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ABSTRACT

This research was conducted to establish the effects of fly ash and foundry sand on strength and durability of concrete. Two series (Series 1 and Series 2) of experiments were performed. All concrete mixtures were produced for and at the production plant of an architectural precast concrete products producer. Concrete mixtures produced were used in manufacture of precast concrete panels. For Series 1, one non-air-entrained control mixture with 20% Class C fly ash (FA) and no used foundry sand (UFS) was proportioned. Additionally, three non-air entrained concrete mixtures were proportioned with used foundry sand content of 15%, 20%, and 45% as a replacement of concrete sand compared to the reference. For Series 2, two air-entrained reference mixtures, with about 25% Class C fly ash, were proportioned without foundry sand. Additional air-entrained mixtures were proportioned to contain used foundry sand as a replacement of regular concrete sand by 15, 20, and 45 percent. Concrete test specimens were evaluated for compressive strength, abrasion resistance, salt scaling resistance, freezing and thawing resistance, and chloride-ion penetration resistance. Based on strength and durability evaluations, it was concluded that both non-air and air-entrained concrete mixtures developed in this investigation are appropriate for manufacture of high-quality, architectural precast concrete using used foundry sand and fly ash.

INTRODUCTION

Over 7 million tonnes (8 million tons) of foundry by-products including sand and slag were produced in the USA in 1996. Used (or spent) foundry sand was the major component of these by-products. Wisconsin alone produced in excess of 550,000 tonnes/year (600,000 tons/year) of used foundry sand in 1996. Majority of the foundry sand generated in Wisconsin and elsewhere are landfilled at high disposal costs and future environment liability to the foundries. Landfilling of foundry sand not only causes significant economic burden to the foundries but also causes a lost opportunity for saving energy and resources. To help solve this problem, Naik and his associates [1-7] started an extensive investigation to find beneficial applications of foundry by-products in cement-based materials. Based upon the results of these investigations, they reported that used foundry sand can be used in the manufacture of cement-based materials with fly ash for several applications including Controlled Low Strength Materials (CLSM), masonry products, and concrete for structural and other applications. Other investigators[8-10] have also supported the use of used foundry sand in construction materials.

Utilization of used foundry sand in concrete can consume large-volume of used foundry sand generated in the USA. However, prior to wide-spread commercial use of concrete containing used foundry sand, long-term strength and durability data are needed for developing material specifications for potential users. There is a lack of data on long-term strength and durability of such concrete systems. Therefore, this research was primarily focused toward determining strength and durability of concrete made with used foundry sand. Fly ash was used to improve strength and durability of such concrete mixtures.

RESEARCH SIGNIFICANCE

This investigation was directed toward obtaining strength and durability data on concrete incorporating used foundry sands with fly ash. The results of this investigation were used to establish material specification for concrete containing used foundry sand for architectural precast concrete panels and other applications. This should lead to increased utilization of used foundry sand in manufacture of concrete for various applications.

EXPERIMENTAL PROGRAM

An experimental program was designed to evaluate the effects of used foundry sand and fly ash on long-term strength and durability of concrete. Pervious investigations by Naik et al. and others [2-3] have established that compressive strength may decrease when used foundry is added to portland cement concrete mixtures. Therefore, in order to compensate for the potential decrease in compressive strength, Class C fly ash was added to all concrete mixtures proportioned in this investigation. Two series of experiments were planned. Series 1 experiments were directed toward evaluating the performance of non-air-entrained concrete while Series 2 experiments were conducted to evaluate performance of air-entrained concrete incorporating used foundry sand, used as a replacement of regular concrete sand, and fly ash as a partial substitute for cement.

Materials

Concrete constituents materials such as portland cement, fly ash, used foundry sand, and normal coarse and fine concrete aggregates, were used in this work. Fly ash was characterized for physical and chemical properties. The chemical properties included determination of oxides, elements, and mineralogical components of fly ash. The following physical properties tests: fineness (ASTM C 430), strength activity index with cement (ASTM C 109), water requirement (ASTM C 109), autoclave expansion (ASTM C 151), and specific gravity (ASTM C 188) were performed. Cement was tested per ASTM C 150 requirements for air content (ASTM C 185), fineness (ASTM C 204), autoclave expansion (ASTM C 151), compressive strength (ASTM C 109), time of setting (ASTM C 191), and specific gravity (ASTM C 188). Fine and coarse aggregates, including used foundry sand, were tested per ASTM C 33 requirements for the following physical properties: unit weight (ASTM C 29), specific gravity (ASTM C 128), absorption (ASTM C 128), fineness (ASTM C 136), material finer than #200 sieve (ASTM C 117), organic impurities (ASTM C 40), and soundness (ASTM C 88).

Micrographs of the fly ash and sand samples were obtained using a Scanning Electron Microscope (SEM) for studying morphologies of the particles. Fly ash, cement, and foundry sand were analyzed for elemental concentrations using Instrumental Neutron Activation Analysis. X-ray diffraction analysis was also conducted on fly ash and cement samples. The detailed results and analysis of the physical and chemical properties of the cement, fly ash, and used foundry sand used in this project are reported elsewhere [1]. The micrographs of used foundry sand exhibited uniform particles size, which were, finer and more rounded in shape than that for the normal concrete sand. The micrographs of fly ash samples showed heterogeneous mixture of predominantly spherical particles of varying sizes.

The predominant phases in cement samples were dicalcium silicate (C_2S), tricalcium aluminate (C_3A), tricalcium silicate (C_3S), tetracalcium aluminoferrite (C_4AF), and periclase. The crystalline phases present in the fly ash samples were quartz (SiO_2), tricalcium aluminate (C_3A), and anhydrite gypsum ($CaSO_4$). The values of amorphous materials were 28.5% in cement and 90.2% in fly ash samples.

The fly ash met the ASTM C 618 requirements for Class C fly ash. The cement conformed to the requirements ASTM C 150 specification for Type I cement. Both the regular coarse and fine aggregates met the ASTM C 33 requirements (Tables 1 and 2). The used foundry sand had finer particles than the regular concrete sand. The used foundry sand did not meet the ASTM C 33 gradation requirements for fine aggregates (Fig. 1).

MIXTURE PROPORTIONS

For Series 1 experiments, one non-air-entrained reference concrete mixture was proportioned without used foundry sand and three other mixtures having used foundry sand in the amounts of 15%, 20%, and 45% as a replacement of regular concrete sand. The reference mixture contained 20% fly ash, while the other mixtures were proportioned to have an additional 10 to 15% fly ash content. The total fly ash content of the used foundry sand mixtures was between 29 to 34% of total cementitious materials (Table 3). These mixtures were proportioned to maintain a practical value of slump in the range of approximately 150 ± 50 mm (6 ± 2 in.). For Series 2 experiments, two air-entrained reference mixtures without used foundry sand, and three other air-entrained mixtures having used foundry sand in the amounts of 15%, 20%, and 45% as a replacement of fine aggregate at corresponding fly ash levels of 34%, 37%, and 40% of total cementitious materials. The two control mixtures included Class C fly ash contents of about 25% of total cementitious materials (Table 4). Slump for these mixtures was specified to be 125 ± 50 mm (5 ± 2 in.). All concrete mixing was done at the Advance Caststone Company's batch plant in accordance with ASTM C 94.

SPECIMEN PREPARATION AND TESTING

Fresh concrete properties such as air content (ASTM C 231), workability (ASTM C 143), unit weight (ASTM C 138), and concrete and air temperature (ASTM C 1064) were measured. All test specimens were cast in accordance with ASTM C 31. These specimens were typically cured for one day in their molds at about 20° C (68° F) at the Advance Cast Stone Company plant. They were then brought to the UWM-CBU lab for further curing and testing. For lab curing, these specimens were demolded and placed in a standard moist-curing room maintained at about 100% R.H. and 22° C (73° F). Each non-air-entrained concrete specimens are tested for compressive strength (ASTM C 39), abrasion resistance (a modified ASTM C 944) [8], and chloride-ion penetration resistance (ASTM C 1202). Air-entrained concrete specimens were tested for compressive strength (ASTM C 39), abrasion resistance, salt scaling resistance (ASTM C 672), freezing and thawing resistance (ASTM C 666), and chloride-ion penetration resistance (ASTM C 1202).

CONCLUSIONS

Considering the test data collected in this work, the following major conclusions may be drawn:

(1) The early-age strength of concrete mixture with UFS was lower compared to the reference mixture without used foundry sand. All non-air-entrained concrete mixtures containing up to 45% used foundry sand achieved compressive strengths comparable to the control mixture at later ages. All non-air-entrained concrete mixtures made with and without used foundry sand exhibited compressive concrete appropriate for manufacture of high-quality, structural-grade concrete.

(2) The general trend for compressive strength data for air-entrained concrete mixtures was similar to the non-air-entrained concrete mixtures. At early ages up to 7 days, mixtures containing more than 20% used foundry sand had compressive strengths lower than the control mixture. However, at 28 days and beyond all used foundry sand mixtures attained compressive strengths comparable to or better than the control mixtures without used foundry sand. All air-entrained concrete mixtures made with or without used foundry sand exhibited compressive strength appropriate for structural applications.

(3) All non-air-entrained concrete mixtures with and without used foundry sand showed very high abrasion resistance.

(4) All air-entrained concrete mixtures, except for the 43% and 47% used foundry sand mixtures, met the ASTM abrasion requirement at the age of 28 days. The mixtures containing 43% and 47% used foundry sand slightly exceeded the maximum ASTM C 944 value of 2.0 mm by an average of 0.4 mm at the age of 28 days. However, at 182 days, all concrete mixtures met the ASTM abrasion resistance requirement.

(5) The salt-scaling resistance of air-entrained concrete containing up to 20% used foundry sand was equivalent to the reference mixture without used foundry sand. The salt-scaling resistance of concrete mixtures incorporating large amounts of used foundry sand (43% and 47%) varied from “moderate scaling” to “severe scaling” per ASTM C 672.

(6) All air-entrained concrete mixtures made with and without used foundry sand showed excellent resistance to freezing and thawing actions.

(7) The chloride-ion penetration resistance of non-air-entrained concrete incorporating used foundry sand was either equivalent to or better than the reference concrete mixtures without used foundry sand. At 56 days, non-air-entrained mixtures showed chloride-ion penetration varying from “low” to “moderate” while at 182 days, it varied from “low” to “very low”.

(8) The resistance to chloride-ion penetration for air-entrained concrete mixtures was not greatly influenced by inclusion of used foundry sand up to 47% with fly ash content ranging from 34 to 40 percent. The chloride-ion penetration for the concrete mixtures, varied from “moderate” to “low” at the age 56 days. At 182 days, all concrete mixtures except the 43% used foundry sand attained “very low” chloride-ion penetration.

(9) Based on the results obtained in this investigation it was concluded that both non-air and air-entrained concrete mixtures containing used foundry sand developed in this investigation are appropriate for structural applications.

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REFERENCES

(1) Naik, T. R., and Kraus, R. N., “Development of Low-Cost Concrete Utilizing Foundry Industry By-Products,” Report No. CBU-1997-21, UWM Center for By-Products Utilization, University of Wisconsin - Milwaukee, 1997, 54 pages.

(2) Naik, T. R., and Patel, V. M., "Utilization of Used Foundry Sand: Current State of the Knowledge," Report No. CBU-1992-02 UWM-Center for By-Products Utilization, Report to WI-DNR, February 1992, 82 pages.

(3) Naik, T. R., Patel, V. M., Parikh, D. M. and Tharaniyil, M. P., "Utilization of Used Foundry Sand: Characterization and Products Testing," Report No. CBU-1992-20, UWM Center for By-Products Utilization, Report to WI-DNR, June 1992, 108 pages.

(4) Naik, T. R., Patel, V. M., Parikh, D. M., and Tharaniyil, M. P., "Utilization of Used Foundry Sand in Concrete," ASCE Journal of Materials in Civil Engineering, Vol. 6, No. 2, May 1994, pp. 254-263.

(5) Naik, T. R., Singh, S., Tharaniyil, M. P., and Wendorf, R. B., "Application of Foundry By-Product Materials in Manufacture of Concrete and Masonry Products," ACI Materials Journal, January-February 1995, pp. 41-50.

(6) Naik, T. R., and Singh, S., "Influence of Source of Foundry Sand and Fly Ash on Permeability of flowable Slurry Materials,” ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 123 No. 5, May 1997, pp. 446-452.

(7) Naik, T. R., and Singh, S., "Flowable Slurry Containing Foundry Sand,” ASCE Journal of Materials in Civil Engineering, Vol. 9 No. 2, May 1997, pp. 93-102.

(8) Burnley, T., “Illinois Examines the Beneficial Reuse of Spent Foundry Sand,” Modern Casting, Chicago, IL, Vol. 81, No. 3, March 1991, pp.28-29.

(9) American Foundrymen’s Society, “Alternate Utilization of Foundry Waste Sand,” Final Report of AFS Research, Prepared for Illinois Department of Commerce and Community Afairs, Published by AFS, Chicago, IL, August 1991, 97 pages.

(10) Baillod, C. R., Rundman, K. B., Murto, S. L., Talford, D. A., and Coduti, L. A., "Foundry Wastes in Michigan: Industrial Uses of Spent Sand," Environmental Engineering Center, Michigan Technological University, Houton, MI, December 1993, 168 pages.

(11) Naik, T. R., Singh, S. S., and Hossain, M. M., "Abrasion Resistance of High Strength Concrete Made With Class C Fly Ash," ACI Materials Journal, Vol. 92, No. 6, 1995, pp. 649-659.

Table 1
Physical Properties of Fine and Coarse Aggregate (ASTM C 33)

	Unit Weight kg/m^3 (lb/ft^3)	**Bulk Specific Gravity**	**Bulk Specific Gravity (SSD)**	**Apparent Specific Gravity**	**SSD Absorb. (%)**	**Void (%)**	**Fineness Modulus**	**Material Finer than 75 ìm (#200 Sieve)**	**Clay Lumps and Friable Particles (%)**	**Organic Impurity for Fine Aggregate**	**Soundness of Aggregate (%) loss**
ASTM Test Designation	C 29	C 127/C 128				C 29	C 136	C 117	C 142	C 40	C 88
Sand (Fine Aggregate)	1714 (107.0)	2.71	2.73	2.76	0.7	36.74	1.66	0.6	0	Passes	7.04
19mm (3/4") Coarse Aggregate	1682 (105.0)	2.76	2.79	2.85	1.1	38.86	3.92	0.16	0	Passes	0.6
Used Foundry Sand	1538 (96.0)	1.97	2.03	2.10	3.2	21.94	1.32	54.9	--	Passes	--

Table 2
Gradation of Fine Aggregate, Used Foundry Sand, and Coarse Aggregate (ASTM C 136)

Sieve Size µm	Concrete Sand (% Passing)	Used Foundry Sand (% Passing)	ASTM C 33 Fine Aggregate (% Passing)	Sieve Size	Coarse Aggregate (% Passing)	ASTM C 33 Coarse Aggregate (% Passing)
4.75 mm (#4)	100	99.9	95 to 100	25mm (1")	100	100
2.36 mm (#8)	100	99.1	80 to 100	19 mm (3/4")	80	90 to 100
1.18 mm (#16)	94.7	97.5	50 to 85	13 mm (1/2")	19	-
600 µm (#30)	79.9	95.7	25 to 60	9.5 mm (3/8")	8	20 to 55
300 µm (#50)	48.6	68.9	10 to 30	4.75 mm (#4)	0	0 to 10
150 µm (#100)	10.6	6.4	2 to 10	2.36 mm (#8)	0	0 to 5

Table 3
Mixture Proportions of Non-Air-Entrained Concrete Mixtures

Mix No.	NA-1	NA-2	NA-3	NA-4
Field Mix Designation	1	3	10	11
Used Foundry Sand (%)	0	15	20	45
Fly Ash (%) [A/(C+A)]	20	29	34	34
Cement, C, kg/m^3 (lb/yd^3)	291 (490)	276 (465)	261 (440)	267 (450)
Fly Ash, A, kg/m^3 (lb/yd^3)	74 (125)	113 (190)	136 (230)	139 (235)
Water, W, kg/m^3 (lb/yd^3)	172 (290)	181 (305)	157 (265)	163 (275)
[W/(C+A)]	0.47	0.47	0.39	0.40
SSD Fine Aggregate, kg/m^3 (lb/yd^3)	789 (1330)	629 (1060)	602 (1015)	403 (680)
SSD Foundry Sand, kg/m^3 (lb/yd^3)	0 (0)	119 (200)	154 (260)	344 (580)
SSD ¾" Aggregate, kg/m^3 (lb/yd^3)	1118 (1885)	1112 (1875)	1077 (1815)	1047 (1765)
Superplasticizer, L/m^3 (liq.oz/yd^3)	2.2 (56)	2.6 (66)	3.0 (77)	7.1 (183)
Air Temperature, °C (°F)	23.9 (75)	22.8 (73)	23.9 (75)	21.1 (70)
Fresh Concrete Temperature, °C (°F)	18.9 (66)	18.9 (66)	21.1 (70)	21.1 (70)
Slump, mm (in.)	216 (8-1/2)	114 (4-1/2)	102 (4)	178 (7)
Air Content (%)	2.1	1.9	2.4	1.8
Fresh Concrete Density, kg/m^3 (lb/ft^3)	2445 (152.6)	2445 (152.0)	2435 (149.4)	2398 (149.7)
Hardened Concrete Density, kg/m^3 (lb/ft^3)	2446 (152.7)	2483 (155.0)	2393 (149.4)	2413 (150.6)

Table 4
Mixture Proportions of Air-Entrained Concrete Mixtures

Mix No.	A-1	A-2	A-3	A-4	A-5	A-6	A-7
Field Mix Designation	2	5	4	6	7	8	9
Used Foundry Sand (%)	0	0	15	15	20	43	47
Fly Ash, [A/(C+A)] (%)	25	23	34	34	37	40	40
Cement, C, kg/m^3 (lb/yd^3)	273 (460)	309 (520)	258 (435)	261 (440)	267 (450)	243 (410)	255 (430)
Fly Ash, A, kg/m^3 (lb/yd^3)	92 (155)	92 (155)	151 (225)	136 (230)	160 (270)	166 (280)	175 (295)
Water, W, kg/m^3 (lb/yd^3)	199 (335)	139 (235)	170 (287)	163 (275)	166 (280)	151 (255)	154 (260)
[W/(C+A)]	0.54	0.35	0.43	0.41	0.39	0.37	0.36
SSD Fine Aggregate, kg/m^3 (lb/yd^3)	789 (1330)	590 (995)	662 (1115)	608 (1025)	558 (940)	392 (660)	371 (625)
SSD Foundry Sand, kg/m^3 (lb/yd^3)	0 (0)	0 (0)	113 (190)	113 (190)	145 (245)	300 (505)	323 (545)
SSD ¾" Aggregate, kg/m^3 (lb/yd^3)	1041 (1755)	1219 (2055)	1035 (1745)	1056 (1780)	1015 (1710)	914 (1540)	991 (1670)
Air-Entraining Admixture, mL/m^3 (liq.oz/yd^3)	232 (6)	310 (8)	348 (9)	658 (17)	851 (22)	1238 (32)	1470 (38)
Superplasticizer, L/m^3 (liq.oz/yd^3)	2.2 (56)	2.4 (63)	2.5 (64)	2.4 (62)	3.9 (101)	6.7 (172)	7.2 (187)
Air Temperature, °C (°F)	23.3 (74)	15.6 (60)	25.0 (77)	20.0 (68)	20.6 (69)	20.6 (69)	23.3 (74)
Fresh Concrete Temperature, °C (°F)	17.8 (64)	20.6 (69)	20.0 (68)	21.1 (70)	20.6 (69)	23.9 (75)	23.9 (75)
Slump, mm (in.)	191 (7-1/2)	140 (5-1/2)	121 (4-3/4)	51 (2)	89 (3-1/2)	102 (4)	83 (3-1/4)
Air Content (%)	4.8	5.2	3.8	4.8	4.9	4.9	5.4
Fresh Concrete Density, kg/m^3, (lb/ft^3)	2397 (149.6)	2353 (146.9)	2374 (148.2)	2339 (146.0)	2315 (144.5)	2284 (142.6)	2283 (142.5)
Hardened Concrete Density, kg/m^3 (lb/ft^3)	2409 (150.4)	2344 (146.3)	2469 (154.1)	2473 (154.4)	2432 (151.8)	2382 (148.7)	2320 (144.8)

Table 5
Abrasion Resistance for Non-Air-Entrained Concrete Mixtures

Mixture No.	Field Designation	Used Foundry Sand (%)	Fly Ash (%)	Depth of Wear, mm (28-day)	Depth of Wear, mm (182-day)
NA-1	1	0	20	1.1	1.2
NA-2	3	15	29	1.2	1.0
NA-3	10	20	34	1.4	1.3
NA-4	11	45	34	1.9	1.4

*Average of three observations

Table 6
Abrasion Resistance for Air-Entrained Concrete Mixtures

Mixture No.	Field Designation	Used Foundry Sand (%)	Fly Ash (%)	Depth of Wear, mm (28-day)	Depth of Wear, mm (182-day)
A-1	2	0	25	1.2	1.1
A-2	5	0	23	1.2	0.9
A-3	4	14	34	1.5	0.8
A-4	6	14	34	1.5	1.2
A-5	7	20	37	1.7	1.7
A-6	8	43	40	2.4	2.0
A-7	9	47	40	2.2	1.7

*Average of three observations

Table 7
Salt Scaling Resistance of Air-Entrained Concrete Mixtures

Mixture No.	Field Mix No.	Used Foundry Sand, %	Fly Ash, %	Specimen No.	ASTM C 672 Visual Rating at Various, cycles **									
Cycles	--	--	--	--	5	10	15	20	25	30	35	40	45	50
A-1	2	0	25	1	0	0	1	2	3	3	3	3	4	4
				2	0	0	0	0	0	1	1	1	1	1
				3	0	1	1	1	1	2	2	2	2	2
A-2	5	0	23	1	0	0	0	0	1	1	1	1	1	1
				2	0	0	0	0	0	0	0	0	1	1
				3	0	0	0	1	1	1	1	2	2	3
A-3	4	15	34	1	0	0	0	0	0	0	1	1	1	1
				2	0	0	0	0	0	0	1	1	1	1
				3	3	3	3	3	4	4	4	4	4	4
A-4	6	15	34	1	0	0	0	1	1	2	2	2	2	2
				2	0	1	1	2	2	2	2	3	3	3
				3	0	1	1	2	2	2	2	3	3	3
A-5	7	20	37	1	3	3	3	4	4	4	4	4	4	4
				2	0	1	1	1	1	1	1	1	1	1
				3	2	2	2	2	2	3	3	3	3	3
A-6	8	43	40	1	5	5	5	5	5	5	5	5	5	5
				2	5	5	5	5	5	5	5	5	5	5
				3	2	2	3	3	3	3	3	3	3	3
A-7	9	47	40	1	2	2	2	3	3	3	3	3	4	4
				2	1	1	1	1	2	3	4	4	5	5
				3	2	3	3	3	3	3	4	4	5	4

**Rating	Condition of Surface
0	No scaling
1	Very slight scaling (1/8 in. or 3.2 mm depth, max. no coarse aggregate visible)
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

Table 8
Freezing and Thawing Resistance of Air-Entrained Concrete Mixtures

Mixture No.	Field Mix No.	Used Foundry Sand, %	Fly Ash, %	Specimen Number	No. of F/T Cycles Completed (ASTM C 666)	Percent Change at the End of 300 Freezing and Thawing Cycles			Relative Dynamic Modulus of Elasticity, %	Durability Factor, %
						Resonant Frequency	Weight	Pulse Velocity		
A-1	2	0	25	1 2 3	300 300 300	9.8 7.9 8.3	-1.3 -1.6 -1.0	2.6 4.7 10.2	82.4 84.8 84.1	84
A-2	5	0	23	1 2 3	300 300 300	6.5 7.7 6.2	-0.9 -0.1 -0.6	5.1 5.1 5.4	87.4 85.2 87.9	88
A-3	4	15	34	1 2 3	300 300 300	4.8 6.9 7.4	-1.0 -1.2 -2.2	0 0.2 1.8	91.1 86.7 85.7	86
A-4	6	15	34	1 2 3	300 300 300	9.2 6.1 7.5	-1.6 -0.3 9.5	4.5 0.1 -0.4	86.1 88.2 85.7	86
A-5	7	20	37	1 2 3	300 300 300	7.8 9.5 8.7	-3.6 -3.4 -3.4	5.3 4.8 3.7	85.0 82.0 83.4	83
A-7	9	47	40	1 2 3	300 300 300	4.7 4.1 2.2	-1.0 -1.5 -2.0	-3.6 -3.0 -5.1	90.8 92.0 95.7	91

Table 9
Resistance to Chloride-Ion Penetration for Non-Air Entrained Concrete Mixtures

Mixture No.	Field Mixture No.	Used Foundry Sand, %	Fly ash (%)	Charge* Passed, Coulombs (56-day)	Charge* Passed, Coulombs (182-day)
NA-1	1	0	20	2226	1015
NA-2	3	15	29	1576	812
NA-3	10	20	34	1492	823
NA-4	11	45	34	2315	1084

*Average of three observations

ASTM C 1202 Charge passed (Coulombs)	ASTM M 1202 Chloride Permeability
> 4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

Table 10
Resistance to Chloride-Ion Penetration for Air- Entrained Concrete Mixtures per ASTM C 1202

Mixture No.	Field Mixture No.	Used Foundry Sand (%)	Fly Ash (%)	Charge, Coulombs* (56-day)	Charge, Coulombs* (182-day)
A-1	2	0	25	2350	700
A-2	5	0	23	1643	778
A-3	4	15	34	---	768
A-4	6	15	34	1442	883
A-5	7	20	37	1434	779
A-6	8	43	40	2271	1368
A-7	9	47	40	1581	831

*Average of three observations

ASTM C 1202 Charge passed (Coulombs)	ASTM C 1202 Chloride Permeability
> 4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

Fig. 1
Sieve Analysis Envelope for Regular Concrete Sand and Foundry Sands

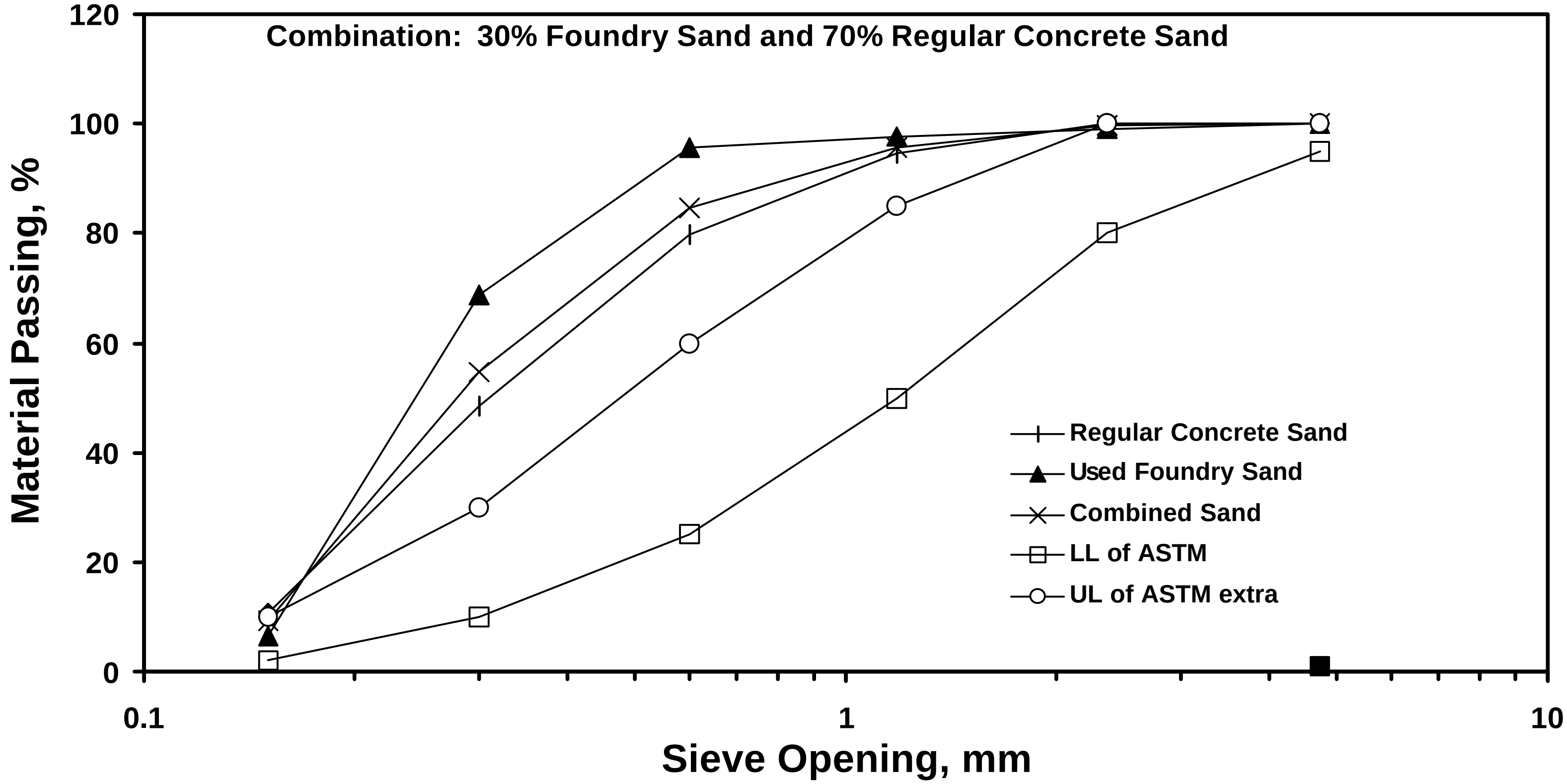

Fig. 2
Compressive Strength Versus Age for Non-Air Entrained Conrete Mixture

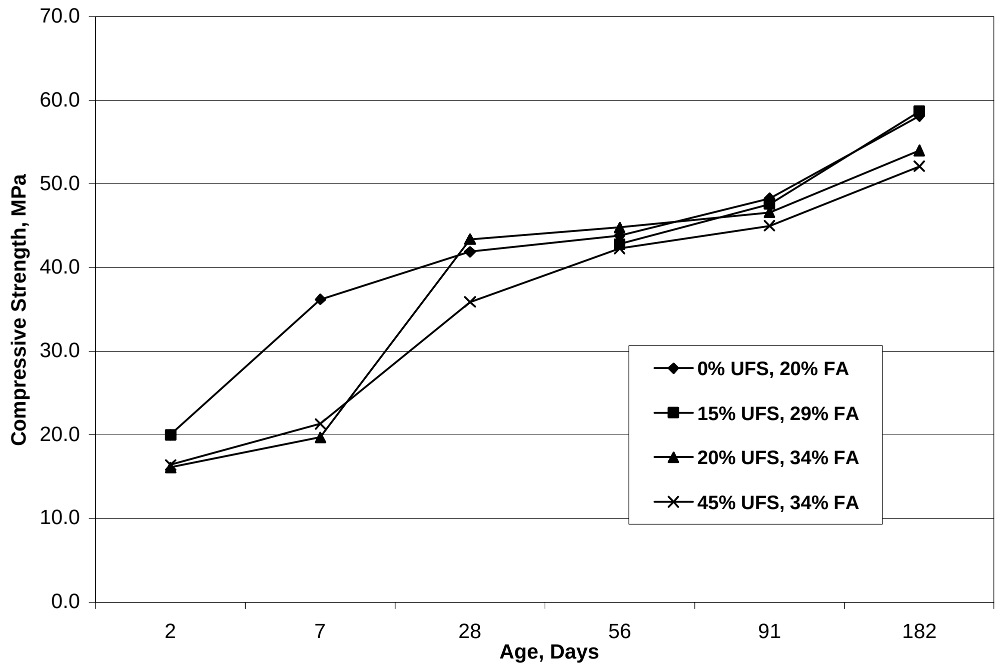

Fig. 3
Compressive Strength versus Age for Air-Entrained Concrete Mixtures