INTERNAL CURING OF CONCRETE PAVING: LABORATORY AND FIELD EXPERIENCE

Tracey Friggle, Don Reeves

Synopsis: The construction of a five-mile section of State Highway (SH) 121 north of Dallas is currently underway by the Texas Department of Transportation (TxDOT) and involves the conversion of a non-freeway into a freeway facility. This technical paper presents the field experience for mixing, placing, finishing, and testing of slipform mainline concrete paving, utilizing rotary kiln expanded lightweight aggregate as both an intermediate gradation and as reservoir to provide water to enhance the cement hydration of a typical paving mix. There is abundant laboratory research on internal curing of concrete including but not limited to numerous studies by Bentz et al "Internal Curing and Microstructure of High Performance Mortars". Construction of SH 121 represents the next logical step, following research, taking the laboratory to the field in the form of this major highway project. TxDOT anticipates higher strengths, leading to reduced paste content, reduced drying shrinkage cracking, and possibly less susceptibility to freeze thaw damage.

Keywords: Concrete; internal curing; lightweight aggregate

BIOGRAPHY

Tracey Friggle, P.E. is the Director of Construction, Dallas District, Texas Department of Transportation. She is a graduate of Texas A&M University, and a Registered Professional Engineer in the State of Texas. Texas Department of Transportation (TxDOT), P. O. Box 133076Dallas, Texas 75313-3067, Phone: 214-320-6199, Fax: 214-320-6119, Email: TFriggl@dot.state.tx.us

ACI member **Don Reeves** is a Customer Representative for the Expanded Shale and Clay Division of TXI Operations, LP. He is a Graduate of the State University of New York and currently serving on The Expanded Shale Clay and Slate Institute (Structural Committee), and The American Concrete Institute's Committee 213 (Structural Lightweight Aggregates). TXI Operations, LP Expanded Shale & Clay, 11111 Wilcrest Green, Suite 410, Houston, Texas 77042, Phone: 713-332-1410, Fax: 713-332-1419, Email: DReeves@TXI.com

INTRODUCTION

On November 16, 2006, approximately 1300 cubic yards of Class P concrete was placed by Balfour Beatty Construction in continuously reinforced concrete paving using a slip-form paving machine. The concrete was produced by TXI Operations, LP North Texas Ready Mix Division, from a nearby central mix plant, and delivered in ready mix trucks.

A portion of the normal weight limestone coarse aggregate and the fine aggregate were replaced by an intermediate grade of rotary kiln structural lightweight aggregate, which had been soaked in a stockpile under a sprinkler system in order to provide a nearly saturated aggregate to both optimize the combined gradation of the aggregates and to provide additional water for the hydration of the cement. In addition to compressive strength samples, specimens were cast for shrinkage measurements, setting time, and measurements of bleeding characteristics. A crack survey was also conducted on the finished pavement to verify the condition of the hardened concrete structure.

CONCRETE MIX DESIGN

The concrete mix was designed to conform to TxDOT Item 360 Class P, which among other requirements specifies a minimum flexural strength of 570 psi or 3500 (3.93 MPa or 24.1 MPa) psi in compression at 7 days. The proposed mix design is shown in **Table 1**. The aggregate gradations and the combined gradation are presented in **Table 2,** and **Figure 1** represents the combined gradation plotted on a graph with the idealized limits commonly known as the power curve.

CONCRETE BATCHING AND PLACEMENT

The concrete was batched utilizing two central mix plants located approximately 5 miles from the project site. The general contractor had central mix plants on site, but these plants were not used because they lacked the bin capacity to handle the additional aggregate. The concrete was delivered using conventional ready mix trucks, which initially proved to be a problem. The standard procedure for this project had been to use dump trucks loaded at the contractor's job site batch plants. Both the contractor's personnel and equipment were geared to handle ¾ inch to 1 inch (19 to 25 mm) slump but the ready mix trucks, even though they were rated by the manufacturer as paving mixers, were not able to discharge the typical slump at the rate required for the project. After increasing the workability of the mix to about a 3 inch (75mm) slump the remainder of the placement went well. The contractor's paving train is shown in the attached **Figure 3 – 6.** Another point of interest was the nearly ideal weather conditions for concrete. The temperature ranged from 38 degrees F (3º C) at 7:00 am to 57 degrees (14º C) at 5:00 pm. The wind was moderate and the humidity ranged from 50% in the morning to 29% in the afternoon. The weather information is provided in **Figure 7**.

CONCRETE FINISHING

The finishing was as directed by TxDOT specifications. The concrete was placed to the proper grade and vibrated in place by the slip-form machine, followed by a float attached to the back of the paver and manual bull floating where necessary. Surface finishing work was enhanced by the addition of the lightweight aggregate. It is believed, based upon observation, that the lightweight aggregate provided bleed water throughout the entire finishing and curing process, which significantly improved finishing.

A carpet drag and tining followed by the spray application of curing compound, after the bleed water had stopped, completed the finishing operation. Perhaps because of the cool temperature or the extra water required to raise the slump the carpet drag was suspended because it was causing the surface to tear. In the end, the finish was considered to be good by all concerned. **(Figure 9-10)** Normally, a 3 inch (75mm) slump is excessive for slip-form pavement due to the necessity of keeping the free edge completely vertical. On this project, one edge of the pavement was placed against the existing lane and the other had to stand on its own. There was no excessive effort required by the contractor to maintain the free standing edge. We believe this added benefit can also be attributed to the use of the lightweight aggregate.

While cooler temperatures can improve the ultimate strength of concrete, they can also increase the setting time of the mix, leading to a greater exposure to drying of the surface. An initial time of set of 340 minutes (5.6 hours), and a finale set of 500 minutes (8.3 hours) was measured by the Center for Transportation Research, The University of Texas at Austin (CTR) on concrete sampled during the placement. Visual inspection of the pavement immediately after the placement and during a survey conducted by CTR on February 1, 2007 confirmed the concrete to be in good condition. **(Figure 8)**

TEST RESULTS

The data from cylinders indicated compressive strengths well above the specified minimums**. (Table 3)** It is likely that the combination of cool temperatures, optimized aggregate gradations, and the benefits of internal curing have together contributed to the above data.

Shrinkage tests were conducted on two samples taken from the plastic concrete during the paving operations. One sample was screened to remove the lightweight aggregate. The testing conducted by The Center for Transportation Research (CTR) indicates that the sample with the intermediate lightweight aggregate removed had approximately 10% greater shrinkage at 28 days then the sample with the lightweight aggregate. **(Figure 2)**

On February 1, 2007, a crack survey was conducted by CTR. The pavement was 76 days old at the time of the crack survey. The graphical representation **(Figure 8)** of the survey indicates that the average crack spacing was 31 feet, in a survey area that was 500 feet long. The standard deviation was 24.1 feet. It is believed that typical crack spacing for a similar pavement is approximately 3 to 4 feet, which is a dramatic improvement.

On September 11, 2007, an additional crack survey was conducted by the Transtec Group (TG). During this inspection, both the test section and an adjacent pavement section placed with the contractor's standard mix were measured and compared for quantity and width of cracks. There is an overwhelming reduction in the number of cracks (21 vs. 52) and a significant reduction in the measured width of the cracks between the standard mix and the test section (90% vs. 63% less than 0.10mm).

CONCLUSIONS

A section of State Highway 121 has been placed with Class P concrete containing rotary kiln structural intermediate grade lightweight aggregate. Compressive strength testing and shrinkage tests indicate positive results. A condition survey of the pavement conducted 76 days after the placement further confirms good quality concrete in the test section. The above data, coupled with their past experience, has convinced the Texas Department of Transportation to write a special provision to their Standard Specifications to allow the use of rotary kiln structural lightweight aggregate in future paving structures. It is believed that the use of lightweight aggregate in concrete pavement could provide benefits including reduction of paste, and reduction of drying shrinkage cracking.

ACKNOWLEDGMENT

The authors would like to thank Randy Ferraresi, Balfour Beatty Construction, Moon Won, The Center for Transportation Research The University of Texas at Austin, Victor Villareal, TXI Operations, LP, North Texas Ready Mix Division, and their respective staffs for their invaluable assistance in the completion of this project.

REFERENCES

Bentz, D " -Curing and Microstructure of High-performance Mortars" This Proceedings, 2007.

Resendez, Yadhira A. and Rogers, Rich B. P.E., "Visual Condition Survey of a Lightweight Aggregate Section on SH-121 near Plano, Texas, 2007 .

Won, M., "SH 121 Testing" Unpublished test results conducted by The Center for Transportation Research at The University of Texas at Austin. 2007

TABLES AND FIGURES

List of Tables:

List of Figures:

Table 1 – Concrete Mix Design

Cement type I / II	413 lbs/y^3	(245 Kg/m^3)
Fly ash class C	91 lbs/y^3	(54 Kg/m^3)
1" - #4 Limestone	1084 lbs/y^3	(643 Kg/m^3)
11/2" – ¾" Limestone	706 lbs/y^3	(419 Kg/m^3)
Concrete sand	857 lbs/y^3	(508 Kg/m^3)
Intermediate lightweight	300 lbs/y^3	(178 Kg/m^3)
Water	241 lbs/y^3	(143 Kg/m^3)
Air entraining agent	2.5 oz.	44 ml/m^3
Water reducer	15.0 oz.	263 ml/m^3

Table 2 – Sieve Analysis

	% Passing					
Sieve Size	Coarse agg.1	Coarse agg. 2	Lightweight agg.	Fine agg.	Combined	Combined % Retained
2"	100				100	0
1 1/2"	99.3	100			99.8	0.2
1"	80	99.3			95.2	4.6
3/4"	51.8	85.8			84.3	10.9
1/2"	34	48.3	100		67.6	16.7
3/8"	12.1	19.8	99.8	100	52.9	14.6
no. 4	1.3	4.2	58.9	97.7	38	14.9
no. 8	0	1.4	15.5	87.9	27.1	10.9
no. 16		0	4.1	75.6	21.4	5.7
no. 30			0	58.9	16.2	5.2
no. 50				22.4	6.2	10
no. 100				2.6	0.7	5.4
no. 200				0.3	0.1	0.6
pan						0.1

Table 3 - Compressive Strength PSI(MPu)

Age	TxDOT	CTR
1		1750 (12.1)
4	3860 (26.6)	3900 (26.9)
7		4900 (33.8)
8	5690 (39.2) 5810 (40.0)	
14		5300 (36.5)
28		6000 (41.4)

Table 4 - Crack information for lightweight aggregate section

	feet from construction joint/start)	Station	Crack Width (mm)
Start	0	765+03	
	58	765+61	< 0.10
	90	765+93	< 0.10
	131	765+34	< 0.10
	147	766+50	0.10
	160	766+63	< 0.10
	177	766+80	< 0.10
	194	766+97	< 0.10
	209	767+12	< 0.10
	218	767+21	< 0.10
	232	767+35	< 0.10
	242	767+45	< 0.10
	255	767+58	< 0.10
	268	767+71	< 0.10
	275	767+78	0.15
	302	768+05	< 0.10
	327	768+30	< 0.10
	341	768+44	< 0.10
	355	768+58	< 0.10
	385	768+88	< 0.10
	424	769+27	< 0.10
End	500	770+03	< 0.10

Table 5 - Cracking information for control section

	feet from construction joint/start)	Station	Crack Width (mm)
Start	0	765+03	
	72	765+75	<0.10
	74	765+77	0.15
	82	765+85	0.15
	92	765+95	<0.10
	103	766+06	<0.10
	116	766+19	<0.10
	118	766+21	<0.10
	125	766+28	<0.10
	137	766+40	<0.10
	147	766+50	0.15
	156	766+59	<0.10
	159	766+62	0.15
	164	766+67	<0.10
	175	766+78	<0.10
	183	766+86	<0.10
	193	766+96	<0.10
	199	767+02	<0.10
	208	767+11	0.15
	220	767+23	0.15
	227	767+30	0.15
	232	767+35	0.15
	243	767+46	0.15
	260	767+63	<0.10
	268	767+71	<0.10
	273	767+76	<0.10
	275	767+78	<0.10
	290	767+93	<0.10
	299	768+02	<0.10
	302	768+05	0.15
	313	768+16	<0.10
	318	768+21	<0.10
	327	768+30	<0.10
	341	768+44	<0.10
	355	768+58	<0.10
	365	768+68	<0.10
	373	768+76	<0.10
	380	768+83	<0.10
	385	768+88	<0.10
	394	768+97	<0.10
	401	769+04	<0.10
	409	769+12	<0.10
	420	769+23	<0.10
"Y" Crack	426	769+29	0.10-0.15, 0.10
	432	769+35	0.15
	442	769+45	0.15
	453	769+56	0.10
	465	769+68	0.15
	475	769+78	0.15
	485	769+88	0.15
	492	769+95	0.10
	495	769+98	<0.10
End	500	770+03	<0.10

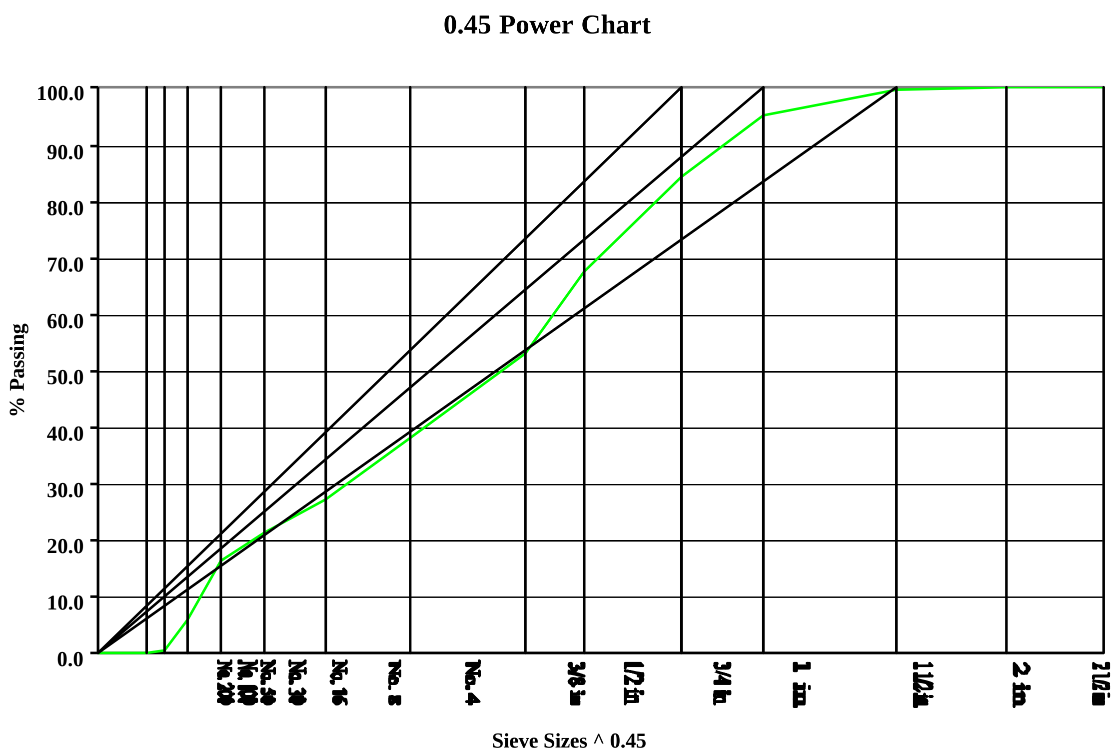

Figure 1 – Power Chart

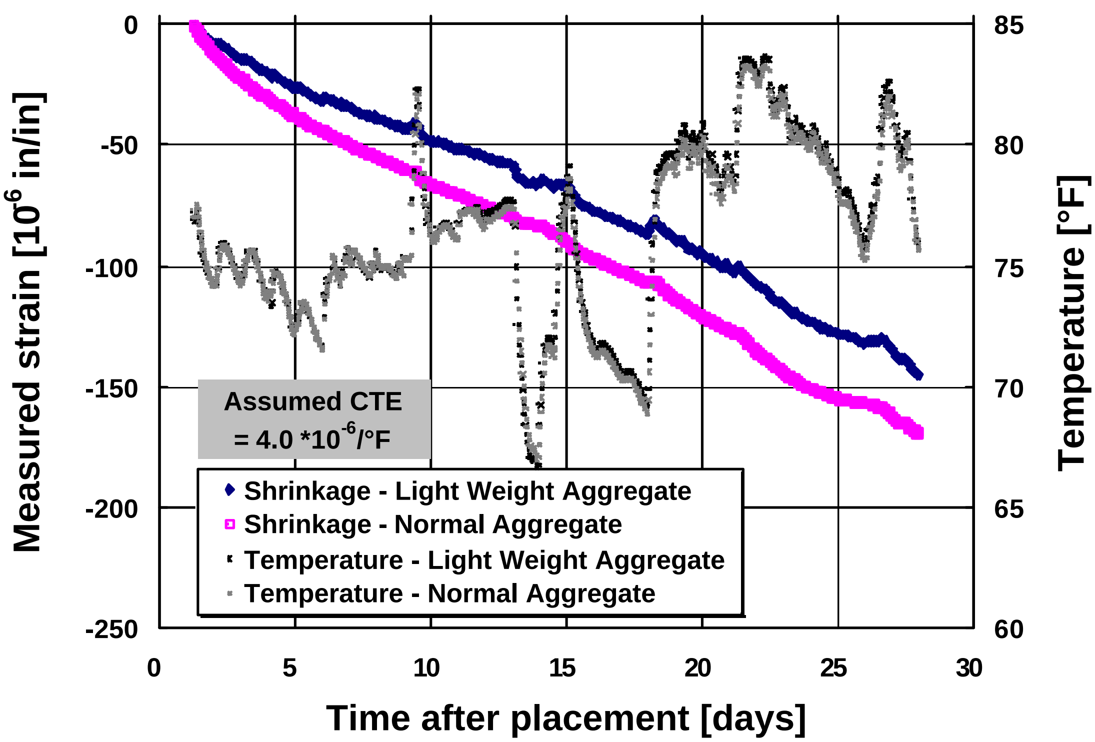

Figure 2 – Shrinkage from Total Strain

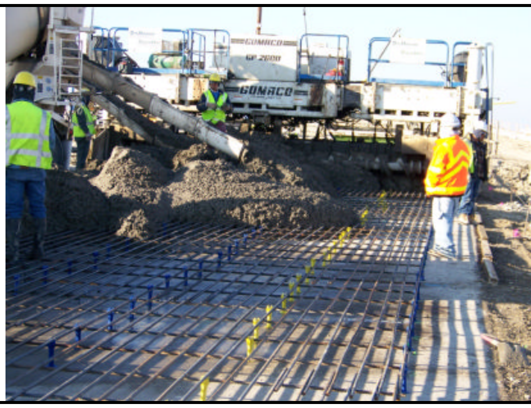

Figure 3 – Paving Train

Figure 4 - Paving Train

Figure 5 - Paving Train

Figure 6 – Carpet Drag

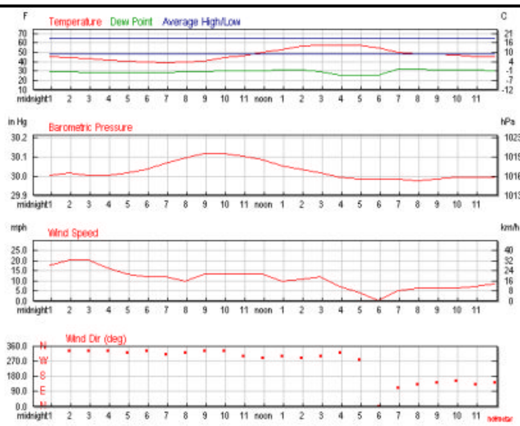

Figure 7 – Weather Data

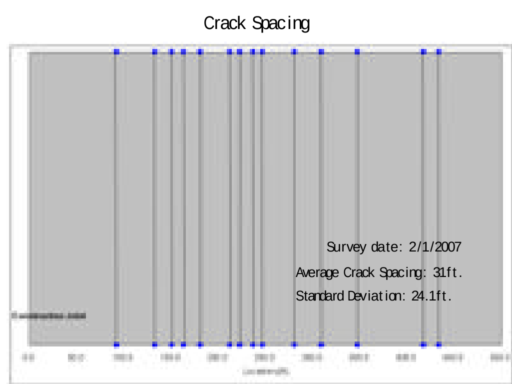

Figure 8 – Crack Survey

	
Figure 9 – Concrete Finish	**Figure 10 – Curing Compound**

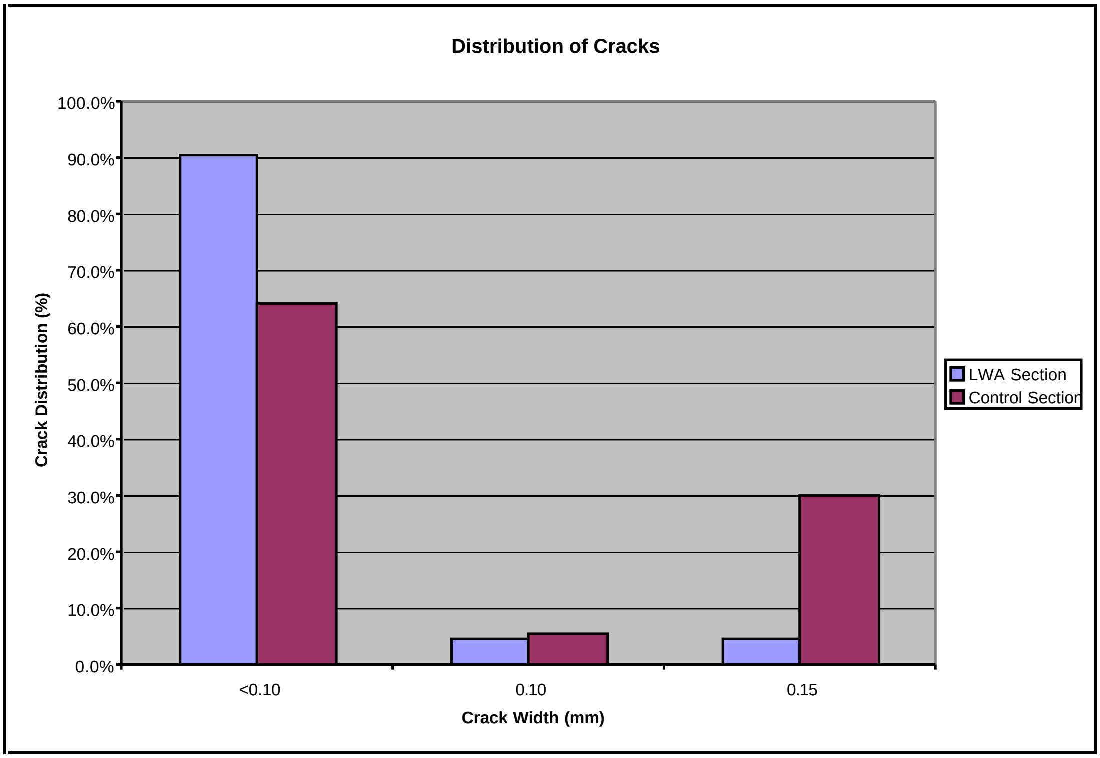

Figure 11 - Crack distributions on lightweight aggregate and control section