Deicer Scaling Resistance of Lean Concretes Containing Fly Ash

by D. Whiting

Synopsis: The resistance to deicer scaling of lean concretes containing fly ash was evaluated using ASTM C 672-84. Concretes were prepared at cement contents of 250, 305, and 335 kg/m^3. Six fly ashes were chosen for evaluation at cement replacement levels of 25 and 50 percent by mass in each of the mixtures. Specimens representative of residential flat work were prepared and cured for 1 and 7 days under moist conditions, then air-dried until initiation of testing at 35 days age. Results indicate that all mixtures containing fly ash exhibit more rapid and severe scaling than those mixtures prepared with cement alone at the same total cementitious material content. Scaling was found to increase with a decrease in the total cementitious content of the mixture and an increase in the amount of cement replaced. Data on compressive strength, and characteristics of air void systems in these concretes are also presented.

Keywords: air voids; concretes; concrete durability; curing; deicer scaling

ACI member David Whiting is a Principal Research Engineer at Construction Technology Laboratories, Inc. Skokie, Ill. Dr. Whiting has been at CTL for fifteen years, working in the area of concrete materials research. His field of activity includes concrete admixtures, corrosion of reinforcing steel, concrete permeability, durability studies, coatings for concrete, and thermal properties. He is a member of ACI Committees 201, Durability of Concrete; 212, Chemical Admixtures; and 222, Corrosion of Metals in Concrete.

BACKGROUND

The use of fly ash in the ready mixed concrete industry continues to grow, with amounts added to portland cement concrete currently close to 5 million metric tons per year (1). As utilization of this byproduct is expected to increase in the years ahead, more definitive information on performance of fly ash concretes in specific use areas is needed. Residential construction occupies a large segment of the market for ready mix concrete and represents an area where competition makes the use of large proportions of fly ash very desirable from an economic standpoint. In severe weathering regions, where applications of deicing agents are frequent, concrete used for residential driveways, walks, curbs, and other exposed flatwork must be properly air-entrained and be of sufficient quality to withstand this harsh environment. Current ACI guidelines (2) suggest a minimum strength of 24 MPa for such elements, with 28 MPa noted as giving "superior durability." In the same document, air content of 6.0 ± 1.5 percent is recommended for concrete using a 19 mm top size aggregate. While these recommendations are not overly stringent, in many cases minimum strength levels are not met. This may be due to such factors as low cementitious contents (necessitating high water-cement ratios to obtain workable concrete), retempering, and poor curing practices. As an example, a survey carried out by the Portland Cement Association in 1984 indicated that quantities of total cementitious materials ranging from 260 to 285 kg/m^3 were in common use for residential concretes in a number of areas of severe weathering in the United States. At slump levels normally employed in residential concrete construction it is extremely unlikely that water-to-cementitious material ratios fall much below 0.6. As ACI 201(3) recommends a maximum W/C ratio of 0.45 for concrete exposed to deicing agents, the much higher W/C ratios typical of these lean mixtures have the potential for a reduction in durability for these concretes.

The increasing use of fly ash in lean residential mixtures raises questions as to its effect on durability in severe exposure conditions. This may be especially true for lean concretes exposed to deicing agents, where a number of studies have indicated their performance to be less than satisfactory. In early studies at the Bureau of Public Roads, Grieb, et. al. (4) reported on tests conducted on air-entrained concretes made with four Class F fly ashes at cementitious contents of approximately 320 kg/m^3 and W/C+F ratio of 0.53. After three winters of exposure to calcium chloride deicer applications, concretes containing fly ash exhibited decreased resistance to scaling as compared with controls without fly ash. Larson (5) related degree of surface scaling to carbon content of the fly ash used. Klieger and Perenchio (6) in tests of Type IP cement concretes, found greatly increased scaling in concretes prepared at cementitious contents of 225 kg/m^3 and W/C+F ratios of 0.53 when compared with control mixtures prepared with Type I cement for equivalent mix designs. In a later study by the same authors (7), cementitious contents were increased to 325 kg/m^3 and W/C+F ratios were lowered to approximately 0.42, performance of all concretes was greatly improved and concretes containing fly ash exhibited only slightly more scaling than control concretes. In a later series of tests reported by Gebler and Klieger (8), ten fly ash concretes were evaluated at cementitious contents of 300 kg/m^3 and W/C+F ratios of from 0.40 to 0.45. Performance of control and fly ash concretes were essentially equivalent.

Although results of these studies represent a rather limited data base, it is clear that when low W/C+F ratios, proper air entrainment, and proper curing are employed, satisfactory performance can be obtained from fly ash concrete used in deicing environments. Problems regarding durability of residential concretes may be related to high W/C+F ratios and improper curing, which unfortunately often occur on small residential jobs. Moist curing (or use of curing compounds) is rarely encountered. Often, the practice is merely to notify the homeowner that the concrete needs to be "kept wet". However, the reasons for this are not fully appreciated by the owner, and in most cases curing is minimal at best. A preliminary study reported by the Portland Cement Association (9) indicated that poorly cured lean concretes containing 25% fly ash replacements were more susceptible to scaling than concretes of equivalent mix properties prepared without fly ash, although performance of none of these concretes could be considered adequate. More data concerning effects of curing, mix designs, and compositions of fly ash on durability of residential concrete are needed so the reasons for susceptibility of such mixtures to deicer scaling may be more fully understood.

MATERIALS

Cement

The cement used in this study was a blend of three Type I cements. Calculated potential compound compositions and other pertinent data are presented in Table 1.

Fly Ashes

Six different fly ashes commercially available for use in concrete were chosen for this study. The fly ashes selected represent a wide range of chemical and physical properties, and were obtained from sources distributed over a broad geographical area within North America. Chemical properties of these ashes are listed in Table 2 and physical properties are listed in Table 3. The letter designations in these tables correspond to those listed by Gebler and Klieger (8) in a previous study. All fly ashes in the current study with the exception of fly ash D were procured from sources used by Gebler and Klieger in their investigation. Classification into "C" or "F" ashes followed the procedure used by Gebler and Klieger.

Aggregates

Natural sand from Elgin, Illinois, consisting of both carbonate (dolomitic) and siliceous particles, and crushed dolomite from Thornton, Illinois were used in all the concretes. Coarse aggregate was dry-sieved and recombined to obtain the desired gradation. Pertinent data for aggregates are given in Table 4.

Air-Entraining Admixture

Neutralized Vinsol resin in 2.27% aqueous solution was used as the air-entraining admixture.

CONCRETE MIXTURES AND MIXING PROCEDURES

Concrete Mixture Proportions

Test concretes were proportioned for nominal cementitious materials contents of 250, 305, and 335 kg/m^3. The mixes included control (no fly ash), and fly ash concretes where fly ash was used to replace 25 percent by mass of cement and 50 percent by mass of cement. Mix designations, cement, and fly ash contents are listed in Table 5. Sufficient water was added to achieve a target slump of 125 ± 25 mm. Air content was 6 ± 1 percent. Actual mix characteristics for each concrete batch are given in Appendix A.

Mixing Procedure

Coarse aggregate was weighed and then inundated with water in a closed container 18 to 24 hours prior to mixing. Immediately before mixing, a measured amount of water was drained from the container such that the water remaining (which was subsequently placed into a second container) would satisfy the absorption of the aggregate plus the net amount of water required for the batch. Fine aggregate was weighed and batched in a moist condition. All mixing was carried out in a countercurrent open pan mixer. Charging sequence was coarse aggregate, cement (and fly ash if used), sand, and the remainder of the mixing water. Concrete was initially mixed for three minutes, the air-entraining admixture (NVR) being added after the batch had obtained a homogenous appearance. The concrete was then allowed to rest for three minutes, then mixed for a final two minutes.

SPECIMEN PREPARATION, CURING, AND TESTING

Specimens were prepared for tests of resistance to deicer scaling (ASTM Designation C 672-84, "Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals"), compressive strength (ASTM Designation C 39-86 "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens"), and analysis of air-void systems (ASTM Designation C 457-82a, "Standard Practice for Microscopical Determination of Air-void Content and Parameters of the Air-Void System in Concrete"). Specimen type, dimensions, and associated test procedures were:

- Resistance to Deicer Scaling - 75x152x380 mm slabs cast in steel molds.
- Compressive Strength - 100x200 mm cylinders cast in plastic molds
- Examination of Air Void Systems - 75x75x285 mm prisms cast in steel molds

All specimens were consolidated using hand-rodding and finished using a wooden float. Specimens were covered with moist burlap and plastic sheeting for 18 to 24 hours after casting. At the end of this time period one set of specimens from each batch was placed in a room maintained at 23 ± 1.5°C and 50 ± 5% R.H. A second set of specimens was placed into a fog room at 23 ± 1.5°C immediately after removal of the moist burlap. After 7 days of moist curing the second set of specimens from each batch was placed in the air-dry environment along with the first set.

At the age of 35 days the 100 mm x 200mm cylindrical specimens were tested for compressive strength. The 75x152x380 mm slab specimens were placed under test for deicer scaling at the same time. Briefly, in this method the specimens are ponded with a four percent solution of calcium chloride and frozen once daily to a temperature of -18 ± 1.7°C for a period of 18 hours. Specimens are then thawed to a temperature of 23 ± 1.7°C for a period of 6 to 8 hours. The chloride solution is flushed from the slabs and replaced every 5 cycles. The amount of scaling was determined visually at intervals and assigned numerical rankings as follows:

0 = no scale
1 = slight scale
3 = moderate scale
4 = moderate-to-heavy scale

2 = slight-to-moderate scale   5 = heavy scale

Although ASTM C 672 suggests that 50 cycles may be sufficient to evaluate a surface or surface treatment, Klieger (10) notes that, based on extensive laboratory experience, specimens that pass 100 cycles of this test with no more than slight scaling normally indicate excellent resistance to surface scaling under field conditions. A test period of 150 cycles was chosen for the present study to simulate the severe exposure that occurs on heavily salted flatwork in many northern climates. Examination of concrete air void systems was carried out using equipment and techniques described in ASTM Designation C 457-82a. Each 75x75x285 mm prism was sawn lengthwise to obtain a 25x75x230 mm slice from the central portion of the prism. One 75x230 mm face was then lapped to a smooth finish suitable for microscopical investigation.

RESULTS AND DISCUSSION

Resistance to Deicer Scaling

After the first 15 cycles of test, data were compiled and are presented in bar chart format in Figures 1 (Moist cure) and 2 (Air Cure). It is immediately apparent that all concretes prepared with fly ash exhibit a greater rate of early scaling than do companion concretes prepared without fly ash. In addition, there are significant differences in behavior between the various fly ashes used. For instance, fly ashes F and J exhibit heavy scaling very early in the test, while fly ash E (at 25 percent replacement) shows only slight amounts of scaling after 15 cycles. There appear to be no consistent trends with regards to effects of curing on scaling at 15 cycles. The data were compared by cumulating the numerical differences in ratings between companion sets of specimens differing only in type of curing. Using this procedure, total cumulative difference for moist versus air curing at 25 percent replacement was -3 units, and -4 units at 50 percent replacement. Considering that each of these sets represents 21 comparisons, the average difference is negligible. A similar procedure was used to compare effect of replacement level. For both moist and air cured sets, total cumulative difference between 25 and 50 percent replacement was -9 units. This represents an average difference of 1/2 unit for each treatment, and considering the relative subjectivity of this test, is not considered significant.

Results after 150 cycles of test are shown in Figures 3 (moist cure) and 4 (air cure). Non-fly ash concretes exhibit only slight and slight-to-moderate levels of scaling. Performance of the majority of fly ash concretes is considered poor, especially at the 50 percent replacement level. Again, differences exist between the various fly ashes. Fly ash E performs relatively well, at least at the 25 percent replacement level. Performance of the other fly ashes is worse, especially at the lowest level of cementitious material (250 kg/m^3). Of interest is the fact that, in most cases, the leanest control mix (250 kg/m^3) exhibited levels of scaling equivalent to (or even less than) the richest (335 kg/m^3) fly ash mixtures. This was most apparent for air-cured mixtures at 50 percent replacement.

As was the case at 15 cycles, there was little difference between behavior of air and moist cured specimens at 150 cycles. Cumulative differences between moist and air cured specimens averaged -8 units, relatively insignificant over the 21 treatments at each replacement level. Effect of replacement level itself, however, was more pronounced. Cumulative difference for both moist and air cured sets was -30 units, indicating significantly better behavior at the lower (25 percent) replacement level.

As a further aid in interpretation of the deicer scaling test data, the number of cycles to "failure" (defined as a scale rating of 5) are reported in Table 6. None of the control mixtures exhibited failure within the 150 cycle test period. In those mixtures where fly ashes were used to replace 25 percent of the cement, failures were confined to the mixtures having a total of 250 kg/m^3 of cementitious material. In this set, mixtures prepared with fly ash J seemed especially prone to early deterioration.

The majority of failures was associated with mixtures where fly ashes were used to replace 50 percent of the mass of cement. Earliest failures occurred in the set having lowest total cementitious content (A2) followed by B2 and C2. Again, fly ash J appeared to be most susceptible to early failure, especially for sets A2 and B2.

Characteristics of Air Void Systems in Hardened Concretes

Linear traverse analyses were carried out on all control concretes and specimens prepared from 3 of the six fly ashes used in this study. Fly ashes E, J, and F were selected to represent a range of behavior as indicated by results of deicer scaling tests (see previous discussion). Characteristics of air void systems are listed in Table 7. On reviewing these results it is worthwhile to refer to current ACI recommendations (11) pertaining to air void characteristics. Recommended values are: a spacing factor less than 0.2 mm, specific surface greater than 23.6 mm^2/mm^3, and the number of air voids per lineal millimeter significantly greater than 0.0394 times the air content of the hardened concrete. Examination of the values in Table 7 indicate, that for controls and mixtures prepared using fly ashes E and J, those recommendations are met with only two exceptions. For fly ash F, however, specific surfaces were generally lower, and spacing factors exceeded 0.2 mm in two instances. The behavior of mixtures with respect to deicer scaling (previously discussed) is only partially explained by air void characteristics. For the most part, characteristics of control specimens were no better than those of most of the fly ash concretes, however, as noted earlier, performance of control specimens was much better. Within the fly ash sets, fly ash E, which showed a somewhat better performance than did the other fly ashes, exhibited a lower average spacing factor. This lower average is most likely attributable to the higher levels of air content retained in the concrete for fly ash E mixtures. Gebler and Klieger (12) noted a tendency towards increased air loss in fly ash concretes having a high demand for air-entraining agent. Figure 5 shows the relationship between dosage of air-entraining agent and scaling resistance at 50 cycles. For the most part, high dosage requirements are associated with high levels of scaling. Low dosage requirements, however, do not necessarily ensure that scaling will be minimized.

Compressive Strength and W/C Ratio Relationship

There are some data that indicate freeze-thaw durability (and resistance to deicer scaling), may, in a general sense, be related to compressive strength of the concrete at the time the concrete is first exposed to freezing. Mather (13) found a general relationship between compressive strength of concrete and durability factor. In Mather's studies, durability factors above 80 were, for the most part, associated with concretes having compressive strengths in excess of about 26MPa. Klieger (10) states, "... the minimum curing period prior to permitting the use of de-icers was indicated by the development of a compressive strength level of about 4,000 psi (27.5 MPa)."

Data developed in the current study do not point to any particular critical strength level as being indicative of satisfactory durability. Compressive strengths at 35 days of age (immediately prior to initiation of C-672 testing) are given in Table 8. In many instances, strengths in excess of 25 MPa were associated with rather high scale ratings. As an example, in the moist cured series, all of the concretes prepared with fly ash F had strength equal to or exceeding 30 MPa at 35 days of age, yet scale ratings ranged from 3 to 5 for these concretes. Likewise, scale ratings of 3 were encountered for other fly ash concretes prepared at 350 kg/m^3 of cementitious material at 25 percent replacement level, even though strengths exceeded 30 MPa.

More significant relationships were obtained between W/C ratios and scale ratings, as illustrated in Figure 6 after 50 cycles of test. These plots are in terms of the true water-to-cement ratio, and do not include the fly ash component of the matrix. Based on Figure 6, one can infer that, at a W/C exceeding 0.80, scale resistance begins to deteriorate considerably. Best resistance is exhibited by concretes having W/C ratios considerably less than 0.60. Behavior in the region close to 0.60 is variable, depending on the particular fly ash used. These results are in substantial agreement with those reported by the USBR (14) in earlier studies, where a pronounced effect of W/C ratio on freeze-thaw durability was found. Likewise, Sturrup, et al (15) reported on long-term studies of air-entrained fly ash concretes in outdoor exposure, where scaling was found to increase with increasing fly ash content (and a corresponding increase in W/C ratio).

CONCLUSIONS

Based on results of this laboratory investigation, the following conclusions may be drawn:

1. To obtain satisfactory resistance to deicer scaling, the water-to-cement ratio (W/C) of concrete should be kept as low as practicable. Use of concretes having low contents of total cementitious material, or high replacement levels of fly ash can result in high values of W/C ratio and poor durability.
2. In some instances, relatively good resistance to deicer scaling with fly ash concrete is possible if total cementitous content is fairly high, the fly ash chosen exhibits a relatively low demand for air-entraining agent, and replacement level is limited to 25 percent by mass of cement.
3. At high replacement levels of 50 percent by mass of cement, resistance to deicer scaling was generally unsatisfactory, irrespective of the particular fly ash or mix design employed.

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TABLE 1--COMPOSITION OF CEMENT BLEND

Item	Percent
C_3S	60
C_2S	15
C_3A	8
C_4AF	9
Alkali (As Na_2O)	0.6
SO_3	2.6
MgO	2.1
Loss on Ignition	1.3
Insoluble Residue	0.1
Specific Gravity	3.12
Blaine Fineness (m^2/kg)	364

TABLE 2--CHEMICAL COMPOSITION OF FLY ASH

Fly ash identification	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Total SiO_2+ Al_2O_3+ Fe_2O_3 (%)	SO_3 (%)	MgO (%)	CaO (%)	Loss on Ignition (%)	Na_2O (%)	K_2O (%)	Total akalies as Na_2O[a] (%)	Moisture content (%)	Classification of fly ash[b]
A	60.94	15.32	5.70	81.96	0.64	2.93	9.96	0.35	3.82	0.73	4.30	0.05	C
D	52.05	27.22	9.03	88.30	0.13	1.61	2.84	3.23	0.24	2.91	2.15	0.16	F
E	57.93	22.86	5.66	86.45	0.55	1.91	7.13	0.32	2.85	1.25	3.67	0.09	F
F	27.75	15.76	7.78	51.29	8.22	6.66	22.95	0.38	7.91	0.72	8.38	0.09	C
G	47.59	21.36	3.92	72.87	0.72	3.53	13.82	2.07	5.42	0.91	6.02	0.18	C
J	48.71	19.98	15.26	83.95	0.67	1.31	5.67	5.00	0.73	2.53	2.39	0.22	F

(a) Percent total alkalies calculated as follows - $Na_2O + 0.658\ K_2O$.

(b) Class of fly ash established based on total lime content, i.e., fly ashes containing at least 10% CaO are considered Class C fly ashes, those less than 10% are considered Class F fly ashes.

TABLE 3--SELECTED PHYSICAL PROPERTIES OF FLY ASH

Fly ash identification	Retained on 45µm sieve[a] (%)	Pozzolanic activity index[b] with cement	Water requirement[c] (%)	Autoclave expansion[d] (%)	Specific gravity[c]
A	16.19	98	94	0.10	2.46
D	18.06	92	99	0.02	2.34
E	21.26	96	96	0.04	2.28
F	9.81	105	93	0.14	2.84
G	29.58	83	101	0.06	2.33
J	14.70	101	100	0.05	2.54

(a) Tested in accordance with ASTM C 430-83.

(b) Tested in accordance with ASTM C 311-85, Sections 29 to 32.

(c) Tested in accordance with ASTM C 311-85, Section 33.

(d) Tested in accordance with ASTM C 311-85, Section 25.

(e) Tested in accordance with ASTM C 311-85, Section 20.

TABLE 4--AGGREGATE PROPERTIES

Elgin, Illinois, Fine Aggregate

Grading - % Retained on Sieve Size Indicated

4.75 mm	2.36 mm	1.18 mm	600µm	300µm	150µ
1	14	30	52	79	96

Fineness Modulus	Bulk Specific Gravity-SSD	Absorption -% by mass
2.72	2.68	1.2

Thornton, Illinois, Coarse Aggregate

Grading - % Retained on Sieve Size Indicated			Bulk Specific Gravity-SSD	Absorption -% by mass
19 mm	9.5 mm	4.75 mm		
0	50	100	2.72	1.8

TABLE 5--NOMINAL CONCRETE MIX DESIGNS

Series	Cement Content (kg/m^3)	Fly Ash Content (kg/m^3)	Fly Ash Replacement Level (%)
A	250	0	0
A1	188	63	25
A2	125	125	50
B	305	0	0
B1	230	77	25
B2	153	153	50
C	335	0	0
C1	251	84	25
C2	167	167	50

TABLE 6--CYCLES TO FAILURE[1]

Mixture[2]	Cure[3]	Fly Ash A	Fly Ash D	Fly Ash E	Fly Ash F	Fly Ash G	Fly Ash J	None
A	A	-	-	-	-	-	-	N/F
	M	-	-	-	-	-	-	N/F
A1	A	50	N/F	N/F	N/F	75	15	-
	M	N/F	N/F	N/F	15	N/F	15	-
A2	A	50	50	25	15	20	10	-
	M	50	20	100	15	70	10	-
B	A	-	-	-	-	-	-	N/F
	M	-	-	-	-	-	-	N/F
B1	A	N/F	N/F	N/F	N/F	N/F	N/F	-
	M	N/F	N/F	N/F	N/F	N/F	N/F	-
B2	A	150	100	75	125	150	25	-
	M	125	25	100	75	150	50	-
C	A	-	-	-	-	-	-	N/F
	M	-	-	-	-	-	-	N/F
C1	A	N/F	N/F	N/F	N/F	N/F	N/F	-
	M	N/F	N/F	N/F	N/F	N/F	N/F	-
C2	A	50	75	50	50	75	N/F	-
	M	N/F	75	N/F	50	N/F	N/F	-

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[1] Failure defined as scale rating of 5.

[2] See Table 5 for mixture designations.

[3] A = 1 day under moist burlap, 34 days at 23 ± 1.5°C and 50 ± 5% R.H.

M = 1 day under moist burlap, 6 days at 23 ± 1.5°C and 100% R.H., 28 days at 23 ± 1.5°C and 50 ± 5% R.H.

N/F = No failure up to 150 cycles of test.

TABLE 7--CHARACTERISTICS OF AIR CONTENT IN CONCRETES

Fly Ash	Cementitious Material Content (kg/m^3)	Fly Ash Content (%)	Air Content (%)		Voids/mm	Specific Surface (mm^2/mm^3)	Spacing Factor (mm)
			Fresh	Hardened			
None	250	0	6.2	7.6	0.38	20.2	0.16
	305	0	6.6	6.3	0.38	24.3	0.18
	335	0	6.5	5.9	0.44	30.1	0.15
		AV =	6.4	6.6	0.38	24.8	0.16
E	250	25	6.4	8.0	0.42	21.0	0.15
		50	6.8	7.8	0.51	26.1	0.12
	305	25	5.9	6.6	0.41	24.5	0.17
		50	6.3	8.6	0.65	30.2	0.10
	335	25	6.9	6.7	0.56	33.2	0.13
		50	6.5	6.0	0.52	35.0	0.13
		AV =	6.5	7.3	0.52	28.3	0.13
J	250	25	6.3	5.2	0.33	25.0	0.18
		50	6.8	6.3	0.38	23.8	0.17
	305	25	6.1	4.8	0.37	31.4	0.16
		50	6.2	4.5	0.39	34.6	0.15
	335	25	6.5	5.1	0.41	32.8	0.15
		50	6.6	4.5	0.44	39.3	0.13
		AV =	6.4	5.1	0.39	31.1	0.16
F	250	25	5.6	4.7	0.23	19.4	0.24
		50	6.5	5.4	0.31	23.5	0.19
	305	25	5.7	5.5	0.29	21.2	0.21
		50	6.9	5.8	0.41	28.2	0.16
	335	25	6.5	6.7	0.39	23.5	0.18
		50	5.8	4.6	0.34	29.3	0.17
		AV =	6.2	5.5	0.33	24.2	0.19

TABLE 8--COMPRESSIVE STRENGTH (MPa) AT 35 DAYS AGE[1]

Cementitious Content (kg/m^3)	Cement Replacement Level (%)	Initial[a] Cure	None	Fly Ash A	D	E	F	G	J
250	0	A	20.3	-	-	-	-	-	-
		M	27.4	-	-	-	-	-	-
	25	A	-	17.1	14.9	15.7	24.8	17.6	16.3
		M	-	24.1	18.7	24.5	30.0	23.0	23.4
	50	A	-	13.0	7.4	9.4	27.0	11.7	8.7
		M	-	20.8	12.4	14.4	29.9	18.3	15.2
305	0	A	29.2	-	-	-	-	-	-
		M	36.1	-	-	-	-	-	-
	25	A	-	25.5	23.2	22.3	32.7	22.8	28.7
		M	-	34.1	32.2	31.1	35.7	32.4	38.8
	50	A	-	19.0	9.9	11.8	36.2	17.4	12.9
		M	-	27.6	16.6	17.6	39.6	26.9	19.8
335	0	A	31.4	-	-	-	-	-	-
		M	38.9	-	-	-	-	-	-
	25	A	-	27.2	24.3	20.9	35.2	28.5	24.8
		M	-	35.6	33.1	29.5	37.2	38.6	33.3
	50	A	-	21.2	11.9	15.0	40.3	18.8	14.0
		M	-	31.7	18.7	23.2	42.7	28.2	22.3

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[1] Each result represents mean of three 100 x 200 mm cylinders.

[a] Initial Cures M = 7 days moist, then to air at 23 ± 1.5°C and 50 ± 5% R.H.
A = 1 day moist, then to air at 23 ± 1.5°C and 50 ± 5% R.H.

APPENDIX A--CONCRETE MIXTURE CHARACTERISTICS

Series[1]	Fly Ash	AEA (mL/kg) of cementitious material	Water-cement ratio	Water-cement + fly ash ratio	Slump (mm)	Initial plastic concrete air content (%)
A	None	3.04	0.62	0.62	142	6.2
A1	A	5.90	0.79	0.59	112	6.1
	D	9.02	0.82	0.61	127	6.0
	E	5.89	0.79	0.59	137	6.4
	F	3.96	0.77	0.58	117	5.6
	G	12.88	0.79	0.59	132	5.8
	J	18.86	0.80	0.60	130	6.3
A2	A	12.06	1.10	0.55	107	6.2
	D	24.12	1.18	0.59	152	6.3
	E	16.08	1.08	0.54	140	6.8
	F	8.04	1.06	0.53	119	6.5
	G	35.38	1.09	0.54	107	7.0
	J	57.89	1.14	0.57	102	6.8
B	None	3.38	0.52	0.52	142	6.6
B1	A	6.58	0.66	0.50	129	6.6
	D	10.09	0.69	0.52	102	5.8
	E	6.76	0.65	0.48	145	5.9
	F	4.39	0.64	0.48	130	5.7
	G	14.47	0.65	0.49	119	7.0
	J	22.14	0.68	0.51	102	6.1
B2	A	11.84	0.89	0.45	102	6.1
	D	26.31	1.00	0.50	137	6.6
	E	19.76	0.89	0.45	142	6.3
	F	10.52	0.89	0.44	112	6.9
	G	32.89	0.91	0.45	114	5.7
	J	56.02	1.01	0.50	124	6.2
C	None	3.57	0.49	0.49	117	6.5
C1	A	6.36	0.62	0.47	142	7.0
	D	10.39	0.63	0.48	102	6.3
	E	9.65	0.60	0.45	112	6.9
	F	6.43	0.60	0.45	135	6.5
	G	11.54	0.62	0.46	140	5.9
	J	21.56	0.62	0.46	117	6.5
C2	A	12.06	0.83	0.42	137	5.7
	D	25.33	0.95	0.48	150	6.2
	E	16.89	0.83	0.42	107	6.5
	F	11.46	0.83	0.41	137	5.8
	G	31.96	0.89	0.44	127	6.1
	J	60.30	0.93	0.47	109	6.6

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[1] See Table 5 for mixture designations.

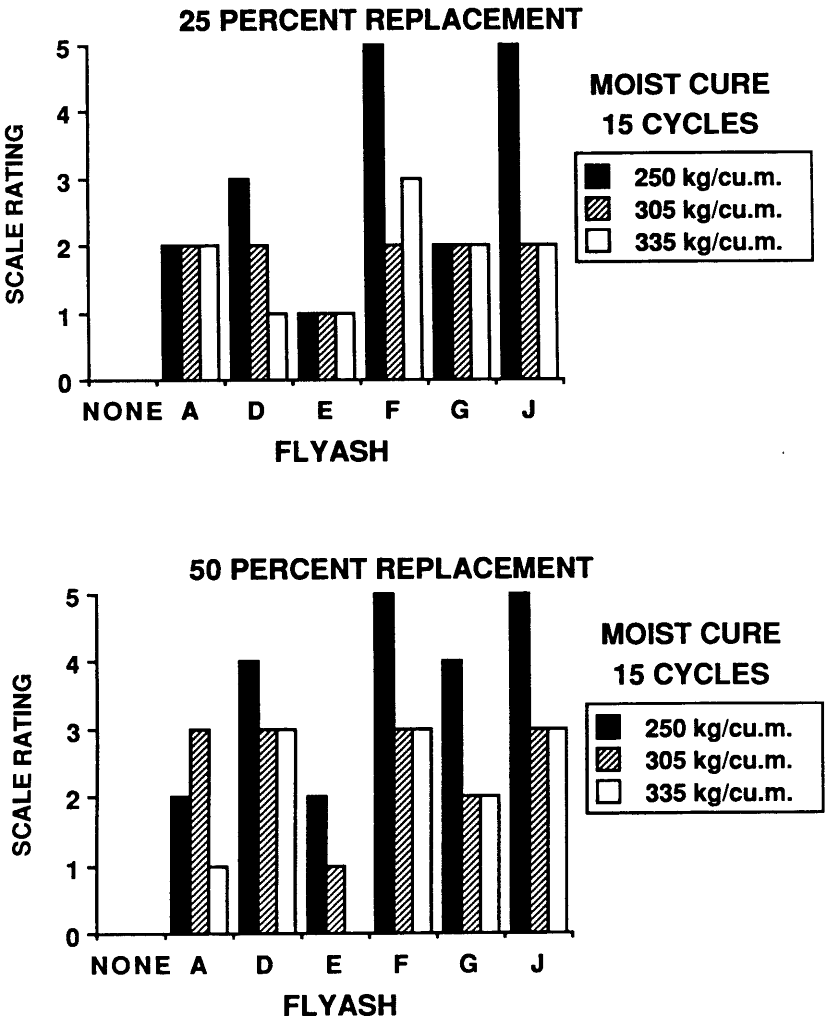


Fig. 1--Deicer scale ratings for moist-cured concretes after 15 cycles of test

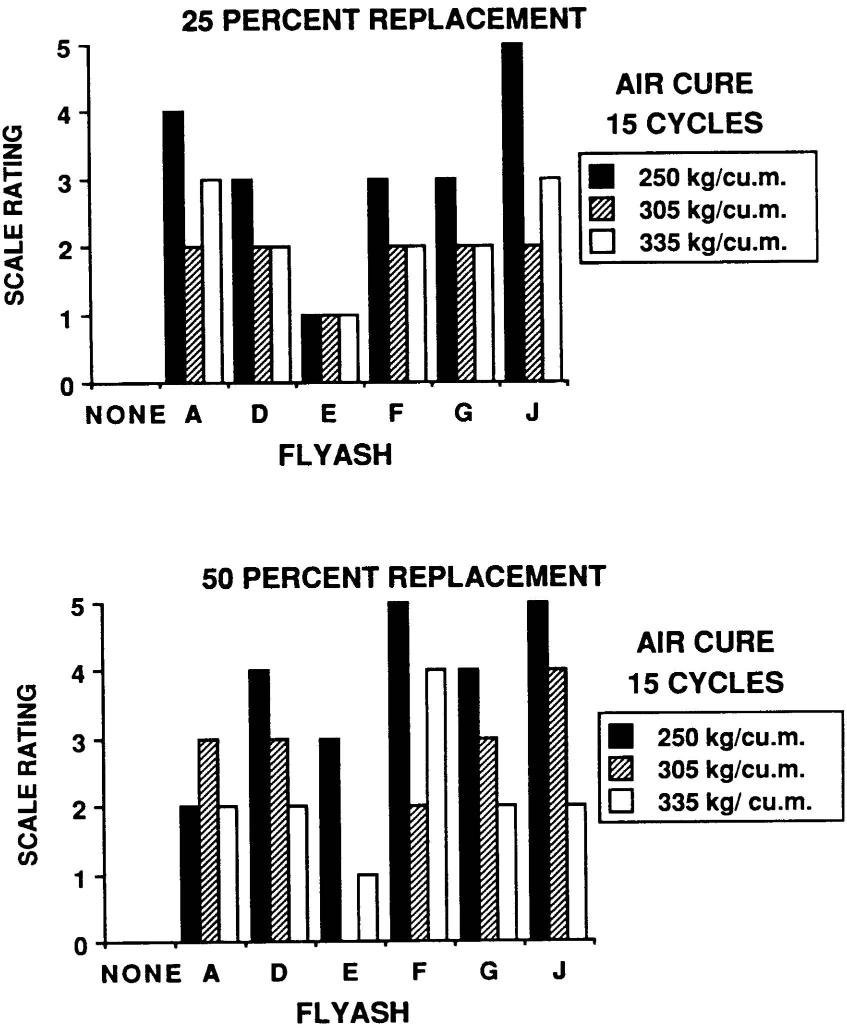


Fig. 2--Deicer scale ratings for air-cured concretes after 15 cycles of test

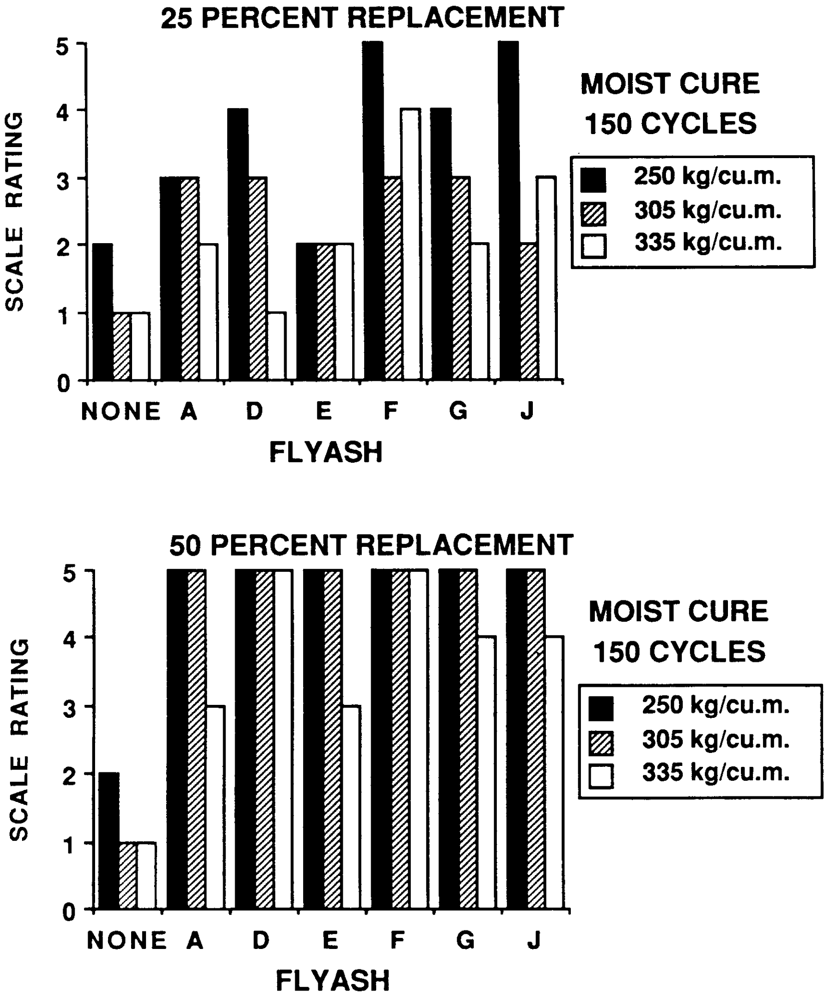


Fig. 3--Deicer scale ratings for moist-cured concretes after 150 cycles of test

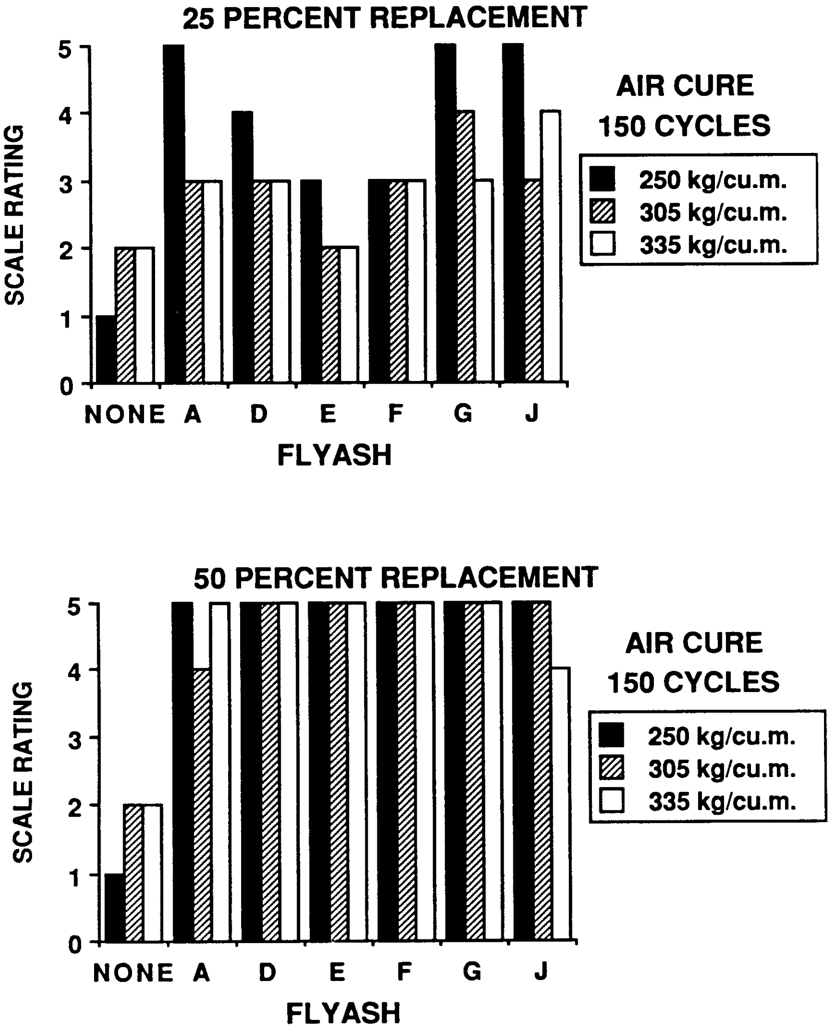
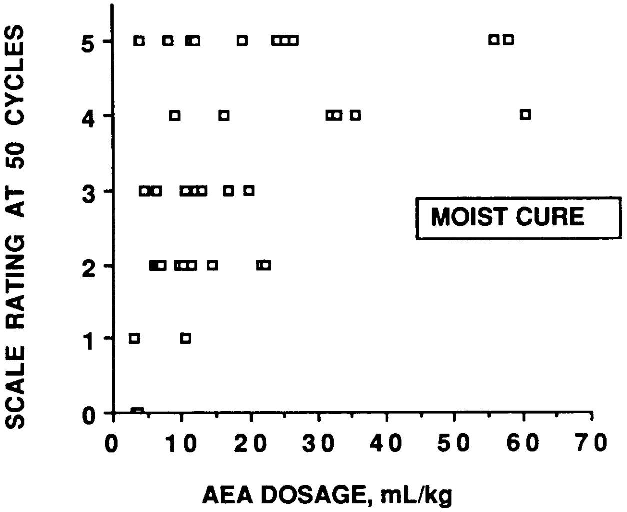


Fig. 4--Deicer scale ratings for air-cured concretes after 150 cycles of test



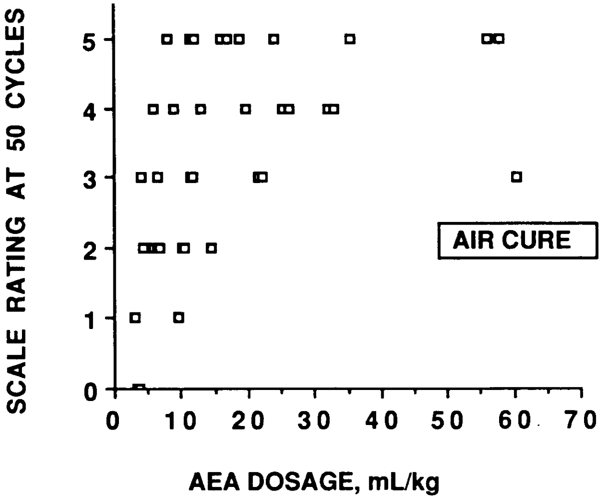


Fig. 5--Relationship of dosage of air-entraining agent to scale rating after 50 cycles of test

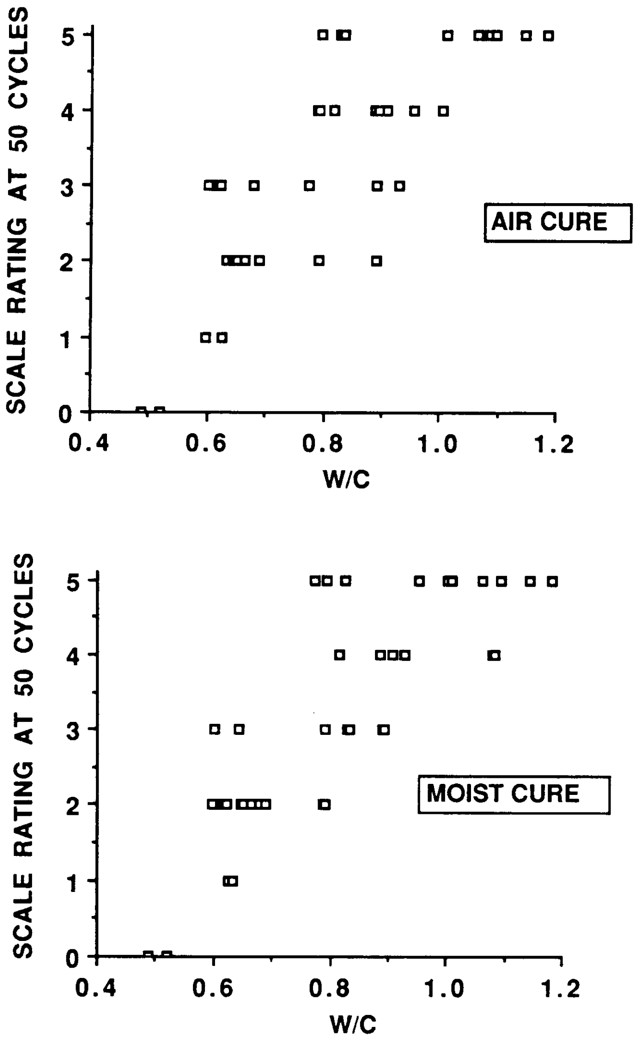


Fig. 6--Relationship of water-to-cement ratio (w/c) to scale rating after 50 cycles of test