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INVESTIGATION OF THE AIR CONTENT OF PLASTIC VS HARDENED CONCRETE

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MATERIALS and TECHNOLOGY DIVISION

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INVESTIGATION OF THE AIR CONTENT OF PLASTIC VS HARDENED CONCRETE

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Abstract

This investigation compared the air content of portland cement concrete in the plastic and hardened states for seven typical mix designs used by the Michigan Department of Transportation (MDOT) in pavements and structures. The mixes included three target air content ranges, low (0 to 3 percent), intermediate (5 to 8 percent), and high (10 to 13 percent). Mix variables included high range water reducer, flyash, and latex. Strength requirements ranged from 3000 to 4500 psi. The air content of concrete in the plastic state correlated well with the air content of hardened concrete in all mixes with exception of the latex-modified concrete, which contained less air in the hardened state in the intermediate and high air content ranges. The investigation also compared the relationship between air content and compressive strength. Increasing air content in both the plastic and hardened concrete correlated well with decreasing compressive strength in all mixes with exception of the latex-modified concrete, which showed less effect of air content upon compressive strength.

Introduction

The technical literature contains considerable information on the relationship between the air content of concrete in the plastic state versus the hardened state. However, the relationship has not been investigated for the mixtures used by MDOT. This investigation was conducted by MDOT's Research Laboratory to acquire specific information for MDOT mix designs.

The primary objective of this study was to compare the measured air content of concrete in the plastic and hardened states, using controlled mixes. An estimation or verification of the original air content of a portland cement concrete mix is of interest when assessing causes of low compressive strength. Conventionally, the air content of hardened concrete specimens, estimated by linear traverse air content determinations, provides an estimate of the air content of the concrete in the original plastic state. This study investigated the relationship in seven typical MDOT mixes designed for use in pavements and structures. The seven mixes included three target air content ranges, low (0 to 3 percent), intermediate (5 to 8 percent), and high (10 to 13 percent). A secondary objective of this study was to investigate the degree of correlation between the compressive strength and the air content of plastic and hardened concrete using the seven MDOT mix designs for comparison.

Test Mixes

The seven test mixes met the design requirements stated in Section 7.01 of the 1990 MDOT Standard Specifications for Construction (1). Six typical pavement and structural concrete mixes contained 6A gravel coarse aggregate with a maximum particle size of one inch. One bridge deck mix, modified with latex, contained 26A crushed limestone coarse aggregate with a maximum particle size of 1/2 inch. All mixes used natural sand for the fine aggregate fraction. The air entraining admixture (AEA) for the six pavement and structure mixes was Master Builders' vinsol resin (MBVR), whereas the air entraining admixture used for the latex modified mix was Master Builders' Microair. The high range water reducer (HRWR) used in this investigation was Rheobuild 1000. The seven concrete mixes with three target air content ranges are:

1. Conventional Concrete, Grade 40S (4000 psi)
   6.5 sacks/cyd, without HRWR, and using MBVR air entraining agent, as follows:

Set No.	Target Air Content, %	AEA Dosage, oz/cyd
1A	0 to 3	0
1B	5 to 8	2
1C	10 to 13	5

2. Conventional Concrete, Grade 45D (4500 psi)
   7.0 sacks/cyd with 12 oz/cyd HRWR, and using MBVR air entraining agent, as follows:

Set No.	Target Air Content, %	AEA Dosage, oz/cyd
2A	0 to 3	0
2B	5 to 8	1 3/4
2C	10 to 13	3

3. Conventional Concrete, Grade 30P (3000 psi)
   5.5 sacks/cyd without HRWR, and using MBVR air entraining agent, as follows:

Set No.	Target Air Content, %	AEA Dosage, oz/cyd
3A	0 to 3	0
3B	5 to 8	1
3C	10 to 13	3

4. Conventional Concrete, Grade 35P (3500 psi)
   5.6 sacks/cyd with 12 oz/cyd HRWR, and using MBVR air entraining agent, as follows:

Set No.	Target Air Content, %	AEA Dosage, oz/cyd
4A	0 to 3	0
4B	5 to 8	2
4C	10 to 13	3

5. Latex-modified Concrete, Grade 45DL (4500 psi)
   7.0 sacks/cyd without HRWR, and using Microair air entraining agent, as follows:

Set No.	Target Air Content, %	AEA Dosage, oz/cyd
5A	0 to 3	0
5B	5 to 8	6
5C	10 to 13	12

6. Flyash-substituted Concrete, Grade 35S (3500 psi)
   5.1 sacks/cyd cement + 72 lbs/cyd flyash, with 12 oz/cyd HRWR, and using MBVR air entraining agent, as follows:

Set No.	Target Air Content, %	AEA Dosage, oz/cyd
6A	0 to 3	0
6B	5 to 8	2 1/2
6C	10 to 13	4

7. Conventional Concrete, Grade 45D (4500 psi)
   7.0 sacks/cyd without HRWR, and using MBVR air entraining agent, as follows:

Set No.	Target Air Content, %	AEA Dosage, oz/cyd
7A	0 to 3	0
7B	5 to 8	2
7C	10 to 13	5

Test Procedures

The concrete specimens used for hardened air determinations and compressive strength tests consisted of six-inch diameter concrete cylinders with 12-inch length, cast according to ASTM C 192-90, Standard Method for Making and Curing Concrete Test Specimens in the Laboratory (2). At the time of casting, technicians measured the plastic air content of each mix, using a Type A Acme air meter according to ASTM C 231-91, Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method (3). Although the standard procedure for determining the air content of plastic concrete requires only a single test, two tests on each mix were conducted for an average, with exception of the latex-modified mixes, which required extra time for clean-up of equipment after testing. To avoid having the latex-modified batches stand a longer time than the non-latex batches before casting into the molds, a single test was done on each of the latex-modified mixes.

After curing, one cylinder from each mix was sectioned horizontally at mid-depth to obtain a one inch thick slice for hardened air content determination by linear traverse. After preparing the slices for examination, a petrographer determined the hardened air contents on the tops and bottoms of the concrete slices, following ASTM C 457-90, Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete, Procedure A, Linear Traverse Method (4), using a Freyer MCS-83 computerized linear traverse analyzer.

One cylinder from each mix was tested for compressive strength, following ASTM C 39-86, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (5).

Data Analysis

A Lotus 1-2-3 statistical program was used to compute least-square best-fit lines for regressions comparing the air content in plastic vs hardened concrete, the air content in plastic concrete vs the compressive strength of hardened concrete, and the air content in hardened concrete vs the compressive strength of hardened concrete. The regression analyses provided a correlation coefficient (R^2), and a standard error of estimate, $S_{Y.X}$, analogous to the standard deviation of a sample population, for each of the three regressions. For the relatively small number of data points in each set, a modified standard error of estimate, $\hat{S}_{Y.X]} = (N/N-2)^{1/2} * S_{Y.X]}$, was computed to more accurately describe the correlations.

Results of the Air Content Determinations

The pressure meter determinations showed that the air content in plastic concrete of all of the test mixes, excepting latex-modified concrete Set No. 5A, had air contents within the target ranges. Latex-modified mix Set No. 5A had a slightly high air content of 3.9 percent. The hardened air content determinations showed that some of the mixes had air contents slightly above or below the target ranges.

Table 1 shows the results of the air content determinations. The table also includes the specific surface and spacing factor values calculated from the linear traverse data. According to ACI 201.2R and ACI 211.1 guidelines, concrete with 3/4 inch to 1/2 inch maximum size aggregate designed for resistance to freezing and thawing under severe exposure conditions, should have an entrained air content of six to seven percent and specific surface values ranging from 600 $in.^{-1}$ to 1100 $in.^{-1}$ (6,7). The mixes in the zero to three percent target air content range had values lower than the recommended minimum, as should be expected for concrete with low entrained air content. The ACI guidelines also state that air-entrained concrete designed for freeze-thaw durability usually has a spacing factor less than 0.008 inch (6,7). The mixes in the zero to three percent target air content range had spacing factor values greater than the recommended maximum, as should be expected for concrete deficient in entrained air.

TABLE 1 - CONCRETE PROPERTIES

Mix No.	Set No.	Plastic	Hardened			
		Air, %	Air, %	Spec. Surf., $in.^{-1}$	Spacing Factor, in.	Compressive Strength, psi @ 28 Day
1. 40S	1A	1.7	2.4	409	0.016	6600
	1B	6.2	7.2	981	0.003	5250
	1C	11.6	11.8	1139	0.001	2890
2. 45D	2A	1.9	2.1	471	0.015	6220
	2B	7.2	7.9	1146	0.003	4740
	2C	11.6	12.5	1199	0.001	3220
3. 30P	3A	1.8	2.0	338	0.018	5400
	3B	5.7	5.4	897	0.004	5100
	3C	11.8	12.4	1042	0.001	3000
4. 35P	4A	2.4	3.4	311	0.018	5120
	4B	7.0	8.1	962	0.003	4320
	4C	10.4	10.2	1134	0.001	3140

TABLE 1 - CONCRETE PROPERTIES							
Mix No.	Set No.	Plastic	Hardened				
		Air, %	Air, %	Spec. Surf., in.$^{-1}$	Spacing Factor, in.	Compressive Strength, psi @ 28 Day
5. 45DL	5A	3.9	3.8	263	0.022	5550
	5B	7.0	5.4	473	0.010	5400
	5C	11.1	7.7	482	0.008	5020
6. 35S	6A	2.2	3.4	366	0.015	5200
	6B	7.0	7.5	1154	0.002	4360
	6C	11.6	11.3	1012	0.002	3860
7. 45DO	7A	1.8	2.7	343	0.018	6560
	7B	7.1	8.2	1056	0.003	4160
	7C	11.4	12.3	1279	0.001	3020

Correlation of Plastic Air Content and Hardened Air Content

Linear regression analysis, including all seven mixes, produced an R^2 of 0.923 indicating a high degree of correlation between the plastic and hardened air contents, with the exception of the latex-modified concrete mixes in the five to eight and ten to thirteen percent target ranges. The plastic air content values for latex-modified mix Set Nos. 5B and 5C were considerably higher than the hardened air values. Recomputation of the linear regression, excluding the latex-modified concrete, resulted in a higher R^2 of 0.985, suggesting that the latex-modified concrete does not appear to have the same relationship between plastic and hardened air content as the non-latex concrete. This behavior of latex-modified concrete has been observed previously in the laboratory.

The regression equation developed from the data, excluding the latex-modified mixes, is as follows:

$$Y = -0.681 + 1.014X$$

where X is the percentage of air in hardened concrete, and Y is the percentage of air in plastic concrete. The regression formula predicted that the air content determined in hardened concrete by linear traverse is approximately 0.6 percent higher than that measured in plastic concrete using a Type A pressure meter, with a modified standard error of estimate of 0.51 percent. The latex-modified concrete showed much greater increases in air content in the plastic versus hardened state in the moderate and high air content target ranges. With exception of the latex-modified concrete, the higher air content of hardened versus plastic concrete has been attributed to the inability of the pressure meter to account for the volume contribution of the very small air bubbles. This could be due to the resistance to compression of the very small bubbles during pressurization (8). Figure 1 shows the results of the linear regression.

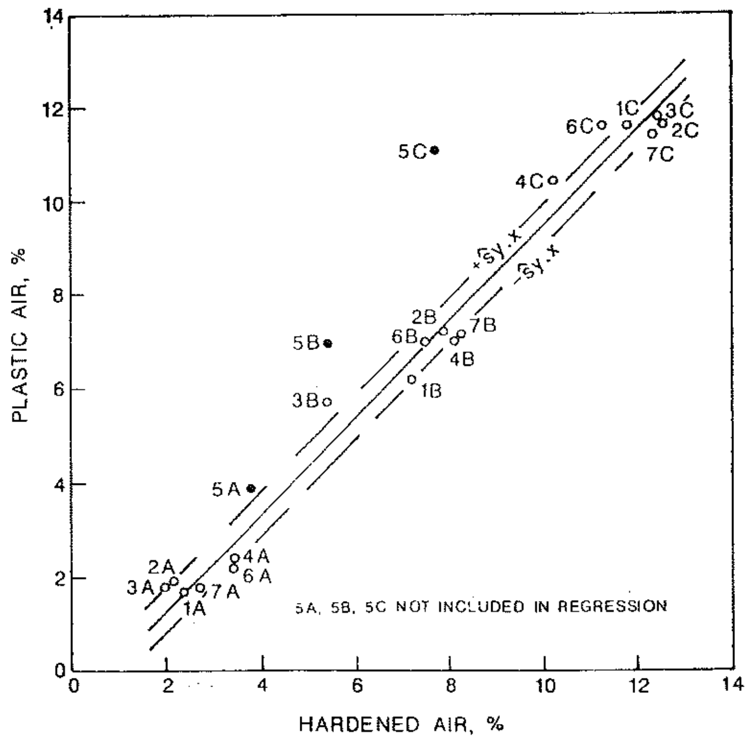

Figure 1. The air content of hardened concrete measured by linear traverse compared to the air content of plastic concrete measured by a Type A pressure meter.

Correlation of Plastic Air Content and Compressive Strength

Linear regression analysis,including all seven mixes, produced an R^2 of 0.755, indicating a relatively high correlation between the two parameters. The compressive strengths of the latex-modified mixes were noted to be somewhat less affected by changes in air content than strengths of the non-latex mixes. Recomputation of the linear regression, excluding the latex-modified mixes, resulted in a considerably higher R^2 of 0.868. The regression equation developed from the data excluding the latex-modified mixes is as follows:

$$Y = 6470.893 - 285.017X$$

where X is the percentage of air in plastic concrete, and Y is the compressive strength, pounds per square inch, of hardened concrete. The regression resulted in a modified standard error of estimate equal to 456.1 psi. According to ACI 214 guidelines, this modified standard error of estimate falls within the amount of variation expected for general construction testing of concrete under good control conditions (9). Figure 2 shows the results of the linear regression.

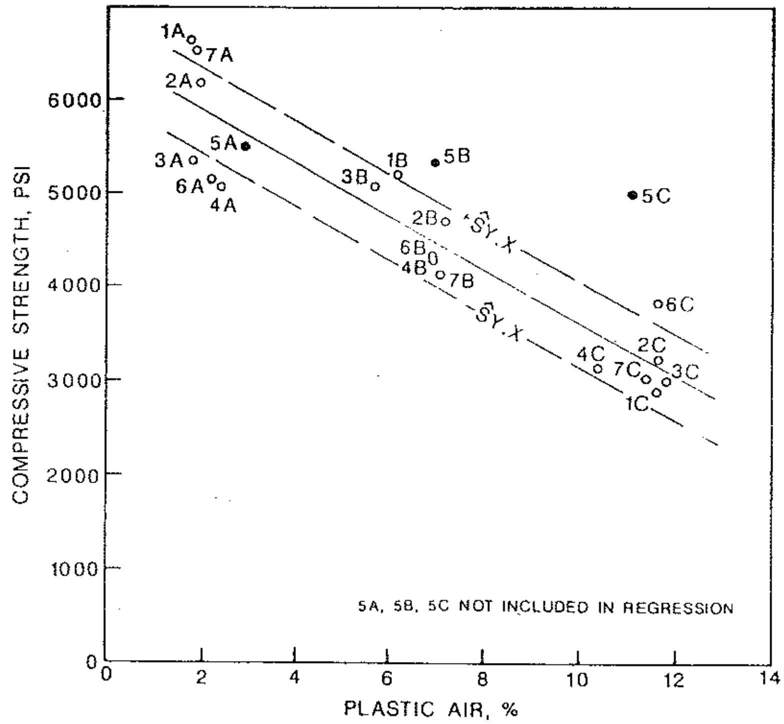

Figure 2. The relationship between the air content of plastic concrete and the compressive strength of hardened concrete.

Correlation of Hardened Air Content and Compressive Strength

Linear regression analysis, including all seven mixes, produced an R^2 of 0.866. This indicates a relatively high degree of correlation between the two parameters. As with the regression analysis of the plastic air content and compressive strength, the compressive strengths of the latex modified mixes were noted to be somewhat less affected by changes in air content than the strengths of the non-latex mixes. Recomputation of the linear regression, excluding the latex-modified mixes, resulted in a higher R^2 of 0.872. The regression equation developed from the data, excluding the latex-modified mixes, is as follows:

$$Y = 6686.322 - 292.001X$$

where X is the percentage of air in hardened concrete, and Y is the compressive strength, pounds per square inch, of hardened concrete. The regression resulted in a modified standard error of estimate equal to 449.0 psi. As with the modified standard error of estimate calculated for the linear regression analysis of the relationship between plastic air content and compressive strength, this modified standard error of estimate falls within the variation expected for general construction testing of concrete under good control conditions, as described in the ACI 214 guidelines (9). Figure 3 shows the results of the linear regression.

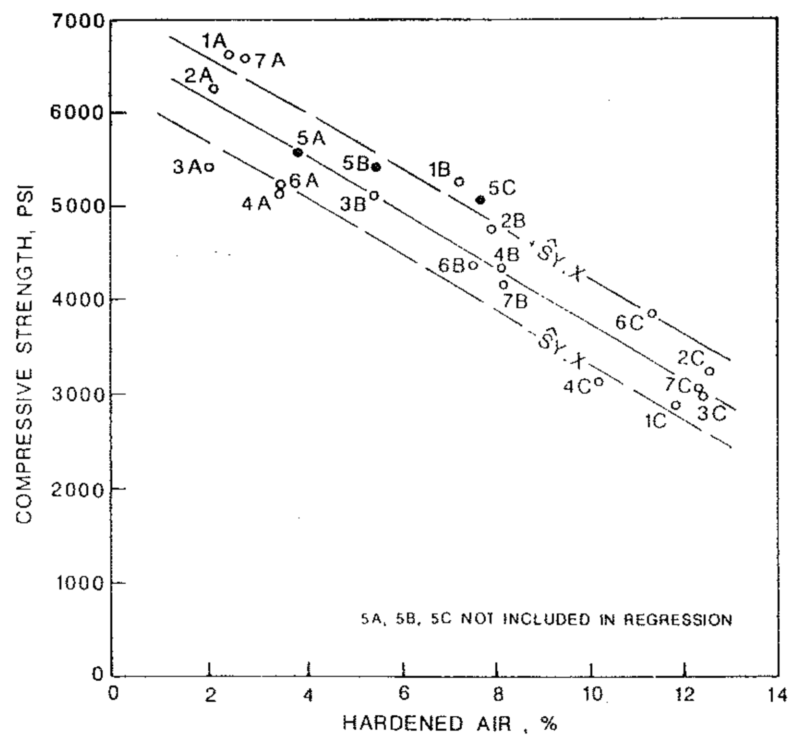

Figure 3. The relationship between the air content of hardened concrete and the compressive strength of hardened concrete.

Conclusions and Recommendations

The air void content of plastic concrete (as measured with a Type A pressure meter) correlated well with the hardened air content (as measured by the linear traverse method). The air contents determined by linear traverse of hardened concrete were approximately 0.6 percent higher than those measured in the plastic state determined by pressure meter, excluding the latex-modified concrete mixes. The latex-modified concrete contained a considerably higher air content in the plastic state than in the hardened state, a characteristic noted in other laboratory tests of latex-modified concrete.

Excluding the latex-modified mixes, increasing air content correlated well with decreasing compressive strength of hardened concrete. Each percent increase in the air content in both the plastic and hardened concrete correlated with a compressive-strength-reduction of approximately 300 psi. The air content in latex-modified concrete had less effect upon compressive strength.

The findings of this investigation indicate that modified concrete mixtures may not have the same relationship between air content and compressive strength as conventional concrete mixtures, as noted by the behavior of the latex-modified concrete. Future investigations of modified concrete mixtures should include tests of the plastic and hardened air contents to determine the relationship to compressive strength.

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