Better Pavements through Internal Hydration

Taking lightweight aggregate to the streets

BY VICTOR H. VILLARREAL AND DAVID A. CROCKER

The benefits of using structural lightweight aggregate (LWA) to replace a portion of the normalweight aggregates in concrete mixtures have been investigated by many researchers. The main purpose of this substitution has been to provide a source of moisture for internal curing that will promote more complete hydration of the cementitious materials. Due to the inherently low permeability of the matrix, internal curing is especially beneficial in concrete with a low water-cementitious material ratio (*w/cm*) where external curing has little effect on hydration in the internal portion of the concrete. If the *w/cm* is below about 0.36, these mixtures can also self-desiccate because the amount of water included in the mixture is not enough to completely hydrate the cementitious materials.

Presaturated structural lightweight aggregate typically contains between 5 and 25% water by weight. This water is released from the lightweight aggregate pores as the concrete cures and replaces a portion of the original mixture water that is consumed by the hydration process.[1-5] As reported by Hammer,[6] the efficiency of LWA as an internal curing agent primarily depends on the amount of water in the LWA, the LWA particle spacing, and pore structure.

TECHNOLOGY IN PRACTICE

At TXI Ready Mix Concrete in Dallas, TX, we successfully blended an intermediate size lightweight aggregate into concrete mixtures more than 5 years ago. The concrete was designed for use in residential applications on a limited basis. The 3/8 in. to No. 8 (9.5 to 2.36 mm) expanded shale lightweight aggregate met all the requirements of ASTM C 330 and replaced a portion of both the coarse and fine aggregates. This aggregate size not only enhanced the hydration of the cementitious materials, but also complemented the total aggregate grading in the concrete.

North Texas is a major market for concrete paving, and the benefits of internal hydration using lightweight aggregate had been presented at recent industry forums. Therefore, the next step to using this intermediate lightweight aggregate in paving was a natural one.

LABORATORY RESEARCH

In previous research, we explored the substitution of differing amounts of lightweight aggregate for normal-weight aggregate in concrete. Substitutions of 3, 5, and 7 ft^3/yd^3 (0.11, 0.19, and 0.26 m^3/m^3) of 3/8 in. to No. 8 (9.5 to 2.36 mm) lightweight aggregate were tested in the laboratory to observe the effects on the workability, density, and compressive strength of the concrete. The prewetted bulk density of the lightweight aggregate was 60 lb/ft^3 (960 kg/m^3). Several cylinders were made from each mixture. Concrete cylinders with and without lightweight aggregate were cured per ASTM C 192 (standard cured). In addition, separate cylinders with lightweight aggregate were also cured in air at room temperature (air curing started 24 hours after molding the cylinders). The results indicated that 3 and 5 ft^3/yd^3 (0.11 and 0.19 m^3/m^3) substitutions improved compressive strength when comparing standard cured cylinders and also improved workability, while a 7 ft^3/yd^3 (0.26 m^3/m^3) substitution decreased compressive strength. At all ages, the compressive strength of the air-cured cylinders containing lightweight aggregate was similar to the strength of the standard-cured cylinders, suggesting that the lightweight aggregate was providing adequate moisture for internal hydration of the concrete.

FIELD APPLICATION

The lessons learned in the laboratory study were used to design a low-slump paving concrete with 5 ft^3/yd^3 (0.19 m^3/m^3) replacement of the normalweight aggregates with lightweight aggregate. It was hoped that this concrete would have reduced shrinkage due to the improved curing and have minimal shrinkage cracking. To implement a new concept in actual ready mixed concrete production, it has to be simple so the production personnel can adapt it easily. The lightweight aggregate replaced about 300 lb/yd^3 (180 kg/m^3) of the coarse aggregate and 200 lb/yd^3 (120 kg/m^3) of the fine aggregate. After the concrete was batched, the yield was measured and the mixture proportions were adjusted to produce a total volume of 27 ft^3/yd^3 (1 m^3/m^3). The mixture proportions for both the original and modified mixtures are given in Table 1.

The individual aggregate gradings are shown in Table 2. The combined aggregate gradings for the original and modified mixtures are shown in Fig. 1 and 2, respectively. As shown in Fig. 2, the addition of the intermediate size lightweight aggregate improves the overall aggregate grading as discussed by ACI Committee 302.[7]

During the past 2 years, this technology has been implemented in several paving mixtures. Numerous municipal and residential paving projects in the Fort Worth, TX, area have used this technology in about 300,000 yd^3 (230,000 m^3) of concrete. The field results have been very encouraging. The average compressive strength of these mixtures has increased significantly. Reports of commonly found cracks, caused by either plastic or drying shrinkage, have been minimal. A major paving contractor has even requested that all their projects include this type of technology.

In January of 2005, the largest project began—a 250,000 yd^3 (190,000 m^3) paving project in Hutchins, TX—that required concrete with flexural strengths of 650 and 750 psi (4.5 and 5.2 MPa) at 28 days. The concrete was batched in a double central-mix batch plant set up at the site (Fig. 3). To our knowledge, this is the largest project in the world that took advantage of the internal hydration concept of prewetted lightweight aggregate in low-slump paving. The 7-day flexural strengths were typically in the range of 90 to 100% of the required 28-day flexural strength. Again, in

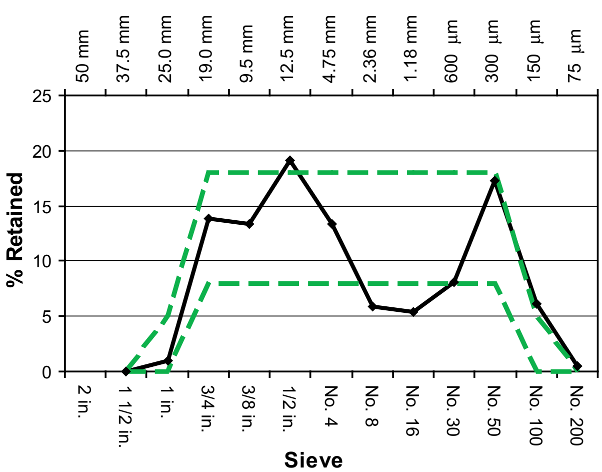

Fig. 1: Aggregate gradation for reference mixture shown with the commonly used 8 to 18% retained limits (green dashed lines)[7]

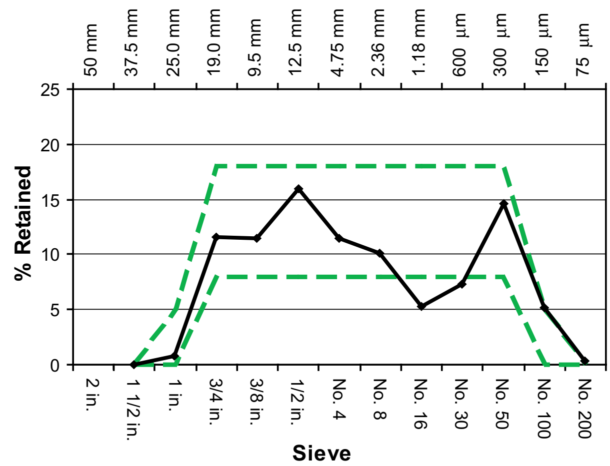

Fig. 2: Aggregate gradation for modified mixture shown with the commonly used 8 to 18% retained limits (green dashed lines)[7]

Fig. 3: Double central-mix batch plant at the Union Pacific Intermodal facility in Hutchins, TX

TABLE 1:
Mixture proportions and properties of reference and lightweight aggregate (LWA) modified concretes

Material	Specification	Reference mixture	LWA-modified mixture
Cement	ASTM C 150, Type I/II	451 lb/yd^3 (268 kg/m^3)	451 lb/yd^3 (268 kg/m^3)
Fly ash	ASTM C 618, Class C	113 lb/yd^3 (67 kg/m^3)	113 lb/yd^3 (67 kg/m^3)
Coarse aggregate	ASTM C 33, No. 57, crushed limestone	1840 lb/yd^3 (1092 kg/m^3)	1540 lb/yd^3 (914 kg/m^3)
Intermediate lightweight aggregate	ASTM C 330, 3/8 in. to No. 8 (9.5 to 2.36 mm)	0 lb/yd^3 (0 kg/m^3)	300 lb/yd^3 (178 kg/m^3)
Fine aggregate	ASTM C 33, natural sand	1301 lb/yd^3 (772 kg/m^3)	1099 lb/yd^3 (652 kg/m^3)
Water	ASTM C 94	242 lb/yd^3 (144 kg/m^3)	242 lb/yd^3 (144 kg/m^3)
Water-reducing admixture	ASTM C 494, Type A	4 fl oz/100 lb (260 mL/100 kg)	4 fl oz/100 lb (260 mL/100 kg)
Air-entraining admixture	ASTM C 260	As required	As required
Air content	3.0 to 6.0%	—	—
Slump	2 ± 1 in. (50 ± 25 mm)	—	—
f'_c	4500 psi (31 MPa)	—	—

contrast to conventional paving mixtures, cracking has been extremely minimal.

Production mixtures that include lightweight aggregate have typically produced compressive strengths that are about 1000 psi (7 MPa) higher than similar mixtures without lightweight aggregate. In Table 3, three different sets of mixtures are compared. The mixtures labeled with an "X" at the end of the label denote the mixtures that included lightweight aggregate. In all of the mixtures, 20% of the cementitious material was Class C fly ash. The average compressive strength test results include several different projects over the last 24 months. As reported by Holm,[8] "The effect of 'internal curing' is further enhanced if a pozzolan (fly ash or suitable lightweight aggregate fine fraction), is introduced into the mix. It is well known that the pozzolanic reaction of

TABLE 2:
Aggregate gradation

	Crushed stone	Lightweight aggregate	Natural sand
Size	1 in. to No. 4 (25.0 to 4.75 mm)	3/8 in. to No. 8 (9.5 to 2.36 mm)	No. 4 to 0 (4.75 mm to 0)
Blend percentage by volume	49.0%	16.0%	35.0%
Percent passing:			
1-1/2 in. (37.5 mm)	100	100	100
1 in. (25.0 mm)	98.4	100	100
3/4 in. (19.0 mm)	74.8	100	100
1/2 in. (12.5 mm)	42.2	100	100
3/8 in. (9.5 mm)	19.4	98.3	100
No. 4 (4.75 mm)	5.4	39.9	96.6
No. 8 (2.36 mm)	1.2	7.9	88.3
No. 16 (1.18 mm)	0	3.2	77.1
No. 30 (600 µm)	0	0	57.7
No. 50 (300 µm)	0	0	16
No. 100 (150 µm)	0	0	1.3
No. 200 (75 µm)	0	0	0.2
Fineness modulus	6.99	5.51	2.63

TABLE 3:
Comparison of cementitious material contents and physical properties of reference and modified grading mixtures

Mixture*	Cementitious material content, lb (kg)	Average slump, in. (mm)	f'_c at 28 days, psi (MPa)	Number of field tests	Average compressive strength, psi (MPa)	Percent of reference	Difference, psi (MPa)
8204SF	517 (235)	2 (50)	3000 (21)	98	5130 (35.4)	—	—
8204SFX	517 (235)	2 (50)	3000 (21)	106	6070 (41.9)	118%	940 (6.5)
8206	564 (256)	5 (125)	4500 (31)	91	5230 (36.1)	—	—
8206X	564 (256)	5 (125)	4500 (31)	68	6510 (44.9)	124%	1280 (8.8)
8206SF	564 (256)	2 (50)	4500 (31)	65	5750 (39.6)	—	—
8206SFX	564 (256)	2 (50)	4500 (31)	110	6750 (46.5)	117%	1000 (6.9)

* Mixtures labeled with an "X" at the end of the label denote mixtures that included lightweight aggregate.

a finely divided alumino-silicate material with the calcium hydroxide liberated as the cement hydrates is contingent upon the availability of moisture."

CONCLUSIONS

Over the last 24 months, several major concrete paving projects in the Dallas-Fort Worth area have benefited from improved concrete performance due to the use of internal hydration. To date, more that 550,000 yd^3 (420,000 m^3) of concrete have been placed, with the greatest portion being low-slump concrete. Actual field conditions have demonstrated the improved hydration of the cementitious materials. This improvement can be quantified as demonstrated by the average compressive strength increase of about 1000 psi (7 MPa) shown herein.

The slow release of moisture from the lightweight aggregate to the concrete matrix has resulted in the mitigation or elimination of plastic and drying shrinkage cracking, as well as limiting the effects of self-desiccation. Enhanced workability and better consolidation due to an improved total grading provided by the use of an intermediate aggregate was also evident, as the contractors reported that it reduced the total placing time.

In addition to enhancing concrete performance, substituting 5 ft^3/yd^3 (0.19 m^3/m^3) of lightweight aggregate reduced the total weight of a cubic yard of concrete by about 200 lb (90 kg), resulting in a 2000 lb (900 kg) reduction in the total weight of a typical 10 yd^3 (7.6 m^3) load of concrete. This can increase a typical load by about 0.5 yd^3 (0.4 m^3) without increasing the weight. The obvious benefits in fuel savings and equipment wear caused by this reduction in weight have yet to be quantified. As this "work in progress" is continued, more will be learned about internal hydration benefits provided by the partial substitution of lightweight aggregate for normal-weight aggregate.

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Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

Selected for reader interest by the editors after independent expert evaluation and recommendation.

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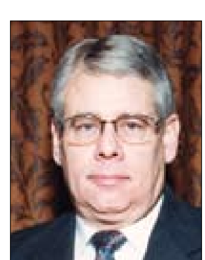

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