SIGNIFICANTLY IMPROVE CONCRETE DURABILITY AND SERVICE LIFE BY USING A 100-YEAR-OLD TECHNOLOGY

by Ken Harmon, Stalite and Chair of the Structural Committee of the Expanded Shale, Clay and Slate Institute

Owners and designers of many new structures are specifying a design life of 100 years or more to ensure durability and sustainability. Tourney Consulting Group LLC (TCG) in Kalamazoo, Mich., recently conducted a study[1] for the Expanded Shale, Clay and Slate Institute (ESCSI) to determine the effects of lightweight coarse and fine aggregates—100-year-old technology—on the transport properties and other durability-related properties of concrete.

Ten expanded shale, clay, and slate lightweight coarse aggregates from across the United States were used in "sand lightweight" concrete mixtures that were compared to a normalweight concrete control mixture with respect to transport properties. Transport properties of concrete are measurements of the ability of ions and fluids to move through the material.

In addition, one mixture with normalweight coarse aggregate and lightweight fine aggregate (an "inverted" mixture); one mixture with lightweight coarse and lightweight fine aggregates ("all-lightweight" concrete); and one mixture with normalweight aggregate with a partial replacement of normalweight sand by lightweight fine aggregate (an "internally cured" mixture) were also evaluated for transport properties.

All mixtures used 658 lb/yd^3 of Type I portland cement. No supplementary cementitious materials were used.

Table 1 lists the 14 concrete mixtures tested and their properties. The transport properties from the TCG tests were used in several service-life prediction software models, including STADIUM® and Life-365™, and analysis according to *fib Bulletin 34: Model Code for Service Life Design*. A bridge deck subjected to deicing salts in Detroit, Mich., was modeled using the two software programs.

The results for the analysis using STADIUM showed that the concrete bridge deck's service life would be increased in comparison to the normalweight concrete control mixture as follows:

- By approximately 22% when using the "sand lightweight" mixtures

Table 1. Concrete Mixture Proportions and Properties[1]

Mixture description	LW1			LW2							ALW	LWF	IC	C
Lafarge Alpena Type I cement, lb/yd^3	658	658	658	658	658	658	658	658	658	658	658	658	658	658
Aggregate Resource Midway Pit NW FA, lb/yd^3 (SSD)	1360	1342	1320	1119	1119	1074	1568	1346	990	1465	—	—	846	1294
Bay Aggregates Cedarville Pit NW limestone CA No. 67, lb/yd^3 (SSD)	450	350	150	—	—	—	—	—	—	—	—	1800	1800	1800
LW CA, lb/yd^3 (SSD)	500	650	862	1215	1209	1209	862	1038	1273	875	1115	—	—	—
LW FA, lb/yd^3 (SSD) Total water, lb/yd^3	250	250	244	243	243	243	242	243	243	246	243	243	243	243
Designed air, %	6.5	6.5	6.0	7.0	7.0	7.0	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Designed plastic density, lb/ft^3	120.5	120.4	118.9	119.7	119.5	117.8	123.3	121.7	117.2	120.1	108.7	130.9	142.6	148
Water-cement ratio	0.38	0.38	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Admixtures														
BASF Master Air AE100, oz/cwt	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.4	0.5
BASF Glenium 7500, oz/cwt	3.2	3.6	3.7	3.9	4.3	3.9	5.2	5.8	3.5	5.0	4.3	5.3	5.0	4.4
Physical properties														
Slump, in.	4.00	5.00	3.50	3.00	8.75	5.00	2.75	5.25	3.00	4.00	3.00	5.00	7.50	4.00
As-tested air, % (volumetric)	6.75	8.00	7.50	7.25	6.50	6.50	7.00	6.25	6.25	7.00	6.25	6.00	7.00	7.10
Plastic density, lb/ft^3 (concrete)	120.5	123.0	118.8	119.1	122.6	122.2	125.7	123.5	121.4	120.7	109.8	133.3	141.6	146.2
Oven-dry density, lb/ft^3 (concrete)	111.9	113.8	108.9	109.2	109.8	108.2	115.7	114.0	109.1	114.1	95.6	130.1	137.2	142.1
Equilibrium air dry density, lb/ft^3 (concrete)	118.6	119.9	115.4	117.3	117.7	115.9	122.3	120.7	117.1	120.3	104.8	136.5	142.9	147.3
No. of days to reach equilibrium (average 2)	112	84	84	140	140	140	112	112	112	56	140	84	84	67
Compressive strength	Average			Average										
1-day strength, psi (3 each)	2870			3370							2700	3500	3570	3310
28-day strength, psi (3 each)	5650			6540							6160	7120	6760	5470
90-day strength, psi (3 each)	6260			7240							7140	8040	7743	5950

Note: For compressive strength tests, three cylinders were tested for each mixture at each age and the average compressive strength is reported.
For LW1 mixtures, the compressive strength value shown is the average of the average values for the three mixtures of this type.
For LW2 mixtures, the compressive strength value shown is the average of the average values for the seven mixtures of this type.
ALW = one "all-lightweight" mixture with LW CA and FA; C = one control mixture with NW CA and FA; CA = coarse aggregate; FA = fine aggregate; IC = one "internally cured" mixture with NW CA, NW FA, and some LW FA; LW = lightweight; LWF = one "inverted" mixture with NW CA and LW FA; LW1 = three "sand lightweight" mixtures with LW CA, some NW CA, and NW FA; LW2 = seven "sand lightweight" mixtures with LW CA and NW FA; NW = natural, normalweight; SSD = saturated surface dry.

- By approximately 88% when using the "inverted" mixture
- By approximately 35% when using the "all-lightweight" mixture
- By approximately 32% when using the "internally cured" mixture

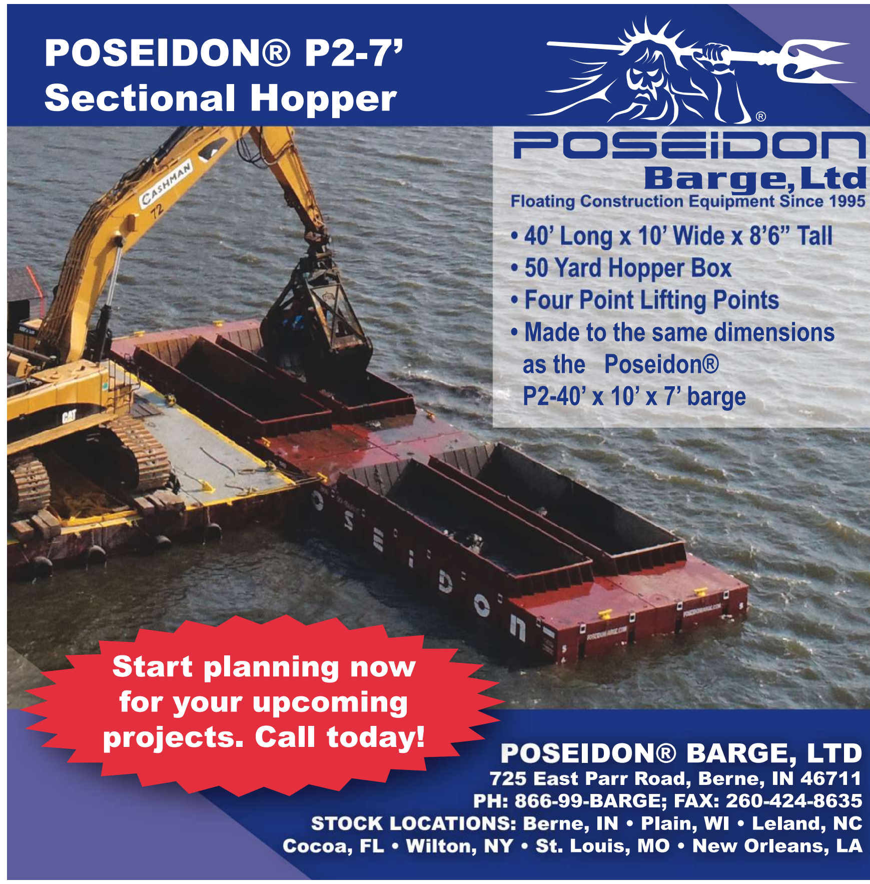
While these results are encouraging, other studies[2–5] have shown greater improvements in properties related to durability and service life for different types of lightweight and internally cured concrete mixtures. Such results would indicate even greater increases in predicted service life than are presented in the findings of the TCG study.

Increased service life of structural lightweight concrete is due to several factors. Water absorbed within the lightweight aggregate pores does not influence the plastic concrete's water–cementitious materials ratio, but it does maintain moisture equilibrium (internal curing) during the early stages of drying, thus delaying drying-shrinkage and reducing drying shrinkage cracks while improving the cement hydration efficiency. Also, lightweight aggregate particles have more surface area than normalweight aggregates and are actually pozzolanic, providing a significantly superior contact zone. Elastic similarity of the lightweight aggregate and the surrounding cementitious matrix allows for reduced microcracking at the matrix-lightweight aggregate interface and developing a concrete that is less pervious.

The results of the Life-365 analysis showed comparable performance between the sand lightweight mixtures and the control mixture. As with the STADIUM analysis, significant increases in projected service life were shown with the lightweight fines (up to three times when lightweight fine aggregate replaced normalweight sand, that is, the "inverted" mixture).

The service-life predictions discussed are estimates for uncracked concrete. As part of the testing program, TCG also evaluated the cracking potential of an internally cured concrete mixture. Compared to the normalweight control mixture, the internally cured mixture was shown to delay restrained shrinkage cracking and increase compressive strength, both of which would be expected to increase service life. In this case, TCG's findings agree with studies by others[2–5] that also found that lightweight concrete has a reduced potential for cracking compared to normalweight control concrete mixtures, providing further benefit for increasing the service life of concrete structures beyond the factors considered in the Life-365 and STADIUM analyses.

For more information on the tests performed by TCG to determine the transport and durability properties of concrete, as well as the assumptions and inputs used for the service-life analyses, see the full report, *Determination of Transport Properties of Lightweight Aggregate Concrete for Service Life Modeling*, dated August 23, 2018, which can be downloaded from www.escsi.org.



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