

**State of Wisconsin/Department of Transportation**  
RESEARCH PROGRESS REPORT FOR THE QUARTER ENDING: June 30, 2006

<b>Program: SPR-0010(36) FFY99</b>	<b>Part: II Research and Development</b>
<b>Project Title: Investigation of Concrete Properties to Support Implementation of the New AASHTO Pavement Design Guide</b>	<b>Project ID: 0092-06-03</b>
<b>Administrative Contact: James McDonnell</b>	<b>Sponsor: WHRP</b>
<b>WisDOT Technical Contact: Jim Parry</b>	<b>Approved Starting Date: 10/01/05</b>
<b>Approved by COR/Steering Committee: \$60,000</b>	<b>Approved Ending Date: 9/30/06</b>
<b>Project Investigator (agency &amp; contact): Tarun R. Naik, UWM Center for By-Products Utilization</b>	

**Percent Complete:** 70%

**Project Description:**

The overall objective of this project is to provide material properties to be used for input into a mechanistic-empirical design procedure for concrete pavements. The use of the mechanistic-empirical design basis for design of concrete pavements is expected to provide increased reliability of pavement structures and to provide a basis for the prediction of service life, and how the pavement design parameters will affect various pavement failure modes including cracking, faulting, and IRI (International Roughness Index). In order to provide the input required for the new mechanistic-empirical design, this project has the following minimum objectives.

- (1) Collect existing literature.
- (2) Develop a work plan for testing splitting tensile strength and coefficient of thermal expansion (CTE) of concrete.
- (3) Evaluate the effect of portland cement, slag, and fly ash sources on splitting tensile strength and CTE of concrete.
- (4) Evaluate the effect of source change of glacial gravel on splitting tensile strength and CTE of concrete.
- (5) Evaluate the effect of source change of crushed stone on splitting tensile strength and CTE of concrete.
- (6) Generate test results for compressive strength in addition to the splitting tensile strength and CTE of concrete.
- (7) Submit a final report to WHRP that contains all test results regarding splitting tensile strength, compressive strength, and CTE of concrete and recommendations for future work.

**Progress This Quarter:**

(Includes project committee mtgs, work plan status, contract status, significant progress, etc.)

Production was completed for all of the 19 concrete mixtures that had been planned for the project. Testing was continued on the concrete mixtures for splitting tensile strength, compressive strength, and CTE. The mixture proportions and test results obtained through June 30, 2006 are given in the Appendix.

**Work Next Quarter:**

The following work is planned during the next quarter of the project:

- Complete testing of the concrete mixtures.
- Complete evaluation of concrete test results.
- Submit a draft of the final report to WisDOT for review.



**Circumstances Affecting Progress/Budget:**

None

**Gantt Chart:**

**PROJECT SCHEDULE**

Tasks	2005			2006								
	Q2			Q3			Q4			Q1		
	O	N	D	J	F	M	A	M	J	J	A	S
<b>Task 1:</b> Literature Review												
<b>Task 2:</b> Selection of Materials and Concrete Mixtures												
<b>Task 3:</b> Production of Concrete Mixtures												
<b>Task 4:</b> Laboratory Testing of Splitting Tensile and Compressive Strengths												
<b>Task 5:</b> Laboratory Testing of Coefficient of Thermal Expansion												
<b>Task 6:</b> Evaluation of Results												
<b>Task 7:</b> Reports												

 Planned activity start/stop and duration  
 Actual project progress

Note: Gantt chart shown in State Fiscal Year Quarters

**APPENDIX**

**Table 1. Sources of WisDOT No. 1 and No. 2\* Coarse Aggregates**

Aggregate Source	Aggregate Type**	Source Name	County
1	Baraboo Quartzite	Williams Quarry	Columbia
2	Prarie Du Chien Dolomite – SW Wisconsin	Slama Quarry	Crawford
3	Galena Dolomite	Haverland Quarry	Grant
4	Glacial Gravel – S End Green Bay Lobe	Janesville, Sand & Gravel	Rock
5	Glacial Gravel – Lake Michigan Lobe	JW Peters	Racine
6	Niagara Dolomite	Franklin Quarry - Vulcan	Milwaukee
7	Galena Platteville Dolomite	Carew Concrete	Outagami
8	Glacial Gravel – Lake Michigan/ Green Bay Trans	Evanson Quarry	Manitowoc
9	Prairie Du Chien Dolomite – NE Wisconsin	Faulk Bros. Quarry	Waupaca
10	Granite	Haske Quarry	Wood
11	Diabase	RME- Athens	Marathon
12	Glacial Gravel – Central Green Bay Lobe	Wimme Pit	Portage
13	Glacial Gravel – Wisconsin Valley Lobe	Crass Road Pit	Lincoln
14	Chippewa River Gravel	Todds Ready-Mix	Barron
15	Basalt Traprock	Dresser Quarry	Polk

\* Same as AASHTO No. 67 (19.0 to 4.75 mm [0.75 to 0.1875 in.]) and No. 4 (37.5 to 19.0 mm [1.5 to 0.75 in.]), respectively.

\*\* Aggregate types are from WisDOT description of the sources.

**Table 2. Mixture Proportions and Fresh Properties of Concrete (SI [Metric] Units)**

Mixture designation*	1	2	2-O	3	3-C2	4	5	6	7	7-S
Cement, Type I (kg/m <sup>3</sup> )	233	229	323	226	231	232	236	232	241	238
Class C fly ash (kg/m <sup>3</sup> )	101	99	0	97	99	100	102	100	104	0
Grade 120 GGBFS (kg/m <sup>3</sup> )	0	0	0	0	0	0	0	0	0	102
Water (kg/m <sup>3</sup> )	130	132	127	123	124	133	135	133	138	137
Fine aggregate, SSD (kg/m <sup>3</sup> )	644	635	634	624	636	641	652	641	664	661
Coarse aggregate, 19-mm max., SSD (kg/m <sup>3</sup> )	712	711	711	707	721	719	729	719	736	731
Coarse aggregate, 38-mm max., SSD (kg/m <sup>3</sup> )	475	475	478	470	479	477	486	478	490	486
Water-reducing admixture (L/m <sup>3</sup> )	0.32	0.32	0.94	0.73	0.16	0.05	0.18	1.31	0.17	0.67
Air-entraining admixture (L/m <sup>3</sup> )	1.93	0.80	1.17	0.89	0.87	0.96	0.93	0.58	1.49	1.56
Water-cementitious ratio, W/Cm	0.39	0.40	0.39	0.38	0.38	0.40	0.40	0.40	0.40	0.40
Slump (mm)	50	105	55	75	65	70	80	65	65	30
Air content (%)	6.1	6.0	6.1	7.3	6.0	6.1	5.9	7.0	6.2	5.6
Air temperature (°C)	22	21	22	22	22	23	22	21	22	22
Concrete temperature (°C)	21	21	22	22	22	21	21	21	19	22
Density (kg/m <sup>3</sup> )	2300	2280	2270	2250	2290	2300	2340	2300	2370	2360

Mixture designation*	8	9	9-F2	10	11	12	13	14	15
Cement, Type I (kg/m <sup>3</sup> )	241	239	234	229	248	241	239	238	244
Class C fly ash (kg/m <sup>3</sup> )	104	103	101	99	107	104	103	103	105
Grade 120 GGBFS (kg/m <sup>3</sup> )	0	0	0	0	0	0	0	0	0
Water (kg/m <sup>3</sup> )	138	138	135	134	143	138	137	136	140
Fine aggregate, SSD (kg/m <sup>3</sup> )	664	661	647	633	685	664	661	657	673
Coarse aggregate, 19-mm max., SSD (kg/m <sup>3</sup> )	737	740	724	701	756	738	735	732	743
Coarse aggregate, 38-mm max., SSD (kg/m <sup>3</sup> )	491	491	480	465	504	491	489	487	494
Water-reducing admixture (L/m <sup>3</sup> )	0.17	0.16	0.16	0.77	0.15	0.05	0.08	0.07	0.05
Air-entraining admixture (L/m <sup>3</sup> )	1.41	2.14	1.64	1.66	1.14	1.49	1.07	0.98	2.35
Water-cementitious ratio, W/Cm	0.40	0.40	0.40	0.41	0.40	0.40	0.40	0.40	0.40
Slump (mm)	80	25	100	75	30	75	75	105	55
Air content (%)	6.4	5.6	6.8	7.9	4.8	5.4	5.8	5.2	6.4
Air temperature (°C)	22	22	22	22	21	22	22	22	21
Concrete temperature (°C)	20	22	21	21	21	22	22	22	21
Density (kg/m <sup>3</sup> )	2370	2370	2320	2260	2440	2380	2360	2350	2400

\* Mixture designation:

n-X

where,

n: Coarse aggregate source

X: Cementitious materials, if different from Cement 1 (Lafarge) + Fly ash 1 (Pleasant Prairie, P4):

O: Cement 1 only.

C2: Cement 2 (St. Marys) + Fly ash 1.

S: Cement 1 + Slag cement (GGBFS, ground granulated blast-furnace slag).

F2: Cement 1 + Fly ash 2 (Weston).

**Table 3. Mixture Proportions and Fresh Properties of Concrete (U.S. Customary Units)**

Mixture designation	1	2	2-O	3	3-C2	4	5	6	7	7-S
Cement, Type I (lb/yd <sup>3</sup> )	393	386	545	381	388	391	398	391	405	400
Class C fly ash (lb/yd <sup>3</sup> )	169	167	0	164	167	169	172	168	175	0
Grade 120 GGBFS (lb/yd <sup>3</sup> )	0	0	0	0	0	0	0	0	0	173
Water (lb/yd <sup>3</sup> )	219	223	213	207	209	224	227	225	233	231
Fine aggregate, SSD (lb/yd <sup>3</sup> )	1090	1070	1070	1050	1070	1080	1100	1080	1120	1110
Coarse aggregate, 0.75" max., SSD (lb/yd <sup>3</sup> )	1200	1200	1200	1190	1210	1210	1230	1210	1240	1230
Coarse aggregate, 1.5" max., SSD (lb/yd <sup>3</sup> )	799	800	804	791	807	804	818	805	825	819
Water-reducing admixture (fl oz/yd <sup>3</sup> )	8.3	8.3	24.2	18.9	4.1	1.2	4.6	33.8	4.3	17.2
Air-entraining admixture (fl oz/yd <sup>3</sup> )	49.8	20.5	30.2	22.9	22.5	24.8	23.9	14.9	38.5	40.4
Water-cementitious ratio, W/Cm	0.39	0.40	0.39	0.38	0.38	0.40	0.40	0.40	0.40	0.40
Slump (in.)	2	4-1/4	2-1/4	3	2-1/2	2-3/4	3-1/4	2-3/4	2-3/4	1-1/4
Air content (%)	6.1	6.0	6.1	7.3	6.0	6.1	5.9	7.0	6.2	5.6
Air temperature (°F)	71	70	71	72	71	73	71	70	71	72
Concrete temperature (°F)	70	70	71	72	71	69	70	70	66	72
Density (lb/ft <sup>3</sup> )	143	142	142	140	143	144	146	144	148	147

Mixture designation	8	9	9-F2	10	11	12	13	14	15
Cement, Type I (lb/yd <sup>3</sup> )	405	403	394	386	418	405	403	401	410
Class C fly ash (lb/yd <sup>3</sup> )	175	174	170	167	180	175	174	173	177
Grade 120 GGBFS (lb/yd <sup>3</sup> )	0	0	0	0	0	0	0	0	0
Water (lb/yd <sup>3</sup> )	233	232	227	225	240	232	231	230	236
Fine aggregate, SSD (lb/yd <sup>3</sup> )	1120	1110	1090	1070	1150	1120	1110	1110	1130
Coarse aggregate, 0.75" max., SSD (lb/yd <sup>3</sup> )	1240	1250	1220	1180	1270	1240	1240	1230	1250
Coarse aggregate, 1.5" max., SSD (lb/yd <sup>3</sup> )	826	827	809	783	848	828	823	821	832
Water-reducing admixture (fl oz/yd <sup>3</sup> )	4.3	4.3	4.2	19.8	4.0	1.3	2.1	1.7	1.3
Air-entraining admixture (fl oz/yd <sup>3</sup> )	36.4	55.3	42.5	42.9	29.5	38.5	27.7	25.4	60.6
Water-cementitious ratio, W/Cm	0.40	0.40	0.40	0.41	0.40	0.40	0.40	0.40	0.40
Slump (in.)	3-1/4	1	4	3	1-1/4	3	3	4-1/4	2-1/4
Air content (%)	6.4	5.6	6.8	7.9	4.8	5.4	5.8	5.2	6.4
Air temperature (°F)	71	71	71	71	70	71	71	71	70
Concrete temperature (°F)	68	71	70	70	70	71	71	71	69
Density (lb/ft <sup>3</sup> )	148	148	145	141	152	148	147	147	150

**Table 4. Compressive Strength of Concrete (MPa)**

Mixture	7-day	14-day	28-day	90-day
1	22.5	25.2	30.1	
2	20.0	23.5	27.2	31.9
2-O	24.1	29.6	32.8	
3	21.7	24.9	29.9	35.0
3-C2	19.6	34.1	36.4	
4	20.3	24.0	28.0	
5	24.5	26.3	33.6	41.2
6	28.3	32.9	36.4	41.4
7	25.0	30.1	35.3	40.7
7-S	27.9	33.8	37.0	
8	19.0	20.5	26.1	31.8
9	25.5	32.4	36.1	40.3
9-F2	19.0	22.0	24.6	
10	23.9	26.4	27.0	34.6
11	26.2	27.5	38.3	40.8
12	23.3	27.4	30.5	
13	19.8	22.4	24.5	30.7
14	19.9	25.0	28.9	37.9
15	19.1	20.8	26.9	29.5

**Table 5. Compressive Strength of Concrete (psi)**

Mixture	7-day	14-day	28-day	90-day
1	3270	3660	4370	
2	2900	3410	3940	4630
2-O	3490	4300	4750	
3	3150	3610	4340	5070
3-C2	2840	4940	5280	
4	2950	3480	4060	
5	3550	3820	4870	5970
6	4110	4770	5280	6010
7	3620	4360	5120	5900
7-S	4050	4900	5370	
8	2760	2980	3780	4610
9	3700	4700	5240	5840
9-F2	2750	3190	3570	
10	3470	3830	3910	5020
11	3800	3990	5560	5920
12	3380	3970	4430	
13	2870	3250	3550	4450
14	2880	3620	4190	5490
15	2770	3020	3900	4280

**Table 6. Splitting Tensile Strength of Concrete (MPa)**

Mixture	7-day	14-day	28-day	90-day
1	3.38	3.45	4.07	
2	3.24	3.45	3.72	4.48
2-O	3.45	3.72	4.07	
3	2.76	2.83	3.45	4.27
3-C2	2.83	3.72	3.86	
4	3.31	3.65	4.00	
5	2.90	3.31	3.79	4.34
6	3.72	4.14	4.62	5.52
7	2.76	3.59	3.59	5.45
7-S	3.86	4.21	4.21	
8	3.03	2.96	3.45	4.62
9	3.45	3.45	3.86	4.69
9-F2	2.62	2.90	3.72	
10	3.03	3.65	3.72	4.21
11	3.65	3.72	4.48	5.03
12	2.83	3.45	3.79	
13	2.76	3.17	3.38	4.14
14	2.76	3.45	3.72	4.48
15	3.24	3.86	4.00	4.76

**Table 7. Splitting Tensile Strength of Concrete (psi)**

Mixture	7-day	14-day	28-day	90-day
1	490	500	590	
2	470	500	540	650
2-O	500	540	590	
3	400	410	500	620
3-C2	410	540	560	
4	480	530	580	
5	420	480	550	630
6	540	600	670	800
7	400	520	520	790
7-S	560	610	610	
8	440	430	500	670
9	500	500	560	680
9-F2	380	420	540	
10	440	530	540	610
11	530	540	650	730
12	410	500	550	
13	400	460	490	600
14	400	500	540	650
15	470	560	580	690

**Table 8. Coefficient of Thermal Expansion (CTE) of Concrete (microstrain/°C)**

Mixture	28-day CTE
1	12.2
2	10.6
2-O	10.7
3	10.5
3-C2	10.5
4	10.7
5	10.4
6	10.6
7	10.4
7-S	10.5
8	10.5
9	10.8
9-F2	10.6
10	9.5
11	9.3
12	9.9
13	9.7
14	10.1
15	9.3