INFLUENCE OF CHEMICAL ADMIXTURES AND MIXING METHODS ON THE AIR VOID SYSTEMS IN PORTLAND CEMENT MORTARS

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ABSTRACT

Variations in the entrained air system in hydraulic cement mortars due to different chemical types of air-entraining agents and retarders and different mixing methods were investigated. Twenty-seven mortar batches were prepared at a fundamentally constant air content using different combinations of three mixing sequences, three air-entraining agents, and three retarders.

The Powers and Philleo spacing factors were determined on specimens from each batch, and were used as the criteria for comparison of the air void systems. Observed differences in the Powers spacing factor were found to be statistically significant for different mixing methods and different air-entraining agents. Comparatively large values of the Powers spacing factor were observed when the air-entraining agent and retarder were combined in the same water phase before being combined with the cement and sand. Relatively low values of Powers' spacing factor were observed when the organic acid retarder was used, regardless of the air-entraining agent used.

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Introduction

The practice of intentionally introducing air bubbles in concrete to improve frost resistance and increase workability was introduced in the 1930's.

Air entrainment in concrete protects the cement paste from the potentially destructive hydraulic pressures developed during the freezing of moisture contained within the concrete matrix.

Work done by T. C. Powers (1)* in 1949 predicted the order of magnitude of this pressure and showed that not only was the total volume of air contained in the concrete of importance, but more importantly the size distribution and frequency of air bubble voids must be such as to provide protection to the paste. Powers states that "... a body of nearly saturated paste more than a few hundredths of an inch thick cannot possibly be frozen rapidly without incurring damage."

To indicate the thickness of the paste, Powers introduced a factor defined as the maximum average distance from a point in the paste to the nearest air void (Powers' spacing factor, $\bar{L}$). This factor is indicative of the distance water would have to travel during the freezing process in order to reach an air bubble void. According to Powers, if these voids are spaced sufficiently close, the internal hydraulic pressure created as a result of the movement of moisture would be sufficiently low to prevent rupture of the paste in tension.

More recent laboratory observations have supported Powers' findings that for a particular air-entrained concrete, the magnitude of the spacing factor serves as an indication of that concrete's ability to withstand freezing and thawing. That is, as the magnitude of Powers' spacing factor for a given concrete decreases, the durability of the concrete subjected to freezing and thawing increases.

The magnitude of Powers' spacing factor is dependent on the frequency distribution of the void sizes in a given concrete mixture. Therefore, either the spacing factor or the frequency distribution of void sizes can be used as an indication of a concrete's durability when subjected to freezing and thawing.

The spacing factor proposed by Powers is not the only indication of a concrete's ability to withstand freezing and thawing. In 1955, R. E. Philleo (2) suggested a factor based on what he termed the protected paste volume concept. Larson et al. (3) reported evidence sufficient to justify further studies of this factor as an indicator of the frost resistance of concrete. To determine the Philleo factor, it is necessary to obtain a bubble size distribution from which the total number of bubbles per unit volume of paste may be calculated. As stated by Larson et al., "This number is used to calculate a factor indicating the protected paste volume, termed the Philleo spacing factor. This may be thought of as the thickness of spherical shells concentric with randomly distributed air voids such that the volume contained within all such spheres in a unit volume of paste constitutes a given percentage of paste."

*Refers to numbers in Selected References.

As with Powers' spacing factor, the magnitude of the Philleo factor is dependent upon the frequency distribution of void sizes.

Due to the above considerations, it is believed that regardless of the factor or factors chosen to indicate a particular concrete's ability to withstand freezing and thawing, the frequency distribution of the void sizes is of primary importance in frost resistance.

It has been shown by previous investigations (4,5) that the frequency distribution of air void sizes in air-entrained concretes and mortars may be greatly influenced by a number of variables and this study consists of an investigation of the following four:

1. Effects of different mixing sequences on the frequency and distribution of air voids in cement mortars.

2. A study of the frequency and distribution of air voids in cement mortars resulting from the use of three different air-entraining agents.

3. A study of the frequency and distribution of air voids in air-entrained cement mortars containing three different retarders.

4. A study of the interaction effects of mixing sequences, air-entraining agents, and retarders.

The criteria used to compare these different variables were the relative magnitudes of the Powers and Philleo spacing factors. The spacing factors were not themselves under a comparative investigation.

This report is based on research of the Texas Transportation Institute and the Texas Highway Department in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads.

Testing Program

The mortars used in these tests were composed of Atlas Type 1 cement, Ottawa standard graded silica sand (as defined in ASTM C185-59) and water. The cement to sand ratio of all mortars was .366 and sufficient water and air-entraining agent was used to produce a flow of 75% and air contents of 11 ± 1%.* The procedures used to determine the flow and air content of the hydraulic mortar is illustrated in Figures 1 and 2.

Three air entraining agents (AV,**AD, AH) and three retarders (RO, RL, RP) were used in this testing program. Each air entraining agent was used in combination with each retarder and three mixing sequences (designated M1, M2, M3, in Table I) were employed to yield 27 batches of mortar. With the exception of retarder RL (lignosulfonate), the manufacturer's recommended dosage was used. Due to the air-entraining characteristic of retarder RL, it was necessary to reduce its dosage in order to maintain the proper air content while using a significant amount of air-entraining agent.

*Test conducted in accordance with ASTM C185-59 except that the dimensions of the cylindrical container were 2 7/16 inches in diameter by 3 21/32 inches in depth. Eleven percent air in mortar corresponds to six percent in a concrete with 57% mortar by volume.

**In the designation used, "A" indicates an air-entraining agent and "R" a retarder. The letter following "A" indicates the type of air-entraining agent (V—vinsol resin, D—synthetic detergent, H—organic salt of sulfonated hydrocarbon.) The letter following "R" indicates the type of retarder (O—organic acid, L—lignosulfonate, P—hydroxylated polymer). M1, M2, M3 indicates the mixing sequence as given in Table I.

The method used to determine the parameters of the air void system was essentially in accordance with ASTM C457-66T, except that the Rosiwal Linear Traverse technique was modified in order to record each individual chord length. The apparatus used for measurement of the parameters is illustrated in Figure 3.

Information necessary to determine the Philleo spacing factor was obtained using the mathematical methods outlined by Larson et al. In order to facilitate the tedious numerical analysis necessary to carry out this investigation, the data reduction was programmed for the IBM 1094 and IBM 1401. Two representative sets of data output with plots of the calculated distribution curves are included in the appendix.

From each mortar batch a prismatic specimen was cast and allowed to moist cure for fourteen days before being prepared for microscopic examination. Figure 4 shows the specimen being sawed to expose a surface approximately at right angles to the finished surface of the mortar. The exposed surface is then ground with silicon carbide abrasive, as shown in Figure 5, until it is suitable for microscopic observation.

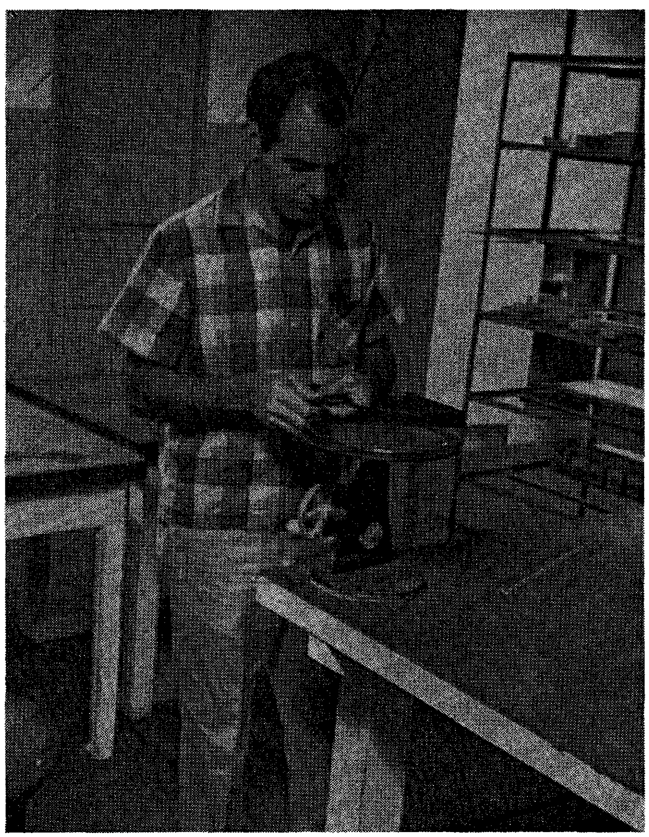

Figure 1. Determining the flow of the hydraulic cement mortar.

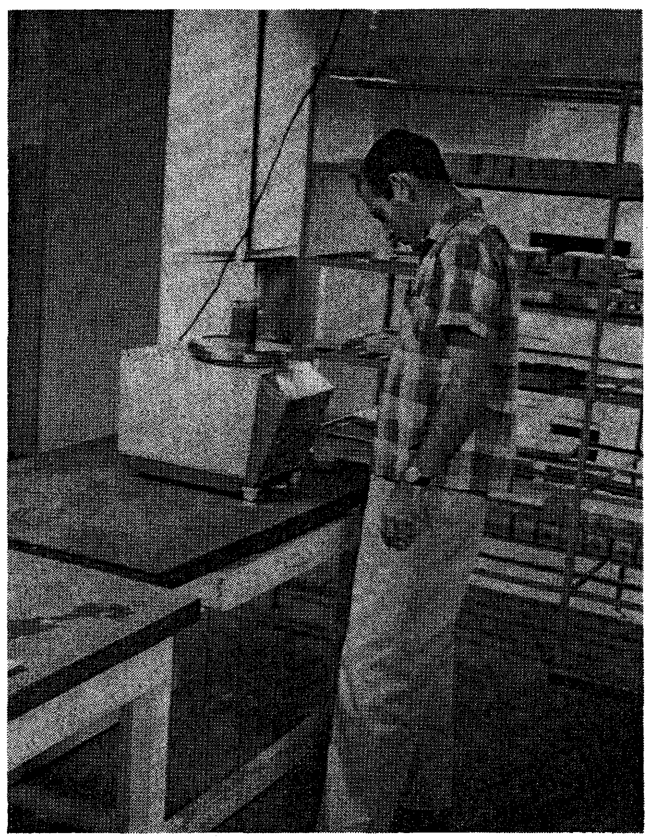

Figure 2. Determining the air content of the hydraulic cement mortar.

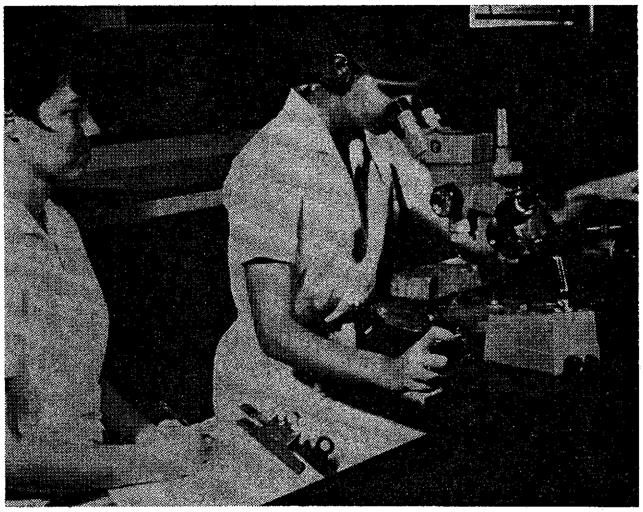

Figure 3. Technicians operating linear traverse device.

TABLE I. MIXING PROCEDURES

Mix Procedure Designation	Description of Mixing Procedure
M1	The sand and cement were placed in the mixer and allowed to dry mix 1 minute at 150 RPM. The air-entraining agent and retarder were combined in the mixing water and introduced into the mixer over a 1 minute time period. The mortar was then mixed an additional two minutes at 340 RPM.
M2	The sand and cement were placed in the mixer and allowed to dry mix 1 minute at 150 RPM. The air-entraining agent was combined with ½ of the mixing water and added over a 30 second period. The retarder was combined with the remainder of the water and added over a 30 second time period. The mortar was then mixed an additional two minutes at 340 RPM.
M3	The sand was placed in the mixer and ½ of the mixing water containing the air-entraining agent was added over a 30 second time period at a mixing speed of 150 RPM. The cement was then added over a one minute time period at a mixing speed of 150 RPM. The remainder of the mixing water containing the retarder was added over a 30 second period and the mortar was then allowed to mix for two minutes at 340 RPM.

The air void parameters of air content, specific surface area and Powers' spacing factor were determined in accordance with ASTM C457-66T. Traverse lengths ranged from 50 to 60 inches on a surface of 9 square inches.

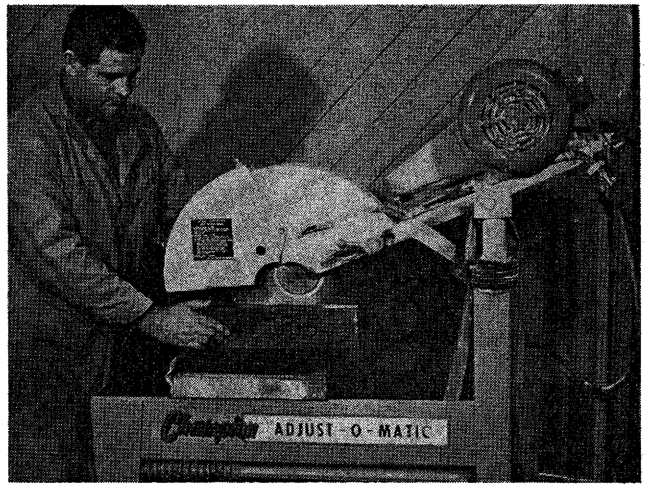

Figure 4. Sawing mortar specimen to expose surface for microscopic examination.

Figure 5. Grinding the exposed surface with silicon carbide abrasive.

Test Results and Discussion

Using the method described by Lord and Willis (6), the number of voids per cubic centimeter in the 0-508 micron range were determined as well as the total number in the 0-2540 micron range. The number of voids per cubic centimeter in the 0-508 micron range was then determined using the mathematical approach described by Larson et al., thus enabling determination of the Philleo spacing factor.

Table II summarizes the information of primary interest in this investigation.

Effect of Different Mixing Sequences

The statistical technique used to determine the significance of the observed differences in the Powers and Philleo spacing factors was a three factor analysis of variance. However, because there was no repetition of the batches, it was necessary to use the three factor interaction as an estimate of error and this may be an underestimate of the true experimental error.

The significance of the difference in the mean values was determined using Tukey's (7) h. s. d. procedure.

The magnitudes of the Powers spacing factors are shown in Figure 6 for each mortar batch. The batches are grouped according to mixing sequences M1, M2, and M3.

Using a three-factor analysis of variance and the Powers factor as a criterion, a difference in mixing sequences significant at the 99 percent level* was found to exist.

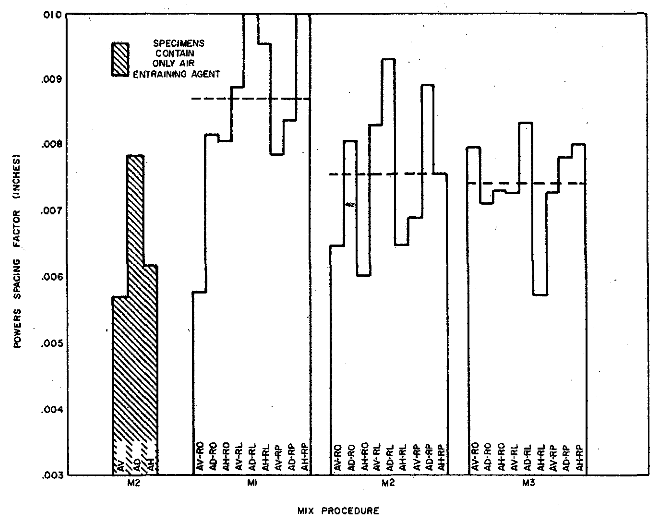

Figure 6. Comparison of Powers' spacing factor between mixing procedures (dashed line represents mean values of spacing factors).

The dashed lines shown on Figure 6 represent the mean value of the spacing factors associated with each

*This means there is a 99% probability that a significant difference exists.

TABLE II. PARAMETERS OF THE AIR VOID SYSTEM

Batch Designation	Microscopic Air Content (%)	Powers' Spacing Factor (in.)	Philleo Spacing Factor (in.)	Specific Surface (in.$^{-1}$)	Bubbles/cc Mortar, After Larson et al. 0-508 μ range	Bubbles/cc Mortar (Lord & Willis) 0-2540 μ range
AV-M2	13.56	.00565	.00359	520	137,251	93,564
AD-M2	14.15	.00771	.00615	358	27,454	17,973
AH-M2	11.47	.00611	.00362	581	131,188	75,136
AV-RO-M1	15.75	.00574	.00567	420	31,355	45,919
AD-RO-M1	10.55	.00815	.00418	471	74,406	30,339
AH-RO-M1	8.67	.00806	.00356	557	94,044	41,864
AV-RL-M1	11.52	.00888	.00503	394	53,667	25,687
AD-RL-M1	11.84	.01173	.00514	289	47,407	8,939
AH-RL-M1	8.16	.00954	.00399	486	111,321	27,563
AV-RP-M1	13.63	.00786	.00519	365	52,431	40,034
AD-RP-M1	15.12	.00837	.00736	306	16,379	13,680
AH-RP-M1	8.80	.01032	.00579	434	42,357	41,540
AV-RO-M2	13.48	.00645	.00330	442	181,449	46,341
AD-RO-M2	13.50	.00805	.00550	353	40,560	25,337
AH-RO-M2	10.92	.00600	.00220	603	384,774	97,841
AV-RL-M2	12.52	.00830	.00521	382	39,278	24,857
AD-RL-M2	12.30	.00931	.00422	349	75,793	17,230
AH-RL-M2	10.21	.00646	.00344	620	154,309	78,622
AV-RP-M2	11.67	.00688	.00349	493	172,164	98,813
AD-RP-M2	11.16	.00890	.00505	400	57,123	38,178
AH-RP-M2	10.69	.00755	.00420	502	99,701	77,816
AV-RO-M3	11.16	.00794	.00481	452	64,799	49,878
AD-RO-M3	16.35	.00708	.00497	325	45,665	19,890
AH-RO-M3	11.00	.00729	.00347	498	145,312	51,534
AV-RL-M3	13.74	.00721	.00617	390	24,574	22,676
AD-RL-M3	12.51	.00833	.00547	381	40,414	21,389
AH-RL-M3	10.51	.00569	.00190	667	597,374	107,340
AV-RP-M3	11.38	.00725	.00344	484	154,537	38,904
AD-RP-M3	11.38	.00779	.00425	452	82,886	41,792
AH-RP-M3	10.57	.00802	.00444	480	87,397	63,526

TABLE III. SUMMARY OF MEAN VALUES OF POWERS AND PHILLEO SPACING FACTORS

Mean Spacing Factor	Powers' Spacing Factor (inches)			Philleo Spacing Factor (inches)		
	M1	M2	M3	M1	M2	M3
Mixing Procedure	.00874	.00754	.00740	.00510	.00407	.00432
	AV	AD	AH	AV	AD	AH
Air-Entraining Agent	.00739	.00863	.00766	.00470	.00513	.00367
	RO	RL	RP	RO	RL	RP
Retarder	.00720	.00838	.00810	.00418	.00451	.00480

particular mixing sequence. It was found that between mixing sequences M3 and M1, and M2 and M1, the mean differences were significant at the 99 percent level with M1 giving larger values of Powers' spacing factor. No significant difference was observed between M2 and M3. Therefore, a less desirable air void system was evident in the mixing procedure where the admixtures were combined prior to their addition.

The above procedure was followed using the Philleo factor as a criterion for observing the effect of the mixing sequence. While the magnitudes of this factor are not presented in graphical form, they are reported in Table II. A summary of the mean values is reported in Table III.

When the Philleo factor was used as the criterion, no significant difference was indicated between mixing sequences.

Effect of Different Air-Entraining Agents

The effectiveness of the air-entraining agents was investigated using the same tests for significance as described previously. It was found that significant differences existed between the air-entraining agents. Air-entraining agent AD produced an air void system which yielded higher values of both the Philleo and Powers spacing factor. No significant difference was observed between agents AV and AH, while the differences in the average Powers' spacing factors of AV and AD, and AH and AD were significant at the 99 percent and 95 percent levels, respectively. Mean values of Powers' factor are shown in Figure 7.

Using the Philleo factor, a significant difference in the means of AD and AH was indicated at the 95 percent level.

Effect of Different Retarders

A significant difference at the 99 percent level existed between different combinations of retarders and air-entraining agents when compared on the basis of the Powers spacing factor.

The values of the Powers factor are shown in Figure 8, with the dashed lines representing the mean value of each group.

The difference in the mean values of RO and RL was significant at the 99 percent level while the difference between RO and RP showed a 95 percent significance.

No significant difference was noted between RP and RL.

Interaction Effects of Mixing Sequences, Air-Entraining Agents and Retarders

The interaction of mixing sequences, air-entraining agents and retarders was found to produce values of the Powers spacing factor with differences significant at the 95 percent level. However, no significance was found to exist between different values of the Philleo factor.

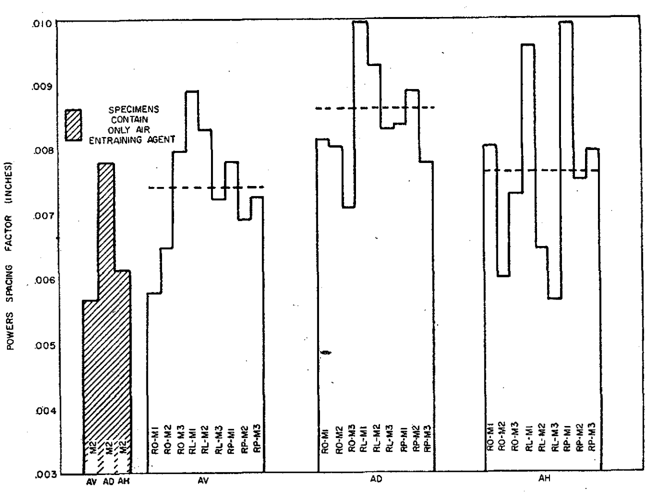

Figure 7. Comparison of Powers' spacing factor between air-entraining agents (dashed line represents mean values of spacing factors).

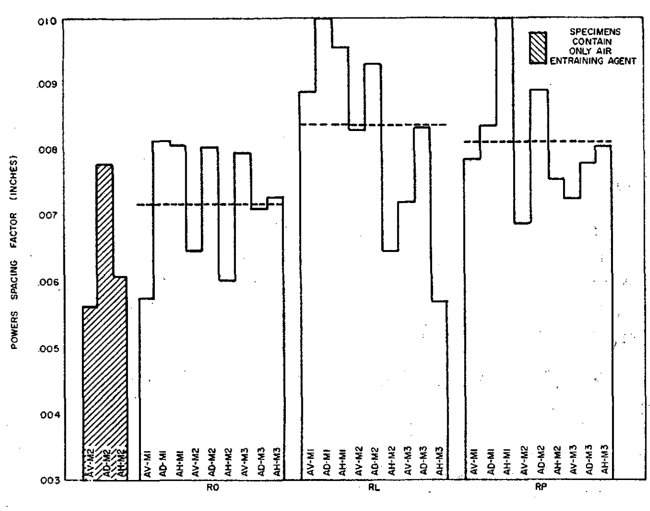

Figure 8. Comparison of Powers' spacing factor between retarders (dashed line represents mean values of spacing factors).

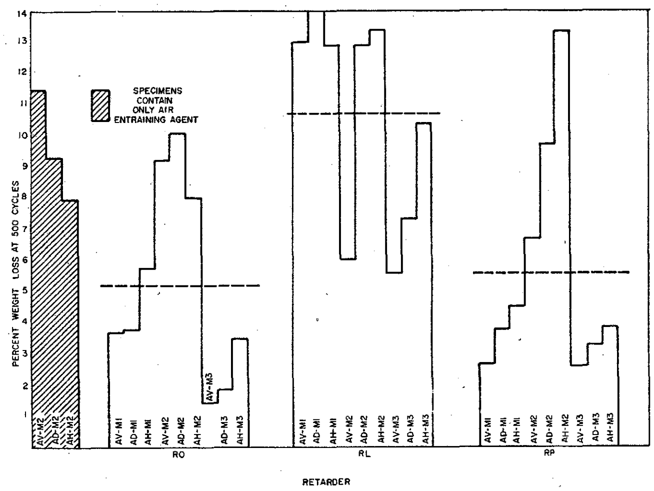

Figure 9. Comparison of freeze-thaw weight loss between admixtures (1- x 1- x 5-inch mortar block).

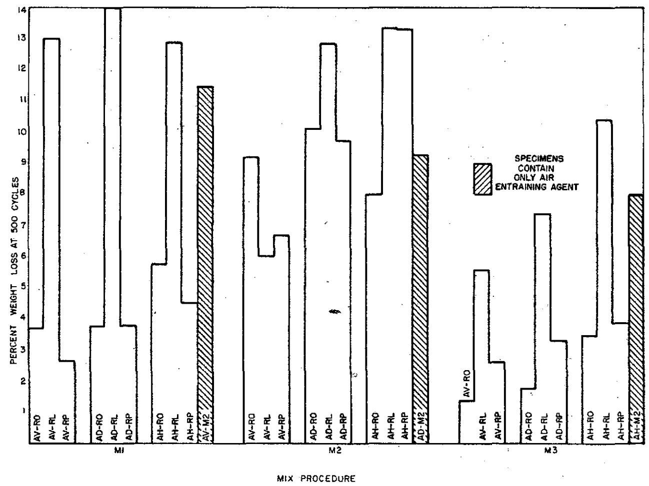

Figure 10. Comparison of freeze-thaw weight loss between air-entraining agents and mixing methods (1- x 1- x 5-inch mortar block).

It was found that when both retarders and air-entraining agents were used, introduction into the batch in accordance with the method described in mixing sequence M1 was least desirable.

With the three mixing procedures and the three retarders used in this investigation, it was found that air-entraining agent AD performed less satisfactorily than did AV and AH.

Under the three conditions of mixing and in combination with the three air-entraining agents, retarder RO was found to be less detrimental to the development of a desirable air void system.

Resistance of Mortar to Deterioration as a Result of Freezing and Thawing

Two 1- x 1- x 5-inch mortar specimens were cast from each mortar batch. After 14 days moist curing, the specimens were subjected to rapid freezing and thawing. Weight loss of the specimens was progressively recorded until the test was terminated at 500 cycles.

It has not been shown that weight loss in mortar is a good criterion for predicting concrete freeze-thaw durability. However, significant discernible trends do seem apparent between the air-entraining agents, retarders and mixing procedures. One indication of a possible correlation between this test and freeze-thaw tests on concrete is shown by the increased weight loss in the RL batches (Figure 9) as compared to the lignosulfonate concrete batches in Research Report 70-3 (Final) (8). In 70-3 it is shown that the lignosulfonate chemical group contains an individual member that can cause significant decreases in concrete frost resistance.

Data shown in Figure 10 indicates lower weight losses occurred in those specimens mixed in accordance with procedure M3.

Conclusions

The following conclusions are made concerning the factors investigated:

1. Of the three mixing procedures, the least desirable air void system was produced as a result of mixing the air-entraining agent and retarder in the same water phase and introducing this mixture into the sand and cement (Procedure M1, Table I).

2. The air-entraining agents investigated differed in their abilities to produce a system of closely spaced air voids. The vinsol resin and sulfonated hydrocarbon type air-entraining agents produced the most desirable system of air voids.

3. Air-entrained mortars containing the polymer and lignosulfonate type retarders possessed a less desirable air void system than did the mortars containing the organic acid type retarder.

4. Lower weight losses due to freezing and thawing were observed in mortar specimens which were mixed by first introducing the air-entraining agent and one-half the mixing water into the sand and blending before adding the other constituents (Procedure M3, Table I).

5. Comparatively larger values of weight loss due to freezing and thawing were observed in mortar specimens containing the lignosulfonate type retarder.

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Appendix

WATER-CEMENT RATIOS

Batch Designation	w/c (weight water/weight cement)
AV-M2	.550
AD-M2	.550
AH-M2	.564

Mixing Sequence M1

AV-RO	.536
AD-RO	.543
AH-RO	.543
AV-RL	.550
AD-RL	.550
AH-RL	.550
AV-RP	.543
AD-RP	.550
AH-RP	.557

Mixing Sequence M2

AV-RO	.509
AD-RO	.509
AH-RO	.509
AV-RL	.543
AD-RL	.550
AH-RL	.550
AV-RP	.522
AD-RP	.522
AH-RP	.543

Mixing Sequence M3

AV-RO	.536
AD-RO	.530
AH-RO	.530
AV-RL	.522
AD-RL	.543
AH-RL	.550
AV-RP	.536
AD-RP	.536
AH-RP	.550

PARAMETERS OF BUBBLE SYSTEM CONTAINING DISTRIBUTED SIZES AD-RP-M1

Chord Length Interval (Microns)	Radius of Spheres (CM)	Number of Chords Intercepted	No. of Bubbles Per CC of Concrete	Percent Air Per Volume of Concrete	Arithmetic Mean of Chord Intercepts	Mean Radii of Bubble System Containing Distributed Sizes R(A) (CM)	R(S) (CM)	R(V) (CM)	Specific Surface (CM)
0. - 25.4	0.001270	3.	0.						
25.4- 50.8	0.002540	32.	166.431						
50.8- 76.2	0.003810	54.	5634.861						
76.2- 101.6	0.005080	44.	1188.789						
101.6- 127.0	0.006350	48.	1210.403						
127.0- 152.4	0.007620	48.	2854.341						
152.4- 177.8	0.008890	27.	345.663						
177.8- 203.2	0.010160	27.	264.331						
203.2- 228.6	0.011430	27.	668.556						
228.6- 254.0	0.012700	20.	125.136						
254.0- 279.4	0.013970	20.	103.373						
279.4- 304.8	0.015240	20.	236.621						
304.8- 330.2	0.016510	17.	62.874						
330.2- 355.6	0.017780	17.	54.202						
355.6- 381.0	0.019050	17.	47.208						
381.0- 406.4	0.020320	17.	41.486						
406.4- 431.8	0.021590	17.	143.735						
431.8- 457.2	0.022860	14.	26.989						
457.2- 482.6	0.024130	14.	24.221						
482.6- 508.0	0.025400	14.	21.858						
508.0- 533.4	0.026670	14.	19.824						
533.4- 558.8	0.027940	14.	18.062						
558.2- 584.2	0.029210	14.	69.641						
584.2- 609.6	0.030480	12.	216.801						
609.6- 635.0	0.031750	4.	83.740						
635.0- 762.0	0.038100	4.	11.023						
762.0-1016.0	0.050800	4.	1.585						
1016.0-1270.0	0.063500	4.	4.882						
1270.0-2540.0	0.127000	4.	0.666	15.1157					
					0.03324	0.007254	0.009237	0.012916	120.3403
The sum through length 508 is			13254.3602						
The sum for all intervals is		571.	13680.5840						

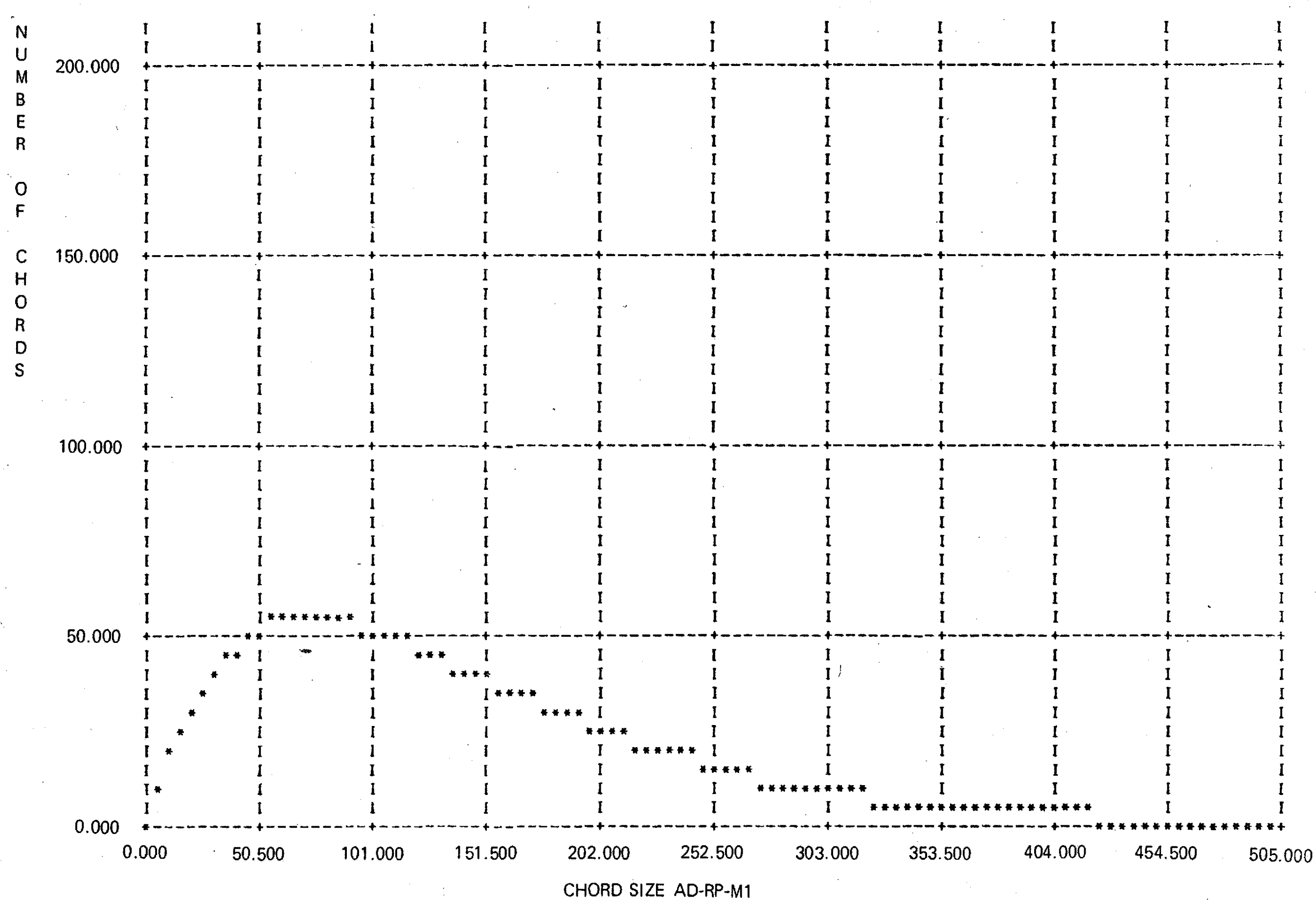
PARAMETERS OF BUBBLES CONTAINING UNIFORM SIZES AD-RP-M1

Radius of Bubbles R(N)	No. of Bubbles Per CC of Concrete
0.024929	0.
	22.8
	773.5
	163.2
	166.2
	391.8
	47.5
	36.3
	91.8
	17.2
	14.2
	32.5
	8.6
	7.4
	6.5
	5.7
	19.7
	3.7
	3.3
	3.0
	2.7
	2.5
	9.6
	29.8
	11.5
	1.5
	0.2
	0.7
	0.1
The sum thru 508 is	1814.9779
The sum thru 2540 is	1873.4896

Constants of F(Y) = A*Y/B**Y A	B	Frequency F(Y)	Percent Air Content Per Unit Vol of Concrete	Relative Frequency Distribution for 0-508 Microns	Vol Fraction of Air in 0-508 Range Per Unit Volume: Concrete	Paste and Air	Number of Bubbles Per CC 0 - 508 Range: Paste	Concrete
2.0542	1.0140	21.8700	0.0977	2064429.906	0.01780	0.04402	40512.7	16379.1
		46.1060						
		54.0000						
		53.1263						
		48.0000						
		41.2267						
		34.2387						
		27.7621						
		22.1105						
		17.3656						
		13.4879						
		10.3810						
		7.9294						
		6.0180						
		4.5423						
		3.4121						
		2.5525						
		1.9024						
		1.4133						
		1.0468						
		0.7734						
		0.5700						
		0.4192						
		0.3077						
		0.2254						
		0.0878						
		0.0079						
		0.0003						
		0.0000						

Spacing Factors

S (Philleo Factor, Inches)	Powers' Factor (Inches)
0.007358	0.011072



PARAMETERS OF BUBBLE SYSTEM CONTAINING DISTRIBUTED SIZES AV-RP-M3

Chord Length Interval (Microns)	Radius of Spheres (CM)	Number of Chords Inter-cepted	No. of Bubbles Per CC of Concrete	Percent Air Per Volume of Concrete	Arith-metic Mean of Chord Inter-cepts	Mean Radii of Bubble System Containing Distributed Sizes			Specific Surface (CM)
						R(A) (CM)	R(S) (CM)	R(V) (CM)	
0. - 25.4	0.001270	3.	0.						
25.4- 50.8	0.002540	95.	2266.569						
50.8- 76.2	0.003810	149.	18491.045						
76.2- 101.6	0.005080	102.	8383.995						
101.6- 127.0	0.006350	69.	1802.953						
127.0- 152.4	0.007620	68.	3770.069						
152.4- 177.8	0.008890	40.	498.147						
177.8- 203.2	0.010160	40.	809.489						
203.2- 228.6	0.011430	34.	255.628						
228.6- 254.0	0.012700	34.	553.861						
254.0- 279.4	0.013970	28.	721.501						
279.4- 304.8	0.015240	17.	266.076						
304.8- 330.2	0.016510	13.	46.770						
330.2- 355.6	0.017780	13.	40.319						
355.6- 381.0	0.019050	13.	113.455						
381.0- 406.4	0.020320	11.	26.113						
406.4- 431.8	0.021590	11.	23.128						
431.8- 457.2	0.022860	11.	20.628						
457.2- 482.6	0.024130	11.	49.646						
482.6- 508.0	0.025400	10.	74.418						
508.0- 533.4	0.026670	8.	11.020						
533.4- 558.8	0.027940	8.	64.006						
558.8- 584.2	0.029210	6.	32.724						
584.2- 609.6	0.030480	5.	5.272						
609.6- 635.0	0.031750	5.	101.824						
635.0- 762.0	0.038100	5.	13.404						
762.0-1016.0	0.050800	5.	3.277						
1016.0-1270.0	0.063500	4.	5.235						
1270.0-2540.0	0.127000	1.	0.162						
				11.3816	0.02097	0.005434	0.006532	0.008797	190.7151
The sum through length 508 is			38667.1196						
The sum for all intervals is		819.	38904.0410						

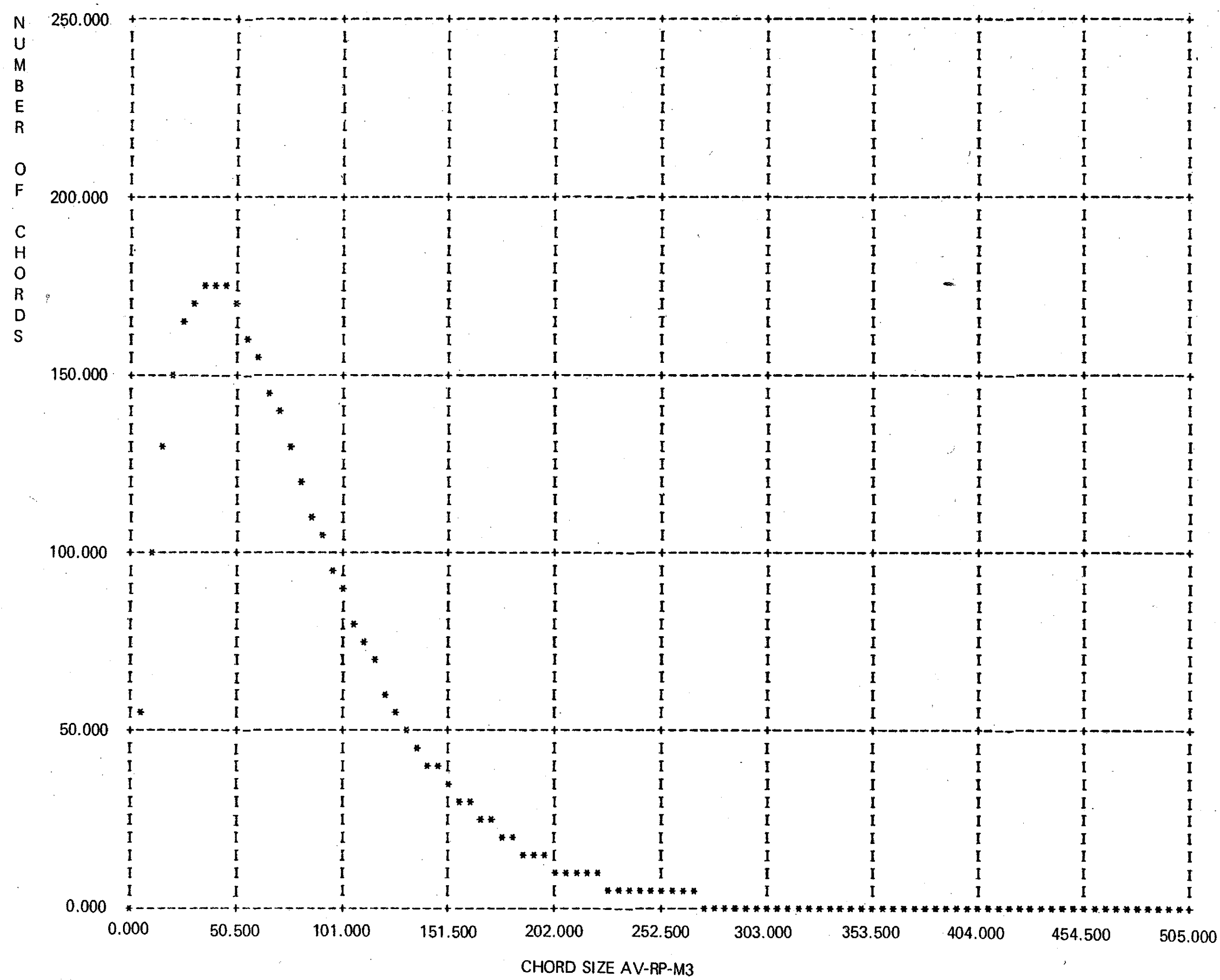
PARAMETERS OF BUBBLES CONTAINING UNI-FOM SIZES AV-RP-M3

Radius of Bubbles R(N)	No. of Bubbles Per CC of Concrete
0.015730	
	0.
	390.9
	3188.8
	1445.8
	310.9
	650.2
	85.9
	139.6
	44.1
	95.5
	124.4
	45.9
	8.1
	7.0
	19.6
	4.5
	4.0
	3.6
	8.6
	12.8
	1.9
	11.0
	5.6
	0.9
	17.6
	2.3
	0.6
	0.9
	0.0
The sum thru 508 is	6590.0381
The sum thru 2540 is	6630.8957

Constants of F(Y) = A*Y/B**Y		Frequency F(Y)	Percent Air Content Per Unit Vol of Concrete	Relative Frequency Distribution for 0 - 508 Microns	Vol Fraction of Air in 0-508 Range Per Unit Volume		Number of Bubbles Per CC 0-508 Range	
A	B				Concrete	Paste and Air	Paste	Concrete
12.8063	1.0271	115.8313	0.0933	31413 1.922	0.02555	0.06004	363148.0	154537.7
		176.2554						
		149.0000						
		105.8058						
		69.0000						
		42.7754						
		25.6413						
		15.0066						
		8.6265						
		4.8903						
		2.7416						
		1.5230						
		0.8397						
		0.4600						
		0.2506						
		0.1359						
		0.0734						
		0.0395						
		0.0212						
		0.0113						
		0.0060						
		0.0032						
		0.0017						
		0.0009						
		0.0005						
		0.0001						
		0.0000						
		0.0000						
		0.0000						

Spacing Factors

S (Philleo Factor, Inches)	Powers' Factor (Inches)
0.003435	0.008065


NUMBER OF CHORDS
250.000
200.000
150.000
100.000
50.000
0.000
0.000
50.500
101.000
151.500
202.000
252.500
303.000
353.500
404.000
454.500
505.000
CHORD SIZE AV-RP-M3