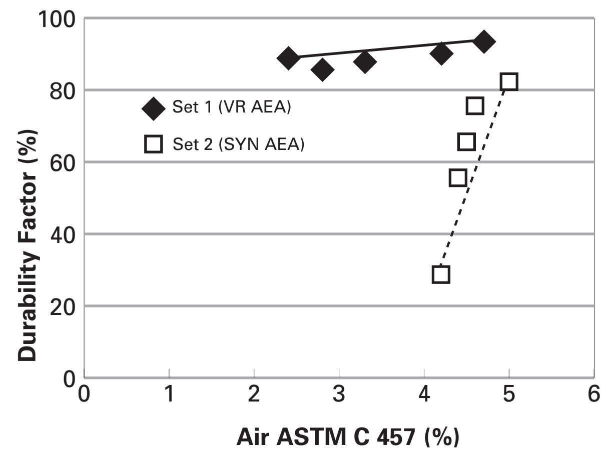

Figure 3. Relationship between the durability factor and hardened air content of mixes with Vinsol resin admixture (Set 1) or synthetic admixture (Set 2).

All specimens suffered some mass change (loss) during testing. The mass loss is an indication of the observed scaling of the exterior of the specimens. Any mass gain due to water entering the concrete through cracks was obscured by the losses due to scaling. No correlation was found between the mass loss and freeze-thaw performance of Sets 1 and 2.

Conclusions

In this study, two sets of concretes with fresh air contents varying from 2.5 to 4.5 percent were prepared. The sets differed only in the type of air-entraining admixture: Vinsol resin and synthetic admixture. For the mixes prepared in this study and for the specific admixtures used, the Vinsol resin mixes exhibited better freeze-thaw resistance but a worse air void system. The reasons for this unexpected observation are not known.

Well-established thresholds for air void parameters date from the time when mainly Vinsol resin admixtures were used. Experience shows that these limits (> 6 ± 1 percent air, specific surface ≥ 24 mm²/mm³ – 600 in²/in³, and spacing factor ≤ 0.20 mm – 0.008 in) would be expected to give good concrete freeze-thaw resistance. The test data presented in this paper suggest these limits may not be adequate to assure durability for some synthetic admixtures containing air-entrained concrete.

This study generated insufficient data to generalize results for all Vinsol resin and synthetic air entraining admixtures and all air content levels. More research is needed to confirm this finding.

Recommendations

The well-established limits for air void parameters would be expected to give good concrete freeze-thaw resistance, but the test data on concrete with marginal air content presented in this study suggest these limits may not apply to air-entrained concrete containing synthetic admixtures.

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Key Words—air-entraining admixture, freeze-thaw, marginal air, synthetic, Vinsol resin

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TECHBRIEF

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Freeze-Thaw Resistance of Concrete with Marginal Air Content

FHWA-HRT-06-118

Abstract

Freeze-thaw resistance is a key durability factor for concrete pavements. Recommendations for the air void system parameters are normally 6 ± 1 percent total air and a spacing factor of ≤ 0.20 millimeter (mm) (0.008 inch). However, it was observed that some concretes without these commonly accepted thresholds presented good freeze-thaw resistance in laboratory studies.

This study evaluated the freeze-thaw resistance of several marginal air void mixes with two types of air-entraining admixtures, a Vinsol® resin and a synthetic admixture. To conduct the study, researchers used rapid cycles of freezing and thawing in plain water, with no deicing salts.

For the specific materials and concrete mixture proportions used in this project, the marginal air mixes (concretes with fresh air contents of 3.5 percent or higher) presented an adequate freeze-thaw performance when Vinsol resin-based air-entraining admixture was used. The synthetic admixture used in this study did not show the same good performance as the Vinsol resin admixture.

Research Significance

There are well-established thresholds for air void parameters that are expected to give good concrete freeze-thaw resistance. Nevertheless, these thresholds were established in the 1940s based on the materials available at that time and for neutralized Vinsol resin as the air-entraining admixture. Although the use of synthetic air entraining admixtures has increased, a sufficient quantity of published data does not exist to compare the freeze-thaw performance of concretes with marginal air content containing these two types of admixtures. Therefore, it is critical to verify whether the thresholds established in the past apply to concretes with synthetic air-entraining admixtures.

Experimental Investigation

For this experiment, researchers compared the freeze-thaw performance of marginal air mixes containing synthetic admixtures and Vinsol resin. This experiment tested concretes with a range of air contents batched with two different air-entraining admixtures.

Two sets of tests were performed, one for each of the two air-entraining admixtures. Set 1 contained Vinsol resin air-entraining admixture (VR AEA), and Set 2 contained synthetic air-entraining admixture (SYN AEA). The mix proportions for the two sets were the same. The concretes represented paving concretes with low slump (25.4 mm (1 inch)). Each set consisted of 5 concrete mixtures proportioned with water-cement ratios of 0.45, cement content of 356 kilograms per cubic meter (kg/m^3) (600 pounds per cubic yard (lb/yd^3)), and target fresh air content of 2.5 to 4.5 percent, in increments of 0.5 percent. In Set 1, an additional nonair-entrained concrete mixture also was proportioned. The aggregates that were used were known to be durable in freezing and thawing exposure.

The specimens were tested in accordance with American Society for Testing and Materials (ASTM) standard C 666, Procedure A[1] (AASHTO T 161[2]) in an automated freezing and thawing machine with the beam specimens contained in vertical containers. ASTM C 666, "Standard Test Method for Resistance of Concrete to Freezing and Thawing," is the standard laboratory test method for assessing concrete's resistance to freezing and thawing.

Researchers monitored the specimens for changes in resonant frequency in accordance with ASTM C 215[3] and for mass changes (to the nearest 1 gram). ASTM C 215, "Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens," uses modal testing to assess damage to specimens undergoing freeze-thaw testing. In the present study, the impact test method was used to measure transverse frequency, following the setup used by Clarke.[4] The ASTM C 215 impact method uses a modally tuned impact hammer to excite vibrations in the specimen and an accelerometer attached to the specimen to record the response. Testing was repeated at regular intervals, usually every 10 to 30 cycles, depending on expected freeze-thaw behavior.

Air-void system evaluations (linear traverse) were conducted on hardened specimens from each mixture in accordance with ASTM C 457, "Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete."[5]

Experimental Results And Discussion

Table 1 presents the air void system for Set 1 (mixes 223 to 227). The air-void parameters were determined in accordance with ASTM C 457 (linear traverse) and represent the average of two measurements. The researchers did not determine the air system of the nonentrained air concrete (mix 302 of Set 1).

Mix	Fresh air (ASTM C 231)	Air (%) ASTM C 457	Accu-mulated chord length (mm)	Voids counted	Mean chord length (mm)	Voids per m	Specific surface (mm^2/mm^3)	Spacing factor (mm)
223	4.0	2.4	55	276	0.22	120	**19.9**	**0.38**
224	3.6	2.8	64	215	0.30	93	**13.5**	**0.49**
225	3.1	4.2	94	288	0.33	126	**12.2**	**0.45**
226	4.7	4.7	106	495	0.21	215	**18.7**	**0.28**
227	2.7	3.3	74	212	0.35	93	**11.5**	**0.54**

Table 1. Air void system of Set 1 (VR AEA) measured by linear traverse.

All mixes from Set 1 presented marginal air void contents. The spacing factors were higher than the maximum value of 0.2 mm (0.008 inch) normally required for good freeze-thaw resistance. Most were above 0.36 mm (0.015 inches). The specific surface areas were lower than normally desired (24 mm^{-1} or 600 inch^{-1}) for the total air volume in the range of the mixes for this study. Some of the mixes, such as mix 227, had specific surface areas that were half of the desired level.

One could expect the freeze-thaw resistance of those mixes to be inadequate. Nevertheless, table 2 shows that the durability factors (DF) were over 80 percent, which is considered a satisfactory performance, except for the nonair-entrained concrete (mix 302) that failed to meet the criteria. All of the air-entrained mixes withstood at least 300 cycles except beam 224–A5, which suffered some damage during the handling of the specimen that was unrelated to testing.

Set 2 presented a much better air system with respect to the spacing factor and specific surface area, but most of the mixes were in the range of the marginal air void parameters, as shown in table 3. It is important to note that the air was well distributed and no clustering was observed in Set 2.

Mix	Fresh air (%)	Durability Factor						
		A1	A2	A3	A4	A5	Average	Standard deviation
302	2.0 non A/E	14.4	14.5	16.7	12.1	15.4	14.4	1.9
227	2.7	86.7	88.1	86.8	89.9	76.8	87.9	1.5
225	3.1	89.4	90.5	90.0	90.8	88.2	90.2	0.6
224	3.6	85.7	87.2	85.4	84.4	*	85.7	1.2
223	4.0	89.6	88.5	89.7	84.4	92.0	88.9	2.8
226	4.7	92.1	94.0	93.0	95.0	95.3	93.5	1.3

*224–A5 suffered damage during handling of the specimen unrelated to testing, so the DF was not included when calculating averages and standard deviations.

Table 2. The durability factor results for Set 1 (VR AEA) sorted by percent of fresh air content.

Mix	Fresh air (ASTM C231)	Air (%) ASTM C457	Accu-mulated chord length (mm)	Voids counted	Mean chord length (mm)	Voids per m	Specific surface (mm^2/mm^3)	Spacing factor (mm)
346	3.2	4.4	101	632	0.16	280	25.2	0.21
347	3.5	4.6	104	642	0.16	280	25.0	0.22
348	2.3	4.2	95	352	0.27	154	15.0	0.37
349	4.0	4.5	101	887	0.11	388	35.3	0.15
350	4.3	5.0	114	966	0.12	423	33.8	0.15

Table 3. Air void system of Set 2 (SYN AEA) measured by linear traverse.

The freeze-thaw performance of Set 2, however, was worse than Set 1, as shown in table 4 and figures 1 through 3. Only mix 350, which had the highest air volume, lowest spacing factor, and highest specific surface area, had a DF above 80 percent. The reasons for these unexpected observations are not known. It is possible that the water reducer or the cement used had an influence on the efficiency of the air void system. Another possibility is that the air-entraining admixture contains nonionic surfactants, which could result in a lack of a hydrophobic tail oriented toward the interior of the air bubbles, preventing water intrusion as pressure develops during freezing.[6] A previous study[7] showed that the cement-alkali level may have a negative impact on the air void system and, as a consequence, on the freeze-thaw performance of concretes with synthetic air-entraining admixture.

Mix	Fresh air (%)	Durability Factor					
		A1	A2	A3	A4	average	standard deviation
348	2.3	38.3	22.2	29.4	24.9	28.7	7.1
346	3.2	66.2	46.0	56.9	53.4	55.6	8.4
347	3.5	68.0	78.3	77.1	78.8	75.6	5.1
349	4.0	82.4	62.5	50.6	66.9	65.6	13.2
350	4.3	76.6	86.2	83.1	83.5	82.3	4.1

Table 4. The durability factor results for Set 2 (SYN AEA) sorted by percentage of fresh air content.

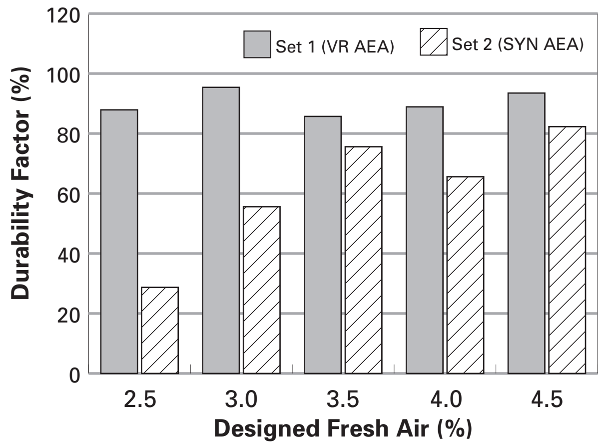

Figure 1. Comparison of the durability factor of mixes prepared with Vinsol resin air-entraining admixture (Set 1) and synthetic air-entraining admixture (Set 2).

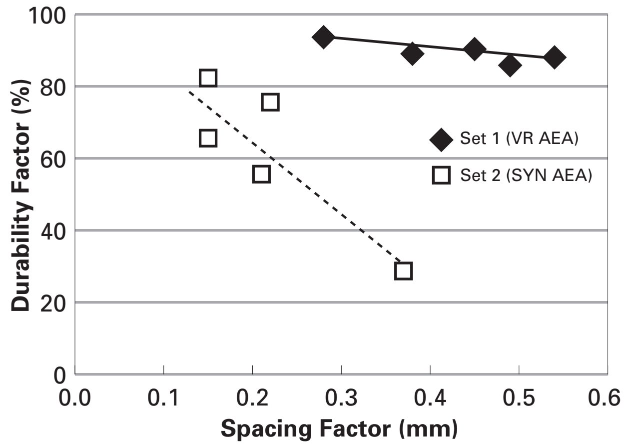

Figure 2. Relationship between the durability factor and spacing factor of mixes with Vinsol resin admixture (Set 1) or synthetic admixture (Set 2).