RAPID CHLORIDE PERMEABILITY OF STRUCTURAL LIGHTWEIGHT AGGREGATE CONCRETE COMPARED WITH NORMAL DENSITY CONCRETE HAVING SIMILAR PROPORTIONS

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Rapid Chloride Permeability of Structural Lightweight Aggregate Concrete Compared With Normal Density Concrete having Similar Proportions

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BACK GROUND

Bremner, Holm, and McInerney (1992) and Sugiyama, Bremner, and Holm (1996) reported that the permeability of lightweight aggregate concrete was extremely low and generally equal to or significantly lower than the results of the normal density control samples used in the testing. Some researchers attribute the low permeability to the high quality transition zone between the paste matrix and the lightweight aggregate. The lightweight concrete aggregate-matrix interface is a boundary between two porous media allowing hygral equilibrium to be reached preventing the accumulation of water at the interface. Normal density concretes aggregate-matrix interface is a boundary between a porous and a solid media. This allows water to collect around the normal weight coarse aggregates, typically demonstrating a zone of higher water/cementious ratio material. Other reasons for the lower permeability of lightweight concrete are the long-term pozzolanic reaction between the silica-rich expanded lightweight aggregate and calcium hydroxide produced during cement hydration, the elastic similarity between the cement paste and the lightweight aggregate minimizing micro cracking at the aggregate-matrix interface, and the extended curing from the internal moisture of the lightweight aggregate. Powers showed that extending the time of curing increased the volume of cementious products formed which caused the capillaries to become segmented and discontinuous.

1991-92 RESEARCH

In 1991 and 1992, Carolina Stalite, under the direction of Roberto Nunez, conducted research to determine the chloride permeability of lightweight concrete mixes produced using Rotary Kiln Expanded Slate Lightweight Aggregate (Stalite) compared to an otherwise similar normal density concrete. Four (4) separate concrete mixes were produced in November 1991. The mix composition was selected in concurrence with the advice of Stalite representatives. These mixes were intended to be representative of actual mixes used in practice. Four types of mixes were tested.

1. A commodity type concrete, conforming to the requirements of North Carolina Department of Transportation, State Class AA, Produced with a class F fly ash. In the data synopsis, this mix is referred to as “DOT AA”. This mix served as the control, or comparison mix.
2. A lightweight concrete, similar to DOT AA in composition (including fly ash) except for the coarse aggregate. This mix was designated “LW Ash”.
3. A lightweight concrete, similar to LW Ash in composition except that only Portland cement was used (no ash). This mix was designated “LW CMT”.

4. A lightweight concrete, using silica fume as mineral admixture, designated "LW Fume".

Permeability for this research was determined in accordance with AASHTO T 277, "Rapid Determination of the Chloride Permeability of Concrete" (RCPT).

Rapid Chloride Permeability tests were run on duplicate samples, each of which was the top two inches sawed from duplicate 3.75 inch diameter cores, drilled after curing. The data synopsis was as follows:

Mix number		DOT AA	LW ASH	LW CMT	LW FUME
Cement (lb)		611	611	705	658
Fly Ash (lb)		115	115		
Silica Fume (lb)					43
57 Stone (lb)		1900			
Stalite (3/4) (lb)			880	880	920
Sand (lb)		940	1200	1220	1230
Water (lb)		260	280	270	240
WRDA 35 *		4	4	4	6
Unit Wt (plastic)		141.2	113.4	112.8	116.2
Slump		3.25	3.25	3	3.5
Air Volume %		6.4	7.5	9.3	6.8
Days Moist	Days Air dry	Compressive Strength (psi)			
14	14	6250	5690	6740	7860
28	0	5510	5410	6150	7460
28	14	6590	6400	7360	8570
Days Moist	Days Air dry	Rapid Chloride Permeability (Coulombs)			
14	14	4750	3860	4530	1700
28	14	4170	3560	4250	1530

Material	Source
Cement	Blue Circle
Fly ash	AMC Belews Creek
Silica Fume	Elkem
Lightweight Coarse Aggregate ¾”	Stalite
Normal Weight #57 Stone	Martin Marietta-Garner
Fine Aggregate	Lillington, NC
Water	Local
Admixture, WRA	Cormix
Admixture, AEA	WR Grace

The 1991-92 research by Roberto Nunez showed lower coulomb values for the lightweight concrete mixtures compared with the normal density concrete control mixture.

CURRENT RESEARCH- (WALL AND FREEMAN)

PURPOSE

The purpose of this research is to further examine the chloride permeability of lightweight aggregate concrete. Tests were conducted to determine the ability of lightweight aggregate concrete to resist chloride ion penetration compared to normal density concrete with very similar mix proportions.

TEST METHOD

The test method used to determine the chloride permeability was ASTM C1202-97 “ Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration”.

TEST PROGRAM

Mactec Engineering and Consulting, Inc performed the laboratory testing under the direction of Shawn McCormick. The concrete mixing and fabrication of the cylinders was conducted by Jody Wall, P.E., Charles Freeman, Damon Loflin and Phillip Stubbs at Carolina Stalite’s laboratory in Gold Hill, NC. A total of eight (8) cylinders were made from each mixture for testing. ASTM C-192 “Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory” was followed in the mixing of the concrete and fabrication of cylinders.

CONCRETE MIXTURE PROPORTIONS

Eight (8) different concrete mixes were produced and tested. The mixes were labeled L-116 thru L-123 and the mix proportions are listed below. The raw materials used in the mixture are also listed below.

Material	Source
Cement	Blue Circle
Fly ash Class F	Stalite Plant
Lightweight Coarse Aggregate ¾”	Stalite
Normal Weight #67 Stone	Vulcan- Cabarrus
Fine Aggregate	Hedrick- Lilesville
Water	Local
Admixture, WRDA 35	WR Grace
Admixture, Dairvair 1400	WR Grace

Mix Designs

Mix number	L-116	L-117	L-118	L-119
Cement (lb)	700	650	700	650
Fly Ash (lb)	0	100	0	100
Silica Fume (lb)	0	0	50	50
Stalite (3/4) (lb)	950	950	950	950
Sand (lb)	1152	1027	1069	970
Water (lb)	290	310	300	310
WRDA 35 *	5	5	5	5
AEA *	.5	.5	.5	.5

Mix number	L120	L-121	L-122	L-123
Cement (lb)	700	650	700	650
Fly Ash (lb)	0	100	0	100
Silica Fume (lb)	0	0	50	50
67 Stone (lb)	1800	1800	1800	1800
Sand (lb)	1127	1002	1023	941
Water (lb)	290	310	300	310
WRDA 35 *	5	5	5	5
AEA*	.5	.5	.5	.5

*oz/100 lb cementious

Mixes L-116 thru L-119 were produced using Rotary Kiln Expanded Slate Lightweight Aggregate (Stalite) from Gold Hill, North Carolina. Mixes L-120 thru L-123 were produced using a normal weight #67 stone (granite) from Concord, North Carolina. Mix L-116 and mix L-120 were produced using the same cement, water and admixture content. These mixes also had almost identical coarse aggregate volumes. Mixes L-117 and L-121, L-118 and L122, L-119 an L-123 were produced as matching samples in a similar method to L-116 and L–120.

The cement content and coarse aggregate volumes used in the mixtures are similar to those being used in high performance lightweight concrete mixes for applications such as bridges and high-rise buildings. The fly ash replacement rate was 13% in mixes L-117 and L-121 and 12.5% in mixes L-119 and L-123. The silica fume replacement rate was 6.6% in mixes L-118 and L-122 and 6.3% in mixes L-119 and L-123. The coarse aggregates were used in SSD condition with the lightweight coarse aggregate having total absorbed moisture content of 6.2%.

Fresh density, air percentage measurements and slump were taken for each concrete mix and are listed below.

Fresh Concrete Properties

Mix number	AIR %	Density pcf	Slump inches
L-116	4.5	114.2	3.0
L-117	4.0	113.7	4.0
L-118	3.5	116.3	3.5
L-119	6.0	114.6	6.0
L-120	4.0	148.0	3.5
L-121	4.0	147.0	5.0
L-122	6.0	144.5	3.0
L-123	5.0	143.5	5.0

Six (6) 4 inch X 8 inch concrete test cylinders were cast from each mix and the cylinders were wet cured per ASTM specifications for compressive strength. The concrete test cylinders were broken at 7, 28 and 56 days. Two cylinders were tested at each test age and the results of the two tests were averaged for the compressive strength. The results of the compressive strength testing are as follows:

Average Compressive Strength

Mix number	7days (Psi)	28 days (Psi)	56 days (Psi)
L-116	5090	6480	7270
L-117	5110	6670	6960
L-118	6330	7140	7930
L-119	5750	7650	7840
L-120	5840	7900	8650
L-121	5830	7570	8350
L-122	5380	6918	8240
L-123	5020	6870	7900

For chloride permeability testing two (2) 4 inch X 8 inch concrete test cylinders were cast from each mix and cured 28 days in water and air-dried until testing age (150 days old). The cylinders were cut and prepared for testing at Mactec Engineering in Atlanta, Georgia. Each specimen was marked as specimen A or B for the specified mix and the results of the two specimens were averaged for the coulomb value. The results of the testing are listed below.

Chloride Permeability Test Results

Mix number	Specimen A (Coulombs)	Specimen B (Coulombs)	Average (Coulombs)
L-116	3700	4210	3960
L-117	3550	3280	3420
L-118	560	640	600
L-119	1250	1130	1190
L-120	3850	4080	3970
L-121	4380	4220	4300
L-122	1900	1760	1830
L-123	2050	1800	1930

CONCLUSIONS

Based on Table 1 of ASTM 1202-97, the chloride permeability of the lightweight aggregate concrete samples ranged from very low to moderate while the chloride permeability of the normal density concrete samples ranged from low to high.

Comparisons of similar mixes

Mix number	L-116 L-120	L-117 L-121	L-118 L-122	L-119 L-123
Cement (lb)	700	650	700	650
Fly Ash (lb)	0	100	0	100
Silica Fume (lb)	0	0	50	50
Water (lb)	290	310	300	310
Coulombs Lightweight	3960	3420	600	1190
Coulombs Normal Density	3970	4300	1830	1930

All the concrete mixes using silica fume showed low chloride permeability and the lightweight concrete mixes using silica fume showed exceptionally low chloride permeability results. The lightweight concrete results using silica fume were on average 985 coulombs lower than the corresponding normal weight concrete.

The mixes made using fly ash showed results typically better than the mixes not using fly ash. The improvement of adding fly ash was not nearly as significant as the addition of silica fume in the tested mixes. The lightweight mixes using fly ash did show lower chloride permeability than the corresponding normal weight mixes. The average permeability of the lightweight mixes using fly ash was 810 coulombs lower than the corresponding normal weight mixes.

Although permeability depends primarily on the quality of the cement paste, the test results indicate significantly lower chloride permeability when lightweight aggregates are used in place of normal weight aggregates. As discussed in the background section of the paper there are several reasons for the improved chloride permeability results when using lightweight aggregates. The high quality transition zone between the paste matrix and the lightweight aggregate and the extended curing from the internal moisture in the lightweight aggregate seem to be two of the more important factors separating lightweight aggregate concrete from normal density concrete.

References

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