547-055
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Virginia Department of Transportation 1221 E. Broad Street Richmond, Virginia 23219	FINAL REPORT August 1988 - March 1990
	14. Sponsoring Agency Code

15. Supplementary Notes

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

16. Abstract

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The results show that, at the ranges commonly used in the construction of pavements and bridges, the air content of fresh concrete measured by pressure meters and that determined by the microscopical method for essentially the same concrete after hardening are, for practical purposes, the same. The air content obtained by a volumetric meter as normally run in the field is generally lower than that obtained for the same hardened concretes by the microscopical method. The unit weight and compressive strength correlate well with the air content. It was also shown that adding water to concrete can significantly increase the air content, as well as the slump. Thus, a higher air content in hardened concretes than that indicated by initial measurements with a pressure meter is likely to be present if water is added during placement.

17. Key Words	18. Distribution Statement
Air content, air void content, pressure meter, volumetric meter, microscopical method, linear traverse, unit weight, strength	No restrictions. This document is available to the public through the National Technical Information Services, Springfield, Virginia 22161

19. Security Clasif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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FINAL REPORT

COMPARISON OF AIR VOID CONTENT MEASUREMENTS IN FRESH VERSUS HARDENED CONCRETES

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Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Transportation and the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

June 1990
VTRC 90-R23

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ABSTRACT

This study compares the air content of freshly mixed and hardened concretes. At the fresh stage, pressure meters (Types A and B) and a volumetric meter were used to determine the air content. At the hardened stage, the air content was calculated using the linear traverse method described in ASTM C 457, which is a microscopical procedure. The unit weight and compressive strength of the concretes were also determined.

The results show that, at the ranges commonly used in the construction of pavements and bridges, the air content of fresh concrete measured by pressure meters and that determined by the microscopical method for essentially the same concrete after hardening are, for practical purposes, the same. The air content obtained by a volumetric meter as normally run in the field is generally lower than that obtained for the same hardened concretes by the microscopical method. The unit weight and compressive strength correlate well with the air content. It was also shown that adding water to concrete can significantly increase the air content, as well as the slump. Thus, a higher air content in hardened concretes than that indicated by initial measurements with a pressure meter is likely to be present if water is added during placement.

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COMPARISON OF AIR VOID CONTENT MEASUREMENTS IN FRESH VERSUS HARDENED CONCRETES

Celik Ozyildirim, Ph.D.
Research Scientist

INTRODUCTION

It is well established that, for proper protection against damage from cycles of freezing and thawing, concretes that can become saturated must have a system of air voids that are uniformly distributed and closely spaced in the paste fraction of the concrete (1, 2). These voids must be of an optimum size and amount to improve the resistance to freezing and thawing without any serious adverse affects on the strength of the concrete. The proper air void system is achieved by adding air-entraining admixtures to the concrete mixture. The important parameters of the air void system are the spacing factor (indicates a certain distribution and proximity of the voids); the specific surface (determines the size); and the content of small (entrained), large (entrapped), and total voids. These parameters are determined at the hardened stage using the methods described in ASTM C 457, which covers two microscopical methods: linear traverse and point count.

Specifications generally require that the air content of freshly mixed (fresh) concrete be measured to ensure that the desired air void system will be present at the hardened stage. It is assumed that the air content measured in the fresh stage will be in close agreement with that actually present in the hardened concrete and that, once the proper air content is obtained, acceptable specific surface and spacing factor values will have been achieved.

Over the years, the Virginia Transportation Research Council (VTRC) of the Virginia Department of Transportation (VDOT) has encountered field concretes that exhibited strengths that were lower than anticipated. In most such cases, the air content of the hardened concretes was found to be much higher than that permitted by the specifications. This raises questions concerning possible errors in air content measurements or lack of representative samples at the fresh stage. In addition, other investigations have shown that differences exist between the measured air content at the fresh stage and at the hardened stage, with the latter being much larger (3-5). It has also been reported that the difference between the air content of fresh and hardened concretes becomes larger as the air content increases (4).

Studies conducted by the VTRC have not shown such differences. Good agreement between the air content of fresh and hardened concretes has been found (6). However, observations on field concretes and data from other sources have raised concerns. Accordingly, a preliminary investigation of field concretes was made. Nine batches of concrete were sampled at different locations. The air content of the fresh concretes was determined in the field using an air meter based on the pressure method described in ASTM C 231 (pressure meter). Concretes exhibiting an air content at the upper end of the specified range were selected. Concrete cylinders measuring 4 by 8 in were then sent to the VTRC for the microscopical determination of the air void system using the linear traverse method described in ASTM C 457. The data given in Table A-1 (Appendix) and displayed in Figure 1 show that the results obtained for the fresh and hardened concretes were significantly different and that the air content was higher at the hardened stage.

The observed differences in this preliminary investigation prompted a more comprehensive investigation involving both laboratory and field testing.

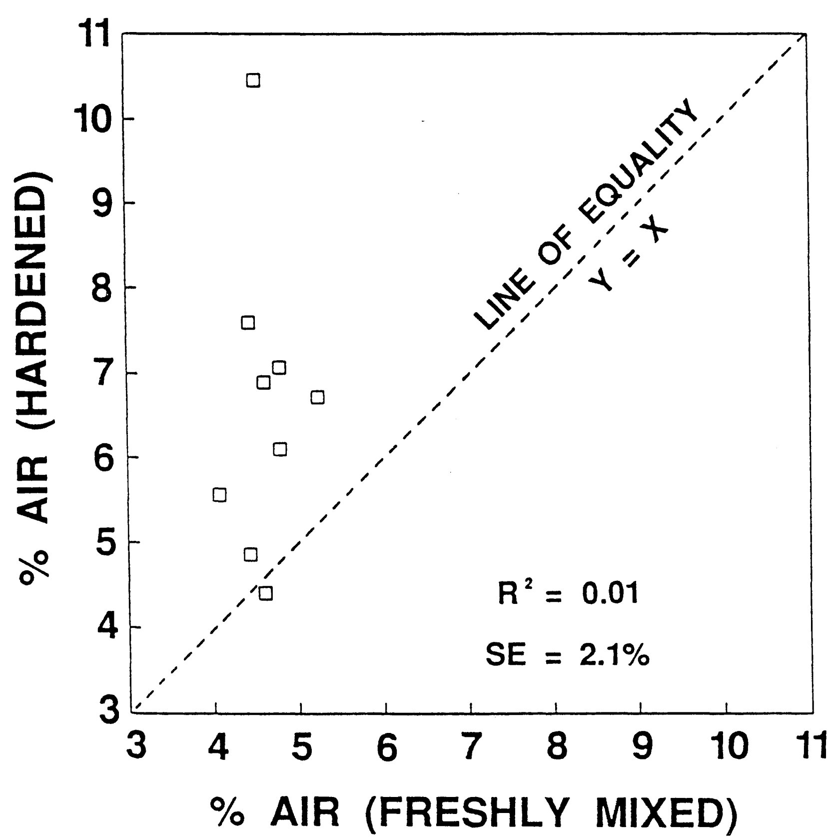

Figure 1. Comparison of the air content of field concretes determined with pressure meters in the fresh stage and determined microscopically in the hardened stage.

OBJECTIVE

The objective of this study was to compare the air content (4 to 10 percent range) of fresh and hardened concretes.

SCOPE

The laboratory investigation was conducted using two types of air-entraining admixtures. Ten batches of concretes were prepared in the laboratory, with the air content ranging from about 4 to 10 percent.

Subsequently, field investigations were conducted at two ready-mix concrete plants. In one plant, eight batches were sampled from four truck-loads of concrete. The air content ranged from about 5 to 9 percent. Then, at another plant, three truckloads of concrete were sampled at the plant and also at the job site, and three additional batches were sampled at the job site. The air content ranged from about 6 to 9 percent. Finally, another trip was made to the first plant and concrete was sampled from a single truckload to determine the effect on the air content of adding water.

In both the laboratory and field concretes, air content was determined at the fresh and hardened stages. At the fresh stage, an air meter (based on the volumetric method described in ASTM C 173) (volumetric meter) and pressure meters, Types A and B (ASTM C 231), were used. Both pressure meters operate on the principle of Boyle's law but differ in their design and operational procedures. At the hardened stage, the microscopical linear traverse method (ASTM C 457) was used. All tests were made by 1 operator in the laboratory, but up to 11 operators were available in the field.

PROPORTIONS AND MATERIALS

All the concretes used in this study were proportioned to meet the requirements of VDOT's bridge deck concretes. The minimum cement content of these concretes is 635 lb/yd^3, and the maximum water/cement ratio is 0.45. The nominal maximum aggregate size is 1 in. The specified slump for bridge deck concrete is 2 to 4 in, and the air content is 6 1/2 $\pm$ 1 1/2 percent. However, during batching or mixing for this investigation, some of the batches were intentionally tempered with water and the slump and air content requirements were allowed to deviate from those specified to determine the effect on air content.

The aggregates used were in a saturated-surface-dry or wet condition. Aggregate correction factors were determined to be small or negligible and were assumed to be zero.

The coarse aggregate used in the laboratory concretes was crushed granite gneiss, and that used in the field concretes was quartzite gravel. All the fine aggregate was siliceous sand.

LABORATORY INVESTIGATION

Specimens and Testing

Ten batches of concrete were prepared and tested at the fresh stage for air content, slump, and unit weight. Six of the batches had neutralized vinsol resin (AE1) as the air-entraining admixture. The air-entraining admixture used in the other four batches was an aqueous solution of the surface active agents composed of fatty acids and salts of sulfonic acids (AE2). The manufacturer claims that this product generates very small and stable air bubbles in concrete. At the hardened stage, the air contents, the compressive strengths at 28 days, and the unit weights were determined using 4-by-8-in cylinders. For the determination of the air content in the hardened stage, additional specimens were prepared in the bucket of an air meter similar to the one used in the determination of the air content of the fresh concrete. This was to provide similar consolidations to achieve equivalence in samples even though exactly the same concrete was not used.

Results

The results of the tests for air content, unit weight of the fresh concrete, and compressive strength at 28 days are given in Table A-2. The parameters of the air void system of the hardened concrete obtained from 4-by-8-in cylinders are given in Table A-3, and the parameters obtained for the concrete in the bucket are given in Table A-4. The unit weights of the hardened concretes obtained from the specific gravities are given in Table A-5. Table 1 summarizes the average air contents of all batches as determined by the different methods. Figures 2, 3, and 4 display the air contents of fresh concretes using a Type A pressure meter versus the air contents of the hardened concretes, unit weights, and 28-day compressive strengths, respectively.

A statistical paired t test (7) was applied to the data to determine if a significant difference existed between the air content of the fresh and hardened concretes and also if differences obtained by the different meters at the fresh stage were statistically significant. The statistical data are summarized in Table A-6.

Table 1

Average Air Contents of the Laboratory Concretes as Determined by Different Methods

Method	Air (%)
Pressure meter, Type A	7.2
Pressure meter, Type B	6.6
Volumetric meter	5.6
Microscopical 1[a]	7.1
Microscopical 2[b]	7.4

[a]Concrete from 4-by-8-in cylinders.

[b]Concrete from the bucket.

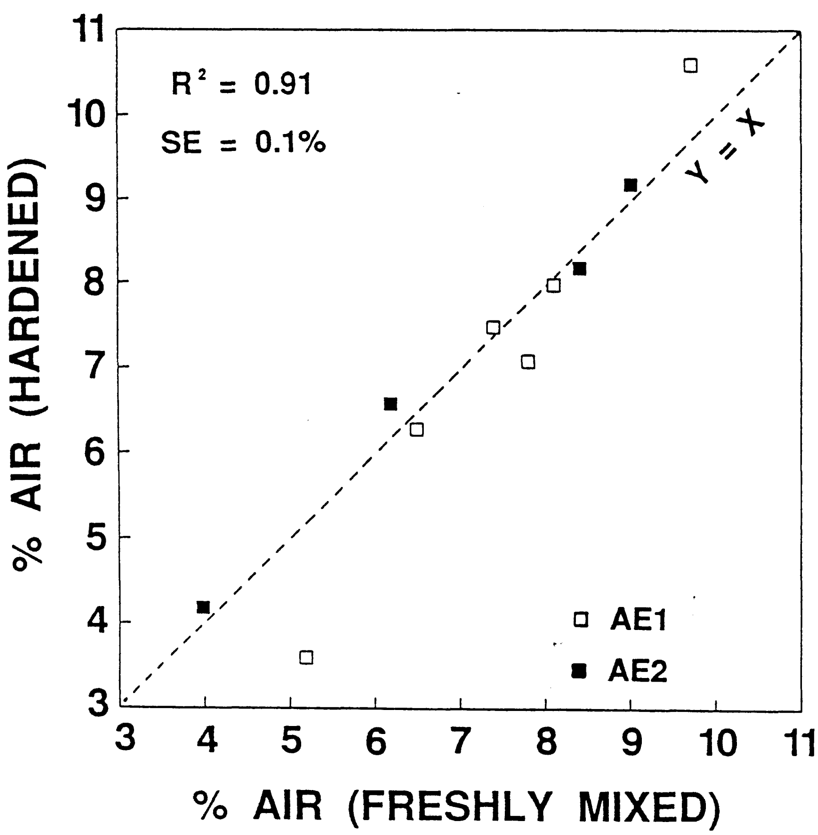

Figure 2. Comparison of the air content of laboratory concretes determined with a Type A pressure meter in the fresh stage with that determined microscopically in the hardened stage.

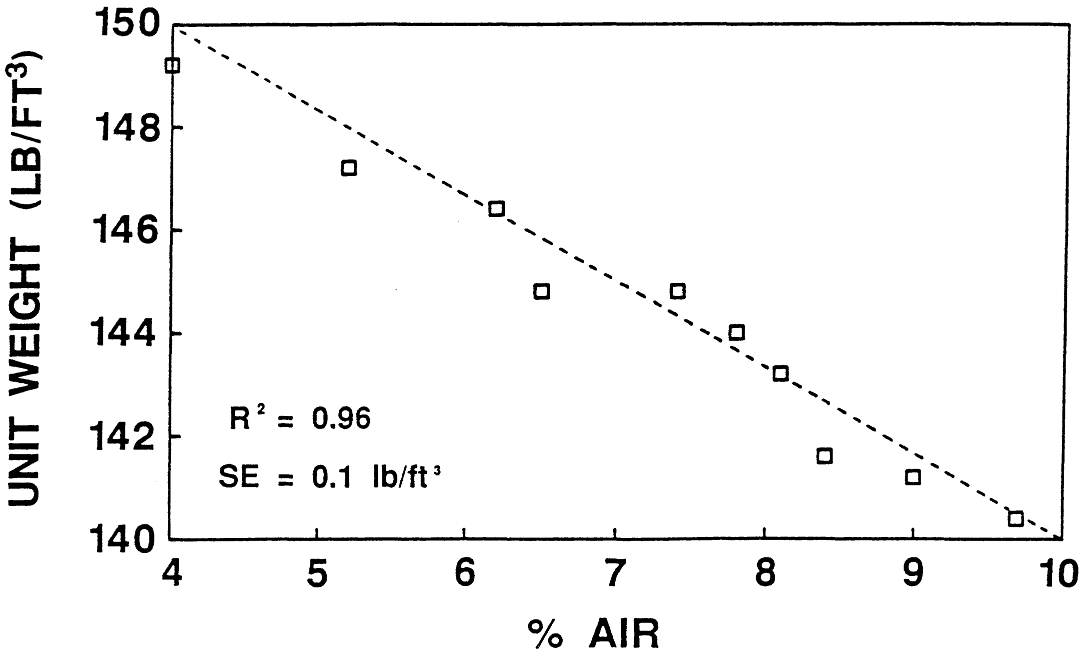

Figure 3. Relationship between the air content measured by a Type A pressure meter and the unit weight of the fresh concrete.

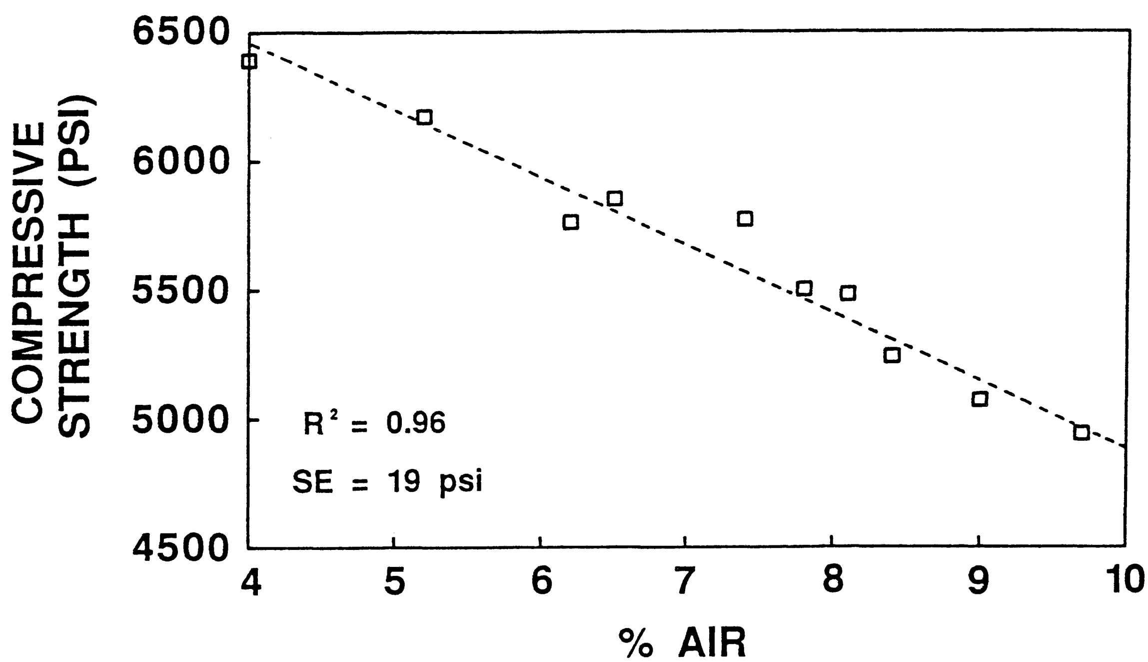

Figure 4. Relationship between the air content measured by a Type A pressure meter and the 28-day compressive strength.

The results of the statistical analysis (Table A-6) indicate that there is no significant difference (at the 5 percent significance level) between the air content measured by the Type A pressure meter and that determined by the microscopical method. Differences in behavior were not detected between the two air-entraining admixtures. Also, there was no significant difference between the air content of the hardened concrete conducted on specimens obtained from a 4-by-8-in cylinder or the pressure meter bucket. Significant differences were found between the measurements by the different meters and the measurements by the Type B pressure meter or the volumetric meter and the microscopical method. However, for practical purposes, differences between measurements obtained with both pressure meters and those obtained by the microscopical method are considered acceptable. The averages shown in Table 1 indicate the closeness of the measurements. Measurements with the volumetric meter were about 1 percent or more than with the pressure meters and the microscopical method. The difference is considered marginal or unacceptable. The time spent for the measurement by the volumetric meter was about 15 minutes. Indications are that, with this test, for results with acceptable accuracy, up to 1 hour may be needed to free all the air bubbles. However, such a time allocation in the field is not practical. Air content measured by the pressure meter and the microscopical method correlated well with the unit weight of the fresh concrete and compressive strength at 28 days (Figures 2-4). The line of best fit for the relationship between air content and strength (Figure 4) shows a 4.6 percent decrease in strength for each percentage point increase in air content. This is well in conformance with a rule of thumb in this range of strengths where a 5 percent decrease in strength is expected for each percentage point increase in air content.

Also, the average unit weight of the dry and the wet hardened concretes correlated well with the unit weight of the fresh concretes. The hardened specimens were wetted by immersion and also by immersion and boiling as directed in ASTM C 642. The difference in findings with the two wetting methods was not significant, which indicates that immersion of the specimen in water would be sufficient and that boiling can be eliminated.

FIELD INVESTIGATIONS

Plant 1

Specimens were prepared from four truckloads of concrete at a ready-mix concrete plant, Plant 1. In three of the loads, the concretes were tempered with water, in one case after a 50-minute agitation period. A total of eight samples were tested, as shown in Table A-7. All the field concretes contained a commercially available neutralized vinsol resin for air entrainment. Eleven operators participated in tests on these concretes; some used only one type of meter, and others used more than one. Four Type A pressure meters, seven Type B pressure meters, and five volumetric meters were available. Various types of meters were used by different operators on the same batch of concrete so that an evaluation of the variability resulting from the type of meter could be determined and the possible operator bias could be included. The measured air contents of the fresh concretes are given in Table A-8 and those of hardened concretes in Table A-9. The slump and unit weights are shown in Table A-7, along with the 28-day compressive strength. The unit weights of the hardened concretes are given in Table A-10, and the results of the statistical paired *t* test in Table A-11. The average air contents are given in Table 2. The relationship of the air content of the fresh concretes (using a Type A pressure meter) and hardened concretes is shown in Figure 5. The effect on the air content and slump of adding water is shown in Figure 6.

A second investigation was made at Plant 1 to verify further the effect on the air content and slump of adding water. Several samples were obtained from one truckload. The initial sample is denoted as Sample 1 in Table 3. Air content was measured, and a specimen was prepared for the microscopical determination of air content. Then, water was added to the concrete in the truck to increase the slump and Sample 2 was obtained. The air content measured by the Type A pressure meter was erroneously not corrected for water level at zero pressure, and it was noticed that the reading was higher than that obtained by the Type B pressure meter. A third sample from the wheelbarrow was obtained about 20 minutes later, and when corrected for water level at zero pressure, equal air content values were obtained with both pressure meters.

Table 2

Average Air Contents of Concretes from Plant 1 as Determined by Different Methods

Method	Air (%)
Pressure meter, Type A	6.8
Pressure meter, Type B	6.5
Volumetric meter	5.5
Microscopical method	6.5

Table 3

Second Set of Air Content Measurements from Plant 1 To Determine the Effect of Adding Water

Sample	Type A	Type B	Slump	Hardened
1	6.7	6.4	1.8	8.7
2	11.6[a]	9.9	5.5	11.0
3	7.8	7.8	4.2	8.8

[a]Not corrected for water level at zero pressure.

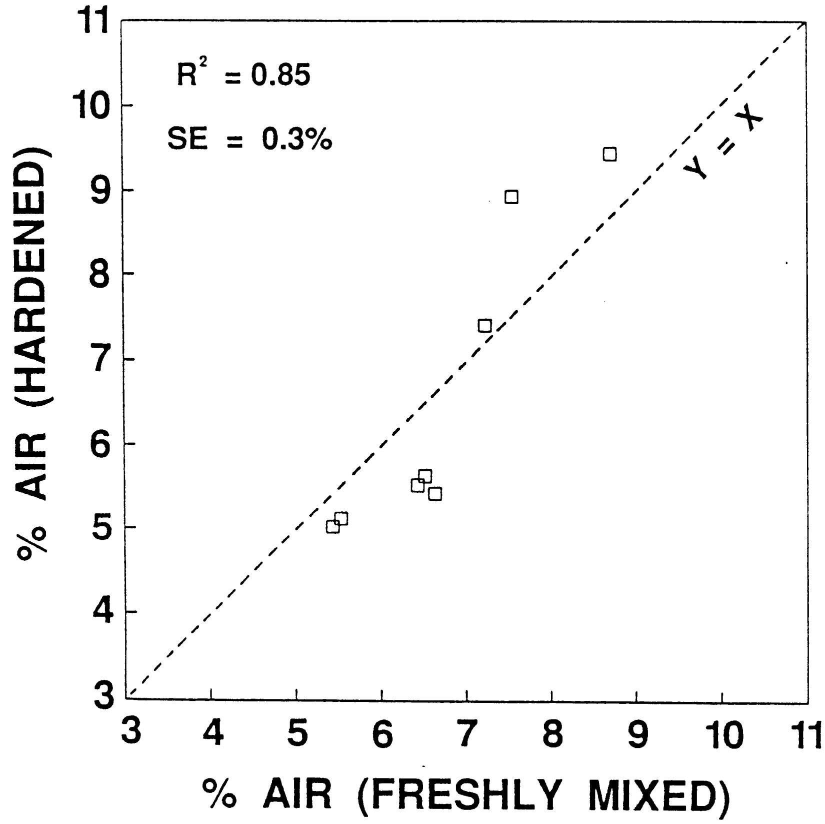

Figure 5. Comparison of air content of concretes from Plant 1 determined with a Type A pressure meter in the fresh stage with that determined microscopically in the hardened stage.

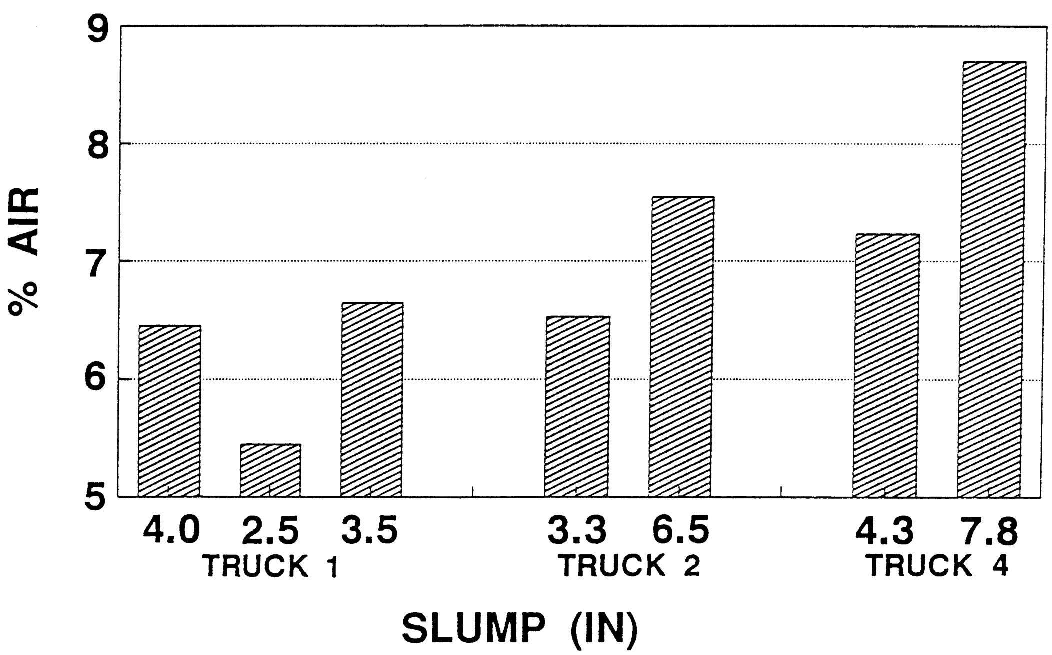

Figure 6. Air content and slump after the addition of water.

Plant 2

Samples were collected from five truckloads for testing at another ready-mix concrete plant, Plant 2, and at the associated job site about 20 minutes away. Three samples were obtained at the plant, and six at the job site. One operator tested the concretes using Type A and Type B pressure meters on five samples, as shown in Table A-12. The remaining samples were tested by the inspector at the job site. One of the samples at the job site was obtained after the concrete was pumped onto the deck and vibrated. Some of the samples were tested for unit weight, as shown in Table A-13, along with the slump and 28-day compressive strength values. The air contents of the hardened concretes are given in Table A-14, and the unit weights in Table A-15. The air content of concretes using a Type A pressure meter are compared to that of the hardened concretes in Figure 7.

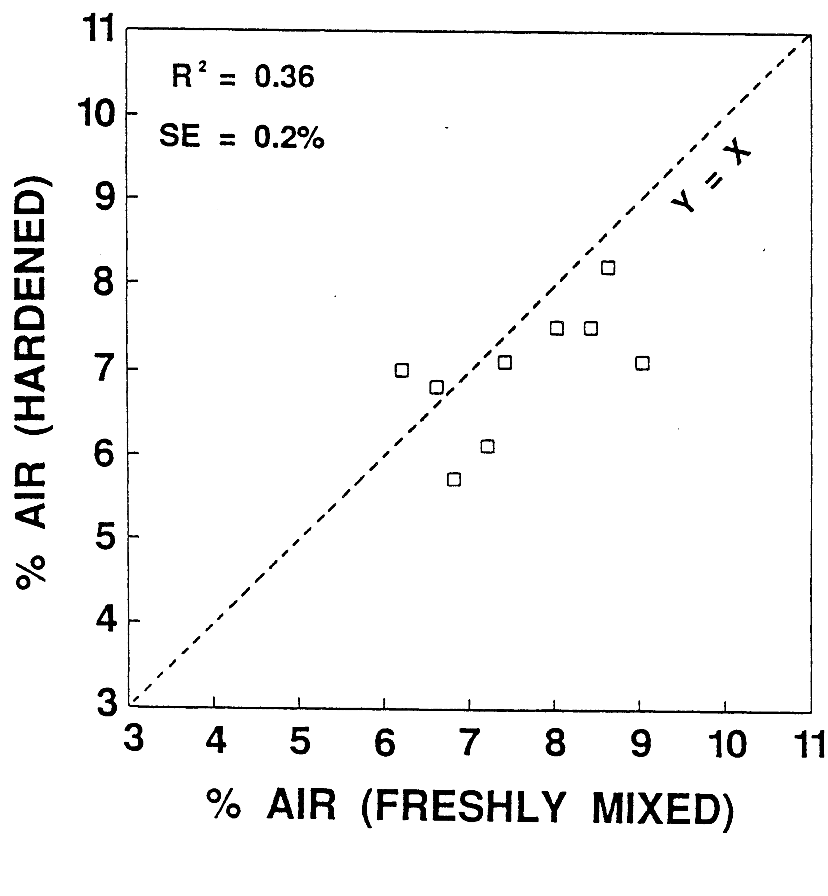

Figure 7. Comparison of air content of concretes from Plant 2 determined with a Type A pressure meter in the fresh stage with that determined microscopically in the hardened stage.

Results

Plant 1

Results from Plant 1 indicate no statistically significant difference between measurements with the pressure meters and the microscopical method at the 5 percent significance level (Table A-11). The air content of the fresh concrete using a Type A pressure meter shows a good agreement with the air content of the hardened concrete as shown in Figure 5; values at the higher end are slightly above the line of equality, indicating higher values at the hardened stage, but the wide differences observed for some field concretes were not obtained. Significant differences exist between the measurements by the volumetric meter and the microscopical method as well as the volumetric meter and the pressure meters. The time allocated to the volumetric test was limited, about 15 minutes. Thus, the differences in air content may be explained by the failure to remove all the air in this time period.

Differences in air content results for different operators were small for the pressure meters. The average standard deviation values were 0.3, 0.4, and 0.6 for the Type A and the Type B pressure meters and the volumetric meter values, respectively.

When concrete was tempered with water, the slump and the air content increased (Figure 6 and Table 3). As shown in Figure 6, for Truckload 1 the slump decreased from 4.0 to 2.5 in by 50-minute agitation, and the air content decreased from 6.4 to 5.4 percent. The addition of water increased the slump to 3.5 in and the air content to 6.6 percent. Similarly, an increase in air content and slump after tempering with water is shown for Truckloads 2 and 4. The average unit weight of the dry and the wet hardened concretes correlated well with the unit weight of the fresh concretes.

Plant 2

Results from the specimens from Plant 2 indicate a statistical difference at the 5 percent level between the air content measured by a Type A pressure meter and the microscopical method, but not between the Type B pressure meter and the microscopical method (Table A-12). However, for practical purposes, the differences were acceptable. The correlation coefficient for the air content measured with a Type A pressure meter and by the microscopical method is 0.60 and is poor (Figure 7). For Type B pressure meter values, it is 0.77 and is fair or good. These correlations are based on a limited number of values and a relatively narrow range of air contents. Additional data would be needed to determine a more precise correlation coefficient. Figure 7 also shows that the air content of the fresh concretes was higher than the air content of the hardened concretes at higher air contents, contrary to the claims that the air content of the hardened concretes is higher. The average unit weight of the dry and the wet hardened concretes correlated well with the unit weight of the fresh concretes.

CONCLUSIONS

Based on the tests made in both the laboratory and the field for this study, the following conclusions are drawn.

1. In the range evaluated (about 4 to 10 percent), there is no practical difference between the air content of concretes as measured by pressure meters at the fresh stage and as determined microscopically at the hardened stage provided the concretes are from the same batch and are not tempered. In many cases, the differences were not statistically significant at the 5 percent level.

2. Differences in behavior attributable to the two types of air-entraining admixtures used were not discernible.

3. The addition of water to fresh concrete increased not only the slump but also the air content.

4. Measurements with a volumetric meter appear to require more time than is practical for field work.

5. The average unit weight of the dry and the wet hardened concretes correlated well with the unit weight of the fresh concretes. To determine an exact relationship, more testing would be desirable with the concretes in question.

6. The unit weight of concretes correlates well with the air content.

ACKNOWLEDGMENTS

Special thanks are expressed to Hollis Walker for valuable discussions and petrographic assistance. Thanks are expressed to Bobby Marshall for the linear traverse testing and to Mike Burton and Leroy Wilson for the preparation and testing of the specimens.

Sincere appreciation is expressed to industry personnel, especially Mr. Don Holder of Tarmac Virginia, Inc., for furnishing material and testing the specimens. Thanks are expressed to the many, but too numerous to mention, VDOT personnel who participated in the testing of the specimen in the field.

Appreciation is extended to Linda Evans for editing and to Arlene Fewell for typing the report.

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APPENDIX

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Table A-1

Air Void Parameters of Test Concretes

Batch	Fresh Air (%)	Hardened, ASTM C457 Voids (%) Total	Voids (%) < 1 mm	Specific Surface in^2/in^3	Spacing Factor (in)
1	8.5	10.2	8.9	763	0.0033
2	7.7	14.4	11.7	627	0.0027
3	7.6	11.2	9.3	713	0.0032
4	7.2	8.9	7.4	750	0.0040
5	8.0	10.6	8.6	652	0.0037
6	7.8	10.4	8.7	589	0.0042
7	7.6	8.1	7.2	880	0.0037
8	7.8	7.6	6.8	965	0.0036
9	8.0	9.5	8.4	686	0.0040
Avg.	7.8	10.1	8.6	736	0.0036

Table A-2

Properties of Fresh Laboratory Concretes and Compressive Strength

Batch	Air Content (%) Type A	Type B	Volumetric	Slump (in)	Unit Wt (lb/ft^3)	Comp Str. (psi)
1	7.8	7.2	6.5	3.0	144.0	5,500
2	8.1	7.5	6.2	3.5	143.2	5,480
3	7.4	6.6	5.1	4.0	144.8	5,770
4	6.5	6.0	5.8	4.0	144.8	5,850
5	5.2	4.6	4.5	3.7	147.2	6,170
6	9.7	9.0	7.4	3.2	140.4	4,940
7[a]	9.0	8.1	6.8	4.0	141.2	5,070
8[a]	8.4	7.6	6.3	3.2	141.6	5,240
9[a]	6.2	5.5	4.8	3.5	146.4	5,760
10[a]	4.0	3.7	3.0	2.5	149.2	6,390
Avg.	7.2	6.6	5.6	3.5	144.3	5,617

[a]Using AE2.

Table A-3

Air Void System of the Hardened Laboratory Concretes Using 4-by-8-in Cylinders

Batch	Air Content (%)			Specific Surface (in^2/in^3)	Spacing Factor (in)
	< 1 mm	> 1 mm	Total		
1	5.7	1.4	7.1	784	0.0048
2	5.5	2.5	8.0	690	0.0048
3	5.6	1.9	7.5	765	0.0047
4	4.9	1.4	6.3	590	0.0073
5	2.6	1.0	3.6	551	0.0102
6	7.5	3.1	10.6	712	0.0034
7	7.1	2.1	9.2	809	0.0035
8	5.7	2.5	8.2	682	0.0047
9	4.6	2.0	6.6	723	0.0057
10	2.6	1.6	4.2	698	0.0075
Avg.	5.2	2.0	7.1	700	0.0057

Table A-4

Air Void System of the Laboratory Concretes Hardened in a Bucket

Batch	Air Content (%)			Specific Surface (in^2/in^3	Spacing Factor (in)
	< 1 mm	> 1 mm	Total		
1	6.0	2.8	8.8	654	0.0046
2	5.7	2.0	7.7	725	0.0048
3	4.3	3.0	7.3	613	0.0060
4	4.1	2.5	6.6	566	0.0072
5	2.1	2.0	4.1	468	0.0113
6	7.8	2.7	10.5	735	0.0034
7	7.0	2.4	9.4	754	0.0037
8	7.0	2.4	9.4	770	0.0036
9	4.5	1.4	5.9	843	0.0053
10	2.4	1.8	4.2	513	0.0102
Avg.	5.1	2.3	7.4	664	0.0060

Table A-5

Unit Weights of Hardened Laboratory Concretes (lb/ft^3)

Batch	Unit Wt. Dry	Unit Wt. Immersion	Unit Wt. Immersion & Boil	Diff.[a]	Diff.[b]
1	141.3	147.9	148.4	-0.62	-0.83
2	140.9	147.6	148.0	-1.03	-1.26
3	140.9	147.9	148.4	0.41	0.14
4	140.7	148.2	148.7	0.31	0.09
5	144.4	151.5	152.1	-0.76	-1.05
6	137.1	143.5	144.3	0.09	-0.30
7	137.0	144.3	145.5	0.56	-0.04
8	138.7	145.5	146.3	-0.48	-0.90
9	141.4	148.6	149.3	1.42	1.08
10	145.5	152.3	152.8	0.33	0.09
Avg.	140.8	147.7	148.4	0.02	-0.30
SD	2.8	2.8	2.6	0.74	0.72

[a]Difference between the unit weight of the fresh concrete and the unit weight obtained by averaging the dry and after-immersion unit weights.

[b]Same as a, except the unit weight after immersion and boiling.

Table A-6

Results of Paired *t* Test for Laboratory Concretes

Air[a]	Avg. Diff.	SD	u[b]	Significant
A-T	0.10	0.67	0.39	No
B-T	-0.55	0.72	0.42	Yes
V-T	-1.49	1.18	0.86	Yes
A-B	0.65	0.17	0.10	Yes
A-V	1.59	0.65	0.38	Yes
B-V	0.94	0.53	0.31	Yes
A-T[c]	-0.16	0.67	0.39	No
B-T[c]	-0.81	0.72	0.42	Yes
V-T[c]	-1.75	1.11	0.64	Yes
T-T[c]	0.26	0.72	0.42	No

[a]Total air contents by A = Type A pressure meter; B = Type B pressure meter; V = volumetric meter; T = microscopical method.

[b]$u = (t_{.95})\,(SD)/\sqrt{n}$.

[c]Hardened sample was prepared in the bucket.

Table A-7

Properties and Information on Concretes from Plant 1

Sample	Truck	Water	Slump (in)	Unit Wt. (fresh)	28-Day Comp. Str.
1	1	--	4.0	144.3	5,530
2	1	a	2.5	143.0	5,720
3	1	Added	3.5	143.2	4,820
4	2	--	3.3	143.6	5,300
5	2	Added	6.5	140.2	4,660
6	3	--	5.5	142.8	5,290
7	4	--	4.3	142.8	5,090
8	4	Added	7.8	135.4	4,130
Avg.			4.7	141.9	5,070

[a]Agitated for 50 minutes.

Table A-8

Air Contents of Fresh Concretes from Plant 1

Sample	Type A		Type B		Volumetric	
	Avg.[a]	SD	Avg.[b]	SD	Avg.[c]	SD
1	6.4	0.3	5.8	0.6	5.2	0.6
2	5.4	0.3	5.4	0.3	4.3	0.6
3	6.6	0.4	6.2	0.4	5.4	0.5
4	6.5	0.4	6.1	0.5	4.8	0.7
5	7.6	0.3	7.3	0.4	6.0	0.7
6	5.6	0.2	5.2	0.2	4.5	0.5
7	7.2	0.5	7.1	0.6	6.4	0.2
8	8.7	0.3	8.5	0.4	7.3	___
Avg.	6.8	0.3	6.5	0.4	5.5	0.6

[a]Average of four, except in Sample 8 is three.

[b]Average of seven, except in Samples 6 and 7 are six, and in Sample 8 is five.

[c]Average of five, except in Sample 7 is four and in Sample 8 is two.

Table A-9

Air Void System of the Hardened Concrete from Plant 1

Batch	Air Content (%) < 1 mm	Air Content (%) > 1 mm	Air Content (%) Total	Specific Surface (in^2/in^3)	Spacing Factor (in)
1	4.5	1.0	5.5	784	0.0057
2	3.8	1.2	5.0	804	0.0058
3	4.5	0.9	5.4	925	0.0049
4	4.3	1.3	5.6	977	0.0046
5	7.9	1.0	8.9	966	0.0034
6	4.7	0.4	5.1	1,109	0.0042
7	6.1	1.3	7.4	846	0.0045
8	8.1	1.3	9.4	883	0.0036
Avg.	5.5	1.0	6.5	912	0.0046

Table A-10

Unit Weights of Hardened Concretes from Plant 1 (lb/ft^3)

Batch	Unit Wt. Dry	Unit Wt. Immersion	Unit Wt. Immersion & Boil	Diff.[a]	Diff.[b]
1	141.3	144.8	144.8	1.27	1.27
2	142.3	145.4	145.4	-0.83	-0.83
3	139.2	143.5	143.5	1.86	1.86
4	141.6	144.8	145.4	0.39	0.08
5	136.7	140.4	140.4	1.67	1.67
6	141.6	145.4	145.4	-0.72	-0.72
7	139.2	142.3	142.9	2.09	1.78
8	134.2	137.9	138.5	-0.63	-0.94
Avg.	139.5	143.0	143.3	0.64	0.52
SD	2.8	2.7	2.6	1.24	1.25

[a]Difference between the unit weight of the fresh concrete and the unit weight obtained by averaging the dry and after-immersion unit weights.

[b]Same as a, except the unit weight after immersion and boiling.

Table A-11

Results of Paired t Test for Concrete from Plant 1

Air[a]	Avg. Diff.	SD	u[b]	Significant
A-T	0.23	0.90	0.60	No
B-T	-0.08	0.82	0.55	No
V-T	-1.03	0.96	0.64	Yes
A-B	0.31	0.17	0.11	Yes
A-V	1.26	0.29	0.19	Yes
B-V	0.95	0.28	0.19	Yes

[a]Total air contents by A = Type A pressure meter; B = Type B pressure meter; V = volumetric meter; T = microscopical method.

[b]$u = (t_{.95})\ (SD)/\sqrt{n}$.

Table A-12

Air Contents of Fresh Concretes from Plant 2

Sample	Type A	Type B	Diff[a]	Diff[b]
1	9.0	7.7	1.9	0.6
2	8.6	7.2	0.4	-1.0
3	8.0	7.4	0.5	-0.1
4	7.2	6.7	1.1	0.6
5	6.8	5.7	1.1	0.0
6	6.2		-0.8	
7	8.4	7.2	0.9	-0.3
8	6.6		-0.2	
9	7.4		0.3	
Avg.	7.6	7.0	0.58	-0.03
SD	1.0	0.7	0.79	0.60

[a]Difference between Type A and microscopical air content.

[b]Difference between Type B and microscopical air content.

Table A-13

Properties and Information on Concretes from Plant 2

Sample	Location[a]	Slump (in)	Unit Wt. (lb/ft^3)	28-Day Comp. Str.
1	P (260)	4.0	136.4	4,840
2	P (218)	6.0	137.6	5,080
3	P (226)	4.0	137.2	5,280
4	J	3.8	141.2	5,370
5	J	3.5	142.4	4,970
6	J (260)	3.5		4,980
7	J (218)	6.0		4,200
8	J (226)	4.0		5,130
9	Deck (226)	4.8		

[a]P = plant; J = job site; the number in parentheses is the truck number. One sample from location "deck" was consolidated in the deck by vibration and then removed.

Table A-14

Air Void System of Hardened Concretes from Plant 2

Sample	Air Content (%) < 1 mm	Air Content (%) > 1 mm	Air Content (%) Total	Specific Surface (in^2/in^3)	Spacing Factor (in)
1	6.3	0.8	7.1	974.00	0.0040
2	74.	0.8	8.2	829.00	0.0042
3	7.0	0.5	7.5	1023.00	0.0036
4	4.4	1.7	6.1	740.00	0.0059
5	5.0	0.7	5.7	837.00	0.0053
6	6.1	0.9	7.0	855.00	0.0046
7	7.1	0.4	7.5	970.00	0.0038
8	5.8	1.0	6.8	831.00	0.0048
9	6.7	0.4	7.1	936.00	0.0042
Avg.	6.2	0.8	7.0	888.00	0.0045

Table A-15

Unit Weights of Hardened Concretes from Plant 2

Batch	Unit Wt. Dry	Unit Wt. Immersion	Unit Wt. Immersion & Boil	Diff.[a]	Diff.[b]
1	135.3	142.1	142.8	-2.34	-2.70
2	134.8	141.6	142.3	-0.60	-0.96
3	135.6	142.3	142.9	-1.71	-2.00
4	137.6	144.4	145.2	0.16	-0.20
5	139.4	145.7	146.6	-0.15	-0.58
Avg.	136.5	143.2	144.0	-0.9	-1.3
SD	1.9	1.8	1.8	1.1	1.0

[a]See Table A-10.

[b]See Table A-10.