

Center for By-Products Utilization

DEVELOPMENT AND DEMONSTRATION OF HIGH-CARBON CCPs AND FGD BY-PRODUCTS IN PERMEABLE ROADWAY BASE CONSTRUCTION, YEAR 2 – FOURTH QUARTER

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**DEVELOPMENT AND DEMONSTRATION OF HIGH-CARBON CCPS AND FGD
BY-PRODUCTS IN PERMEABLE ROADWAY BASE CONSTRUCTION**

Year 2 –Fourth Quarter

CBRC Midwestern Regional Center Subcontract SIUC 99-17

By

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PROJECT OBJECTIVES

This investigation was conducted to develop and demonstrate permeable base course materials using coal combustion products (CCPs) for highways, roadways, and airfield pavements. Three types of CCPs, two flue-gas desulfurization (FGD) by-products, and a variable-carbon fly ash, are being evaluated for no-fines or low-fines concrete as a permeable base material. This project was undertaken to develop high-volume applications of such CCPs in manufacture of permeable base materials for highways, roadways, and airfield pavements. Use of FGD by-products and high-carbon or variable carbon CCPs in permeable base course is expected to utilize significant quantities of these by-products. It will also help to reduce the cost of installing permeable base materials for pavement, which will lead to increased use of such permeable bases for highways, roadways, and airfield pavements. Reducing the cost of permeable base materials is expected to expand its use in many other types of pavement construction with increased pavement life and increased utilization rate of CCPs and FGD by-products.

To meet the objectives of the project, the entire work was organized in two major phases. These two phases have been subdivided into the following tasks:

Phase 1 - Year 1: Laboratory Activities

Task 1: Acquisition, Characterization, and Evaluation of Materials

Task 2: Development of Base Course Mixture Proportions

Task 3: Testing and Evaluations

Task 4: CCPs and FGD By-Product Utilization Criteria and Base Course Specifications

Task 5: Base Course Design Criteria and Construction Guidelines

Task 6: Reports

Phase 2: Field Demonstration and Technology Transfer

Task 7: Field Demonstrations, Testing, and Evaluation

Task 8: Demonstration/Technology Transfer

Task 9: Optimization of Construction Specifications

Task 10: Reports

BACKGROUND

Presence of excess water in the pavement structure is known to be the primary cause of pavement distress. Extended exposure to water can lead to pumping, D-cracking, faulting, frost action, shrinkage, cracking, and potholes. Out of these parameters, pumping is known to be the most dominating mechanism of pavement distress. The water that infiltrates through the pavement is trapped within the pavement structure when draining capabilities of the pavement base is low. When high pressure is applied to these pavements from heavy traffic loads, pumping occurs in the presence of water. This causes erosion of the base because fines are pumped out along with the water. Consequently, a loss in pavement support occurs, leading to early failure of pavement. This can be avoided by using free-draining pavement base.

In order to meet current and future EPA air quality standards, utilities are utilizing supplemental flue gas treatments to reduce emissions. These treatments either alter the quality of the coal combustion by-products, or generate another type of "waste" material. Two processes typically used are flue gas desulfurization (FGD) to reduce SO_x emissions and low-NO_x burners to reduce NO_x emissions. FGD by-products are high-sulfite and/or sulfate by-products, and low-NO_x burners generate high-carbon CCPs. Approximately 18 million tons of FGD by-products were generated in 1998 in the USA with a utilization rate of less than ten percent. Consequently, most of FGD by-products are landfilled at high disposal costs and potential future environmental liabilities to the producer. To avoid these, there is a need to develop beneficial uses of these by-products.

STATUS

This report summarizes the work completed during the period from April 1, 2002 through June 30, 2002. During this period, testing and evaluation work pertaining to Task 3 of the project, "Testing and Evaluations" was completed through the age of 365 days for Series 7 mixtures (open-graded base course mixtures) using ash sources FGD-1, FGD-2, and FGD-3, and Series 8 mixtures (dense graded base course mixtures). Long-term testing related to Tasks 3 for Series 9, (intermediate-graded base course) is in progress. Testing of Series 9 permeable base mixtures have been started for the final testing (for the age of 365 days). Additional work for Tasks 7 of the project, "Field Demonstrations, Testing, and Evaluation," and Task 8, "Demonstration/Technology Transfer," has begun. Meetings were held with the FGD-3 coal ash producer, construction management members, and concrete manufacturer. Based on these

meetings, the field demonstration and technology transfer seminar was scheduled for September 19, 2002 in Green Bay, Wisconsin. The source of ash to be used for the construction demonstration has also been selected based on test results and construction requirements. The technology transfer workshop announcement has been finalized and will be mailed to a comprehensive list (approximately 5,500) that UWM-CBU maintains. Additional work pertaining to the construction demonstration has also been scheduled and will be held in Green Bay on July 12, 2002. Work on July 12 will consist of prototype scale manufacturing of up to four different mixtures selected from mixtures developed during the laboratory phase of the project. Test specimens will be taken from each of the prototype scale mixtures for evaluation of compressive strength, splitting tensile strength, flexural strength, etc.

Laboratory Base Course Mixture Development and Evaluation

The laboratory evaluation completed to-date is composed of two parts. The first describes experimental work related to characterization of constituent materials. The second part deals with development of mixture proportions, and manufacturing and testing of mixtures for base course materials. Currently, long-term testing for the second part of the investigation is continuing. Constituent materials of the permeable base mixtures (fine aggregate, coarse aggregate, cement, and CCPs) were tested and evaluated using applicable ASTM standards or other applicable standards. Three sources of CCPs (FGD-1, FGD-2, and FGD-3) were selected for this investigation. FGD-1 and FGD-2 contained high levels of sulfite/sulfates; and, therefore, it did not meet the ASTM C 618 requirements for coal fly ash for use as mineral admixtures in concrete. FGD-3 conformed to the ASTM C 618 requirements for Class C fly ash. Both FGD-1 and FGD-2 contained high amounts of sulfate and unburned carbon as measured by loss on ignition (LOI).

Mixture proportions for the base course materials were developed and optimized using a two-step process. The first step involved developing mixture proportions for permeable base course materials without CCPs. The optimum mixtures developed from the first step of the experimental process were used for developing mixture proportions for the second step of the optimization process. The second step of the mixtures included various combinations of CCPs for developing mixtures for base course materials.

Experimental work pertaining to the first step of optimization has been completed. To date, a total of 56 concrete mixtures have been proportioned, manufactured, and tested in nine different series of experiments. Of these, 26 mixtures were proportioned for the first step of optimization. All concrete mixtures were tested and evaluated for fresh and hardened concrete properties using applicable ASTM standards. The fresh concrete properties measured were air content, unit weight, and temperature. Ambient air temperature was also recorded.

For the first step of optimization, hardened concrete properties measured were density and compressive strength. For this step of investigation, the effects of amount of cement and water to cementitious materials ratio on the performance of permeable base course mixtures were

investigated. Based on the compressive strength results, three candidate mixtures were selected, which formed the basis for mixture proportioning for the second step of optimization.

For the second step of the optimization process, a total of 30 mixtures were proportioned using FGD-1, FGD-2, and FGD-3. Three series of mixtures were developed, one open-graded base course structure (Series 7), one intermediate-graded (Series 9), and one dense-graded (Series 8) base course structure. Each series of mixtures incorporated all three sources of CCPs material used for this project. Long-term evaluation of the open-graded and dense-graded series mixtures have been completed during the last quarter while final testing of the intermediate-graded base course will be completed during the next quarter. Each mixture is being tested for strength and durability properties. Strength properties include compressive strength, tensile strength, and flexural strength. These properties were measured as a function of time up to the age of one year. Durability-related properties include shrinkage, sulfate resistance, and freezing and thawing resistance. Freezing and thawing testing has been completed for approximately 75% of the mixtures from Series 7, 8, and 9. The remaining mixtures are expected to be completed over the next quarter. Testing and evaluation of Series 7, 8, and 9 mixtures for shrinkage and sulfate resistance also will continue over the next quarter.

Testing of Base Course Materials

The testing of the base course mixtures associated with this project has established the data necessary for optimizing mixture proportions for base course materials incorporating CCPs. Hardened concrete properties such as density, compressive strength, tensile strength, flexural strength, sulfate resistance, and freezing and thawing resistance have been determined. From these results, specifications for the use of CCPs will be developed for use in the construction demonstration to be conducted during the second year of the project.

Strength and Durability Properties—Compressive strength results of Series 1 mixtures have been completed. Compressive strength at the age of 28 days ranged from 850 to 2230 psi. Typically, mixtures with decreased fine aggregate contents exhibited lower compressive strengths. Results of Series 2 compressive strength tests are also complete.

Series 3 mixtures were proportioned to determine optimum cement contents for permeable base course materials. Testing of Series 3 mixtures are complete. Compressive strength of the mixtures at the age of 28 days ranged from 1560 psi for Mixture R1A containing 286 lb/yd³ cement, to 150 psi for Mixture R1D, which contained 48 lb/yd³ cement.

In the Series 4 investigation, Mixtures R1B1, R1B2, and R1B3 contained sand contents of 70%, 36%, and 0%, respectively of sand used in Mixture R1B. The compressive strength of Series 5 mixtures was used to investigate the effect of water to cementitious materials ratio on the performance of permeable base course mixtures. The three mixtures also varied fine aggregate content. Testing of mixtures for Series 6 investigations have been completed.

Compressive strength, splitting tensile strength, and flexural strength of Series 7 mixtures (open-graded structure) have been evaluated through the age of 365 days. Compressive strength, splitting tensile strength, and flexural strength of Series 7 mixtures are given in Tables 1-9, respectively. The compressive strength of the mixtures reported in Tables 4 and 7 includes tests conducted during the last quarter at the age of 365 days. Test results of Series 8 mixtures (dense-graded) have also been evaluated at the age of 365 days and are included in Tables 10-18. Compressive strength results at the age of 365 days for mixtures containing FGD-3 fly ash, FGD-1 fly ash, and FGD-2 fly ash are given in Tables 10, 13, and 16 respectively. Series 9 (intermediate graded) mixtures containing FGD-3 fly ash were also evaluated for compressive strength at the age of 365 days; and results are given in Table 19. The remaining Series 9 compressive strength tests at the age of 365 days will be completed during the next quarter.

Drying Shrinkage, Resistance to Freezing and Thawing, and Sulfate Resistance—Progress is continuing on the evaluation of base course durability properties, such as drying shrinkage, resistance to freezing and thawing, and sulfate resistance. These tests began at the age of 28 days or later, particularly for the test for resistance to freezing and thawing cycling. Results for specimens subjected to freezing and thawing are given in Fig. 1-8. The weight loss of the test specimens is expressed as the percentage weight loss based on dried sample weight.

Demonstration/Technology Transfer

The testing of the base course mixtures for this project has created the data necessary for selection of mixtures and applications for the permeable base materials as well as dense graded and intermediate graded pavements and base materials.

Prototype Testing and Evaluation—Ash source FGD-3 has been selected for demonstration and testing associated with the technology transfer workshop. The application chosen for the construction demonstration is for the use of concrete as a permeable base course material for an asphalt parking lot. Mixtures will be tested on a prototype basis at the concrete manufacturing plant during the next quarter. Prototype mixtures will be tested for compressive strength, flexural strength, etc., to obtain data necessary for the final selection of mixture(s) to be used during the final full-scale construction demonstration.

Demonstration/Technology Transfer—Green Bay, WI, has been selected as a location for the construction demonstration. The workshop location is also near the source of ash FGD-3. In consultation with construction personnel, the date of the construction demonstration has been selected as September 19, 2002. The technology transfer program will consist of approximately four hours of presentations of technology on the use of permeable base course materials based upon the results of this CBRC project followed by the construction demonstration. This program will be mailed and distributed to approximately 6,000 people representing engineers, government employees, architects, contractors, owners, etc. A copy of the technology transfer workshop announcement is given in Appendix A.

PLANS for the NEXT QUARTER

The following progress is expected over the next quarter:

- Complete testing of Series 9 mixtures for compressive strength at the 365-day age.
- Continue to analyze and evaluate long-term test data from laboratory mixtures.
- Conduct prototype-scale mixture work at a concrete manufacturer in Green Bay, WI, to be used for the proposed construction demonstration.
- Test prototype-scale mixtures for compressive strength, splitting tensile strength, flexural strength, etc.
- Select handout materials for the technology transfer workshop.
- Assemble registration information.

BUDGET DATA (AS OF JUNE 30, 2002)

The budget information presented below reflects total expenditures of the project through June 30, 2002. The total budget requested from SIU has been expended for the project. Additional funds required to complete the remaining portions of the project will be obtained from the sources designated as "UWM" and "Other." No increase in the budget from SIU is requested at this time.

STATEMENT OF ACCOUNT
THROUGH 6/30/02

BUDGET CATEGORY	TOTAL PROJECT BUDGET	<i>EXPENDITURES BY SOURCE</i>					
		THIS PERIOD			INCEPTION TO DATE		
		SIU	UWM	OTHER	SIU	UWM	OTHER
Salaries & Wages	\$ 52,725.00	\$ -	\$ -	\$ -	\$ 36,197.79	\$ 7,798.03	\$ 14,191.00
Fringe Benefits	\$ 8,528.00	\$ -	\$ -	\$ -	\$ 6,705.23	\$ 2,532.27	\$ 3,250.76
Sub (Concrete producer)	\$ 5,000.00	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Equipment User Fee	\$ 480.00	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Travel:							
Domestic	\$ 1,200.00	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Foreign	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Supplies & Expense	\$ 4,000.00	\$ -	\$ -	\$ -	\$ 2,432.59	\$ -	\$ 1,228.22
Meeting Facilities	\$ 800.00	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Total Direct Costs	\$ 72,733.00	\$ -	\$ -	\$ -	\$ 45,335.61	\$ 10,330.30	\$ 18,669.98
Indirect Costs:							
46% MTDC	\$ 33,457.00	\$ -	\$ -	\$ -	\$ 20,854.39	\$ 4,751.93	\$ 8,587.18
TOTALS	\$ 106,190.00	\$ -	\$ -	\$ -	\$ 66,190.00	\$ 15,082.23	\$ 27,257.16

Table 1 - Compressive Strength of Series 7 Permeable Base Course Mixtures Incorporating FGD-2 Fly Ash

Mixture Number	Compressive Strength, psi											
	3-Day		7-Day		28-Day		91-Day		182-Day		365-day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
MO	740		740		785		1265		1290		1315	
	955	915	840	805	1000	970	830	1025	1230	1250	--	1225
	1055		835		1120		985		1225		1130	
MO1	615		800		835		865		905		960	
	625	600	735	800	540	660	620	860	975	925	915	1010
	550		870		610		1095		895		1150	
MO2	745		840		685		815		955		1040	
	740	760	860	810	800	800	1025	940	1000	945	1010	1025
	800		725		910		975		875		1025	
MO3	345		290		530		560		540		575	
	310	330	425	395	605	540	605	590	705	640	675	620
	340		470		485		610		620		605	

Table 2 – Splitting Tensile Strength of Series 7 Permeable Base Course Mixtures Incorporating FGD-2 Fly Ash

Mixture Number	Splitting Tensile Strength, psi							
	7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
MO	90*		145		195		195	
	90*	90*	120	130	170	185	160	180
	95*		120		185		180	
MO1	55		110		195		155	
	90	95	120	110	135	155	145	160
	145		95		135		175	
MO2	130		125		165		185	
	130	130	160	140	140	165	205	185
	130		130		185		160	
MO3	135		75		75		--	
	40	70	55	65	55	65	--	--
	30		60		70		--	

*10-Day Test Age

Table 3 – Flexural Strength of Series 7 Permeable Base Course Mixtures Incorporating FGD-2 Fly Ash

Mixture Number	Flexural Strength, psi									
	3-Day		7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
MO	--		140		110*				230	
	285	215	125	130	175*	140*	--	--	155	215
	150		130		135*				255	
MO1	110		135		110		145		225	
	85	95	125	115	130	125	205	195	175	190
	85		85		140		230		175	
MO2	105		105		120		105		175	
	50	85	120	105	120	135	155	135	155	150
	95		90		165		140		120	
MO3	55		40		65		45		95	
	55	55	40	40	40	55	55	75	35	80
	60		45		65		125		105	

* Tested at 35 days.

Table 4 - Compressive Strength of Series 7 Permeable Base Course Mixtures Incorporating FGD-3 Fly Ash

Mixture Number	Compressive Strength, psi											
	3-Day		7-Day		28-Day		91-Day		182-Day		365-day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
MO4	480		702		955		970		1275		1225	
	520	560	883	826	1075	1010	985	920	1000	1175	1475	1330
	680		893		1000		800		1250		1295	
MO5	*710		730		936		1150		1275		1330	
	660	*700	825	765	959	980	1175	1125	1215	1255	1125	1210
	725		735		1038		1045		1280		1175	
MO6	360		800		1055		960		2290		1495	
	490	385	660	725	1010	935	1030	1090	1250	1570	1360	1380
	310		710		745		1275		1165		1290	

• Tested at 5-day age

Table 5 – Splitting Tensile Strength of Series 7 Permeable Base Course Mixtures Incorporating FGD-3 Fly Ash

Mixture Number	Splitting Tensile Strength, psi							
	7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
MO4	152		165		190		190	
	107	138	140	145	130	145	205	190
	155		125		115		170	
MO5	75		158		150		200	
	55	65	52	110	200	180	205	190
	70		112		185		170	
MO6	130		65		180		200	
	105	120	150	125	150	185	210	210
	125		155		220		220	

Table 6– Flexural Strength of Series 7 Permeable Base Course Mixtures Incorporating FGD-3 Fly Ash

Mixture Number	Flexural Strength, psi									
	3-Day		7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
MO4	120		260		105		120		275	
	105	115	150	235	120	135	210	185	165	215
	120		295		180		225		210	
MO5	110		165		195		175		245	
	130	125	120	145	185	185	200	185	205	210
	140		150		180		175		180	
MO6	85		75		225					
	65	70	70	73	185	182	235	240	215	225
	65		75		135		240		235	

Table 7 - Compressive Strength of Series 7 Permeable Base Course Mixtures Incorporating FGD-1 Fly Ash

Mixture Number	Compressive Strength, psi											
	3-Day		7-Day		28-Day		91-Day		182-Day		365-day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
MO7	945		825		1110		1075		1210		1425	
	800	885	980	900	1170	1135	1195	1170	1330	1265	1415	1395
	905		890		1120		1240		1250		1340	
MO8	590		585		600		635		990		1130	
	530	500	685	610	755	680	680	710	960	955	645	950
	380		560		690		820		915		1080	
MO9	445		670		890		1030		1090		1145	
	575	535	695	695	735	855	935	960	1185	1105	1230	1160
	580		720		935		910		1040		1110	

Table 8 – Splitting Tensile Strength of Series 7 Permeable Base Course Mixtures Incorporating FGD-1 Fly Ash

Mixture Number	Splitting Tensile Strength, psi							
	7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
MO7	120		145		210		220	
	125	140	175	170	150	165	165	190
	170		190		140		190	
MO8	75		65		120		170	
	75	80	110	85	160	130	150	150
	85		85		115		135	
MO9	80		145		150		165	
	80	75	130	135	15	145	205	155
	70		135		135		100	

Table 9 – Flexural Strength of Series 7 Permeable Base Course Mixtures
Incorporating FGD-1 Fly Ash

Mixture Number	Flexural Strength, psi									
	3-Day		7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
MO7	85		75		140		190			
	85	85	100	100	145	135	150	185	--	--
	90		130		125		215			
MO8	90		105		110		155		125	
	85	95	105	105	100	95	140	150	155	145
	115		110		80		155		150	
MO9	60		65		60		80		175	
	55	60	90	75	120	95	120	100	145	160
	60		75		105		--			

Table 10 - Compressive Strength of Series 8 Permeable Base Course Mixtures
Incorporating FGD-3 Fly Ash

Mixture Number	Compressive Strength, psi											
	3-Day		7-Day		28-Day		91-Day		182-Day		365-day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M1	2570		1065		1450		2070		1725			
	95	1465	1545	1255	1645	1480	2100	1810	1975	1805		
	1730		1150		1345		1800		1715			
M11	1550		1355		3265		2175		2105		2740	
	1550	1345	740	915	1160	1875	1935	2080	2175	2320	2000	2380
	930		645		1195		2135		2685		2400	
M12	225		1105		265		860				985	
	300	240	450	615	190	260	1315	995	735	960	930	1075
	200		285		330		8155		1185		1315	
M13	970		755		985		800		1255		1545	
	795	780	1090	970	610	900	1375	960	1640	1450	1585	1555
	575		1065		1100		710		1450		1530	

Table 11 – Splitting Tensile Strength of Series 8 Permeable Base Course Mixtures Incorporating FGD-3 Fly Ash

Mixture Number	Splitting Tensile Strength, psi							
	7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M1	225		155		305		470	
	305	235	220	190	265	275	320	395
	175		200		255		390	
M11	110		230		250			
	225	155	315	310	340	295	--	--
	125		385		300			
M12	150		25		125		--	
	50	85	200	100	110	110	170	180
	55		80		95		190	
M13	145		260		285		295	
	160	135	195	215	160	240	190	215
	100		185		270		155	

Table 12 – Flexural Strength of Series 8 Permeable Base Course Mixtures Incorporating FGD-3 Fly Ash

Mixture Number	Flexural Strength, psi									
	3-Day		7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M1	165		160		115		400		420	
	145	160	155	155	140	130	300	320	235	320
	175		155		135		260		310	
M11	--		195		--		290		385	
	--	--	220	180	205	205	255	255	385	415
	--		130		205		215		480	
M12	20		75		25		75		160	
	20	35	--	75	200	100	100	95	160	185
	65		--		80		110		235	
M13	140		215		165		185		480	
	105	105	95	175	235	195	250	220	505	470
	75		210		180		220		420	

Table 13 - Compressive Strength of Series 8 Permeable Base Course Mixtures Incorporating FGD-1 Fly Ash

Mixture Number	Compressive Strength, psi											
	3-Day		7-Day		28-Day		91-Day		182-Day		365-day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M14	1780		2125		2540		1730		1655		2100	
	1095	1370	1795	1790	2015	2090	1510	1455	1580	1895	2110	1920
	1235		1450		1710		1130		2450		1555	
M16	805		1175		1110		760		435		590	
	810	660	435	735	1340	1195	785	645	725	575	690	690
	360		590		1135		385		565		785	
M15	90		300		650		605		670		--	
	315	210	210	330	700	670	395	530	450	560	--	--
	220		475		655		585					

Table 14 – Splitting Tensile Strength of Series 8 Permeable Base Course Mixtures Incorporating FGD-1 Fly Ash

Mixture Number	Splitting Tensile Strength, psi							
	7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M14	190		160		240		425	
	220	190	165	140	330	275	350	320
	155		100		260		180	
M16	15		65		50		110	
	70	75	125	75	145	100	90	115
	140		30		105		140	
M15	55		45		70		45	
	40	75	50	40	105	70	45	85
	125		35		40		125	

Table 15 – Flexural Strength of Series 8 Permeable Base Course Mixtures Incorporating FGD-1 Fly Ash

Mixture Number	Flexural Strength, psi									
	3-Day		7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M14	120		205		245					
	85	135	145	165	270	245	--	--	--	--
	205		140		220					
M16	55		105		50		50			
	95	55	95	100	70	70	45	50	--	--
	15		--		95		--			
M15	100		60		25		35			
	90	70	10	35	25	50	65	60	85	80
	25		--		105		75		75	

Table 16 - Compressive Strength of Series 8 Permeable Base Course Mixtures Incorporating FGD-2 Fly Ash

Mixture Number	Compressive Strength, psi											
	3-Day		7-Day		28-Day		91-Day		182-Day		365-day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M17	320		405		490				250		605	
	440	310	605	550	340	425	--	--	685	560	685	645
	170		635		445				740			
M18	560		775		585		920		710		885	
	210	550	490	610	695	960	1110	1090	1030	870	1080	980
	880		565		1605		1240					
M19	645		1015		715		535		925		1425	
	710	680	525	755	1315	840	2160	1040	800	865	1425	1425
	680		720		490		420					

Table 17 – Splitting Tensile Strength of Series 8 Permeable Base Course Mixtures Incorporating FGD-2 Fly Ash

Mixture Number	Splitting Tensile Strength, psi							
	7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M17	245		60		90		85	
	85	145	80	80	150	100	125	90
	105		105		65		65	
M18	80		120		150		165	
	80	95	85	105	60	120	170	175
	120		115		145		190	
M19	110		140		80		110	
	170	135	165	135	110	95	80	95
	125		95		90		90	

Table 18 – Flexural Strength of Series 8 Permeable Base Course Mixtures Incorporating FGD-2 Fly Ash

Mixture Number	Flexural Strength, psi									
	3-Day		7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M17	140		65		110		160		120	
	40	75	45	45	45	80	100	125	105	125
	40		25				115		150	
M18	25		65		65		130			
	20	35	80	80	70	70	50	90	--	--
	65		90		75		--			
M19	35		50		65		60		210	
	40	40	100	80	65	60	85	80	205	195
	40		90		50		100		170	

Table 19 - Compressive Strength of Series 9 Permeable Base Course Mixtures Incorporating FGD-3 Fly Ash

Mixture Number	Compressive Strength, psi											
	3-Day		7-Day		28-Day		91-Day		182-Day		365-day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M2A	1055		1190		1820		1490		1805		1580	
	700	1050	1075	1220	970	1330	1750	1525	1620	1670	1575	1580
	1400		1400		1190		1330		1580		1580	
M21	1415		1235		1945		1905		2270		1840	
	960	1285	1240	1180	1105	1755	1450	1790	1625	2000	1900	1770
	1485		1070		2210		2015		2110		1575	
M22	1070		1870		2095		2740		2190		2150	
	1880	1615	2245	2155	2175	2175	2255	2560	2465	2355	1965	2150
	1890		2355		2255		2680		2105		2335	
M23	795		685		1710		1720		2010		1975	
	675	710	805	890	1830	1770	2100	1835	1765	1870	1645	1835
	655		1185		1770		1690		1830		1880	

Table 20 – Splitting Tensile Strength of Series 9 Permeable Base Course Mixtures Incorporating FGD-3 Fly Ash

Mixture Number	Splitting Tensile Strength, psi							
	7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M2A	185		240		205		480	
	100	170	210	220	335	265	355	410
	230		215		250		390	
M21	155		300		350		330	
	175	175	310	250	200	255	340	335
	200		140		210		335	
M22	325		385		380		365	
	250	270	400	410	305	370	--	365
	240		440		425		--	
M23	210		220		345		265	
	160	175	285	245	275	290	250	250
	155		225		255		230	

Table 21 – Flexural Strength of Series 9 Permeable Base Course Mixtures Incorporating FGD-3 Fly Ash

Mixture Number	Flexural Strength, psi									
	3-Day		7-Day		28-Day		91-Day		182-Day	
	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.	Actual	Ave.
M2A	180		565		390		300		360	
	185	185	130	310	250	290	310	320	340	360
	180		240		230		355		385	
M21	180		215		310		350		330	
	240	200	235	240	300	355	250	315	390	360
	175		270		450		350		365	
M22	235		290		380		325		345	
	195	250	270	295	435	410	445	375	515	430
	320		330		415		360		425	
M23	185		220		230		430		450	
	205	190	190	195	410	320	385	405	470	460
	185		180		--		--		465	

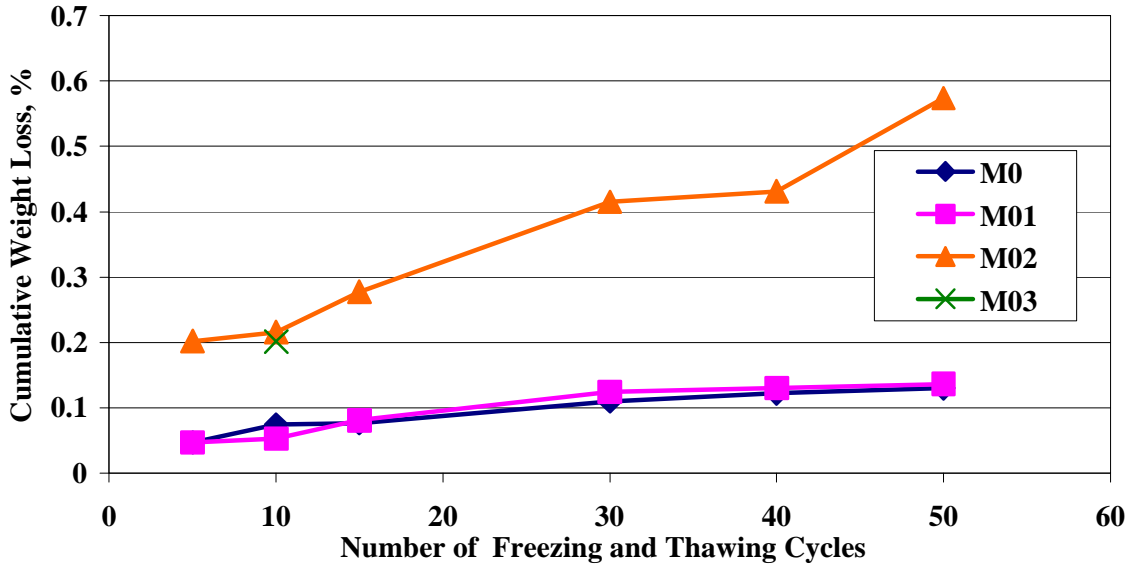


Fig. 1 - Freezing and Thawing Resistance of Series 7 Mixtures Incorporating FGD-2 Fly Ash

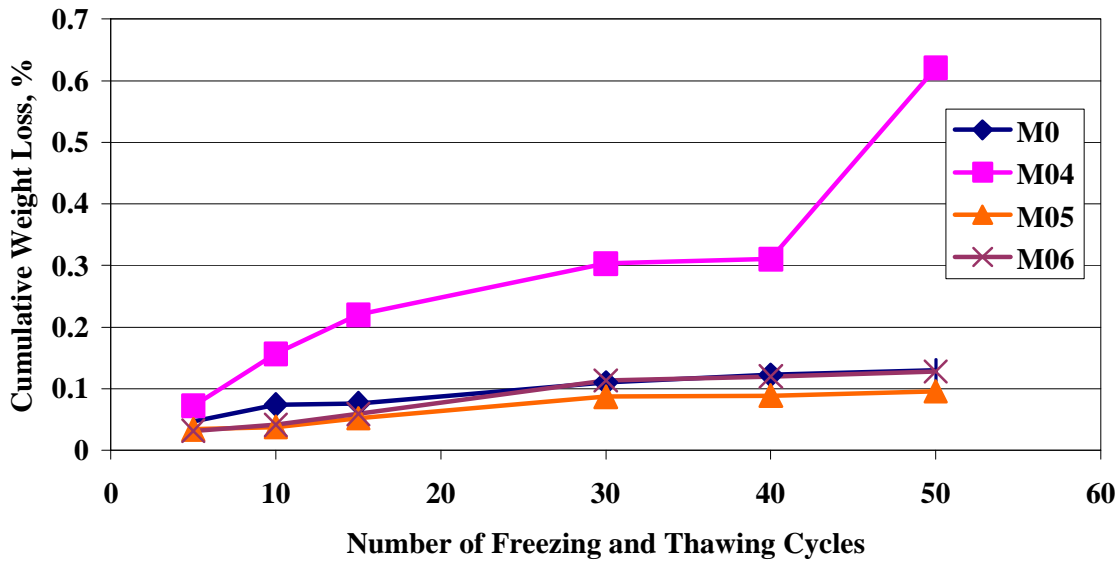


Fig. 2 - Freezing and Thawing Resistance of Series 7 Mixtures Incorporating FGD-3 Fly Ash

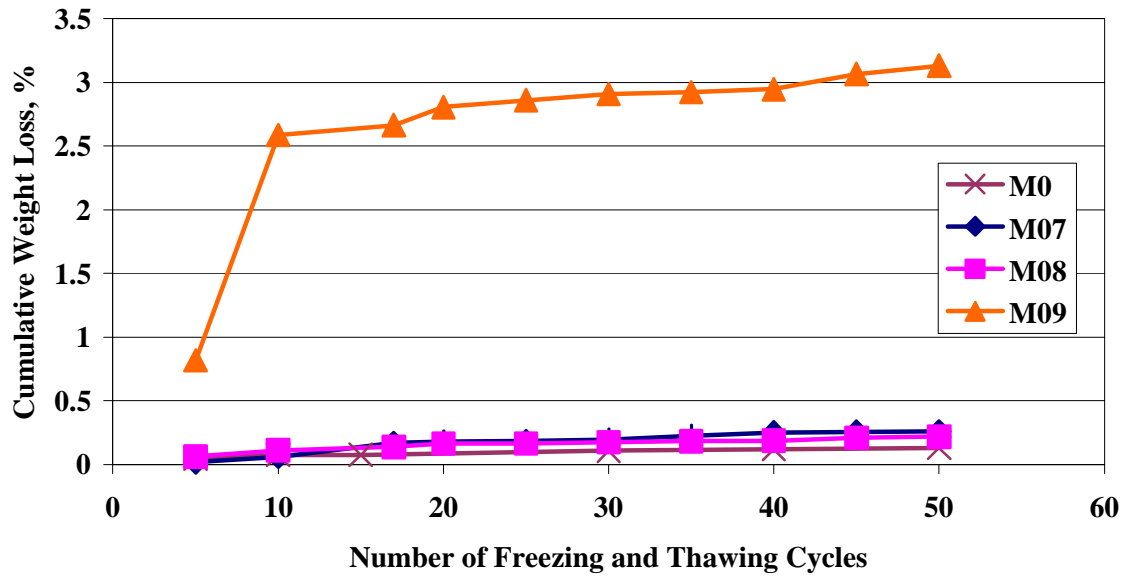


Fig. 3 - Freezing and Thawing Resistance of Series 7 Mixtures Incorporating FGD-1 Fly Ash

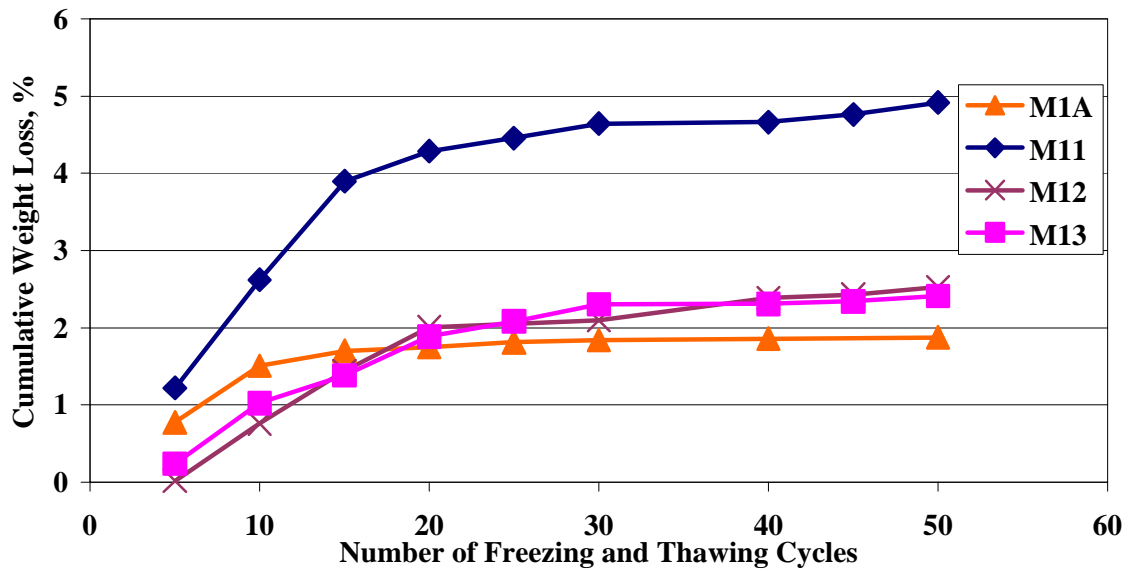


Fig. 4 - Freezing and Thawing Resistance of Series 8 Mixtures Incorporating FGD-3 Fly Ash

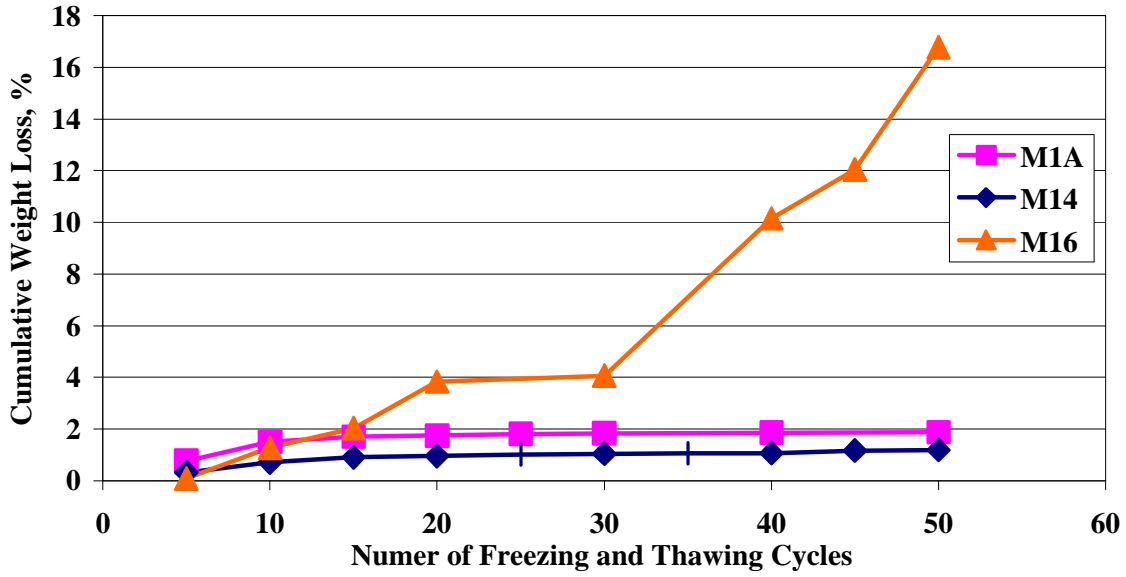


Fig. 5 - Freezing and Thawing Resistance of Series 8 Mixtures Incorporating FGD-1 Fly Ash

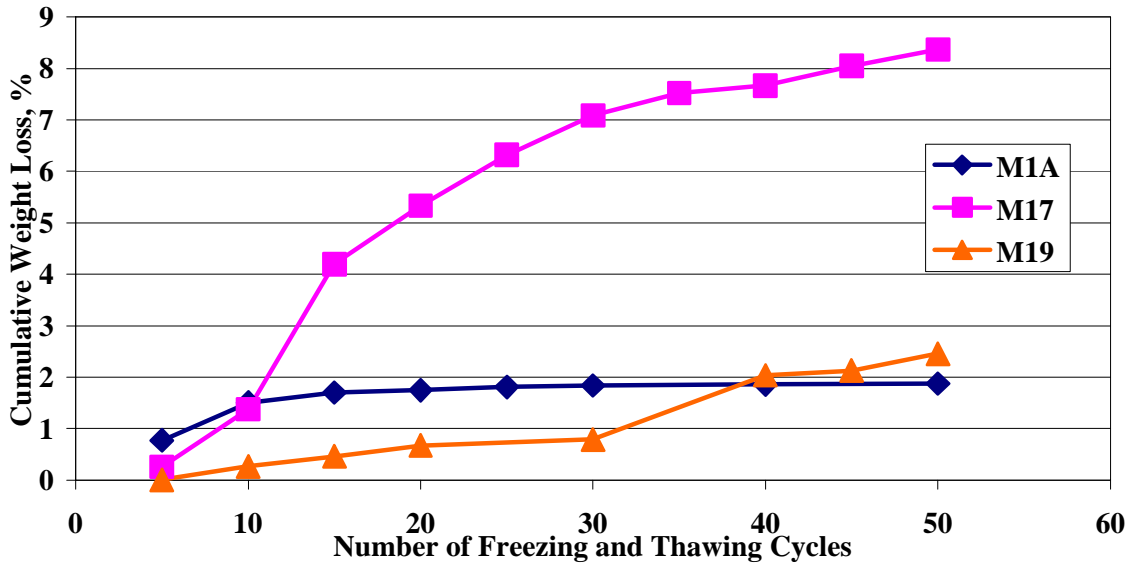


Fig. 6 - Freezing and Thawing Resistance of Series 8 Mixtures Incorporating FGD-2 Fly Ash

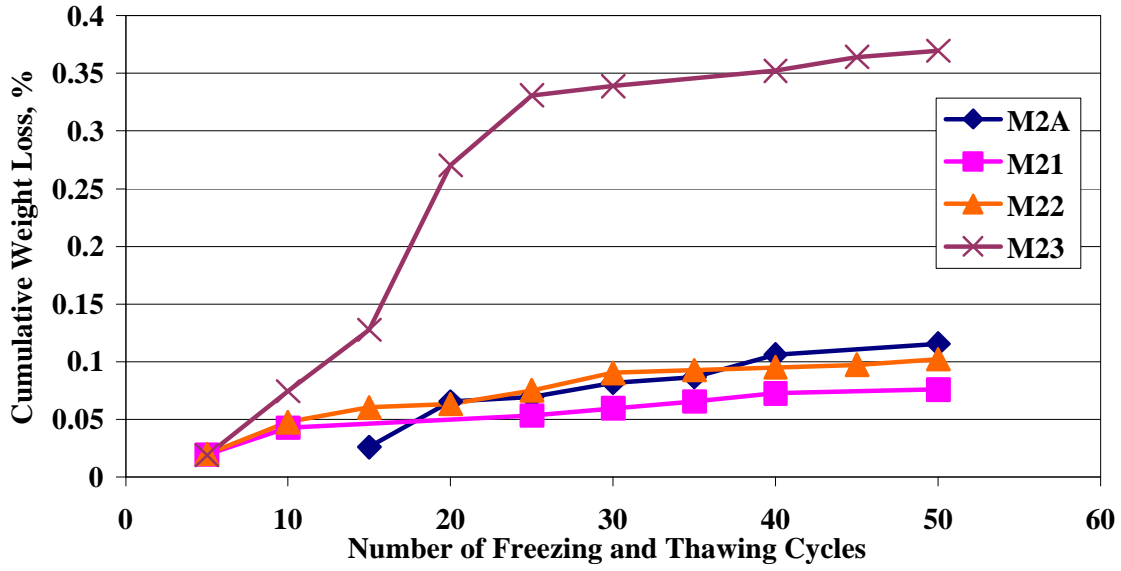


Fig. 7 - Freezing and Thawing Resistance of Series 9 Mixtures Incorporating FGD-3 Fly Ash

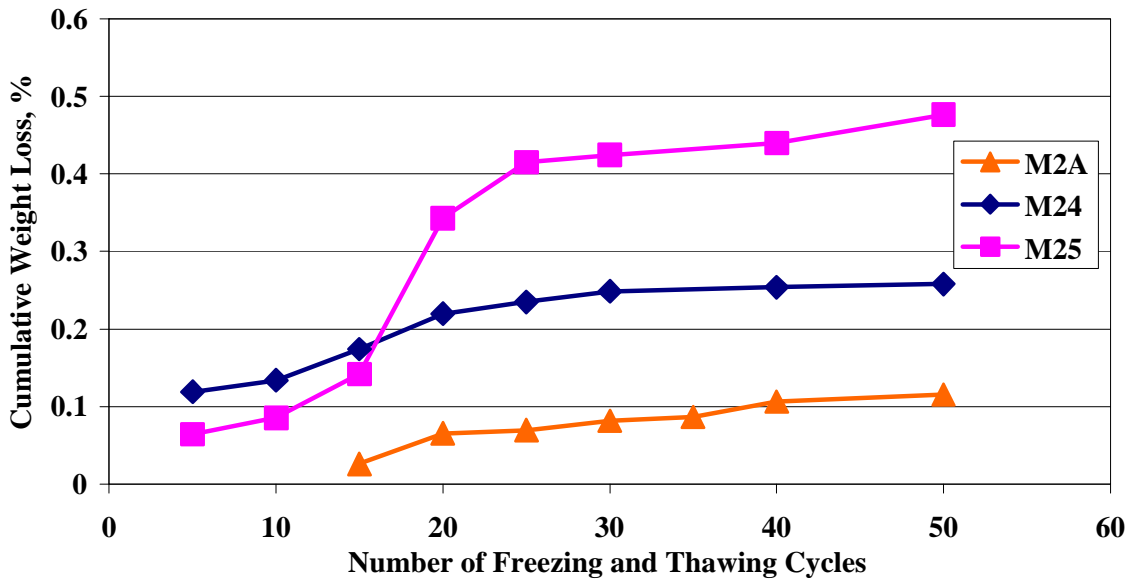


Fig. 8 - Freezing and Thawing Resistance of Series 9 Mixtures Incorporating FGD-1 Fly Ash

APPENDIX A

UWM-CBU WORKSHOP ANNOUNCEMENT

Workshop and Field Demonstration for Use of Permeable Concrete in Base Course – A Solution for Pavement Drainage Management



Center for By-Products Utilization
3200 North Cramer Street, Room W309
P. O. Box 784
Milwaukee, WI 53201

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UWM-CBU Concrete Materials Technology Series Program No. 54

Workshop and Field Demonstration for Use of Permeable Concrete in Base Course – A Solution for Pavement Drainage Management

Sponsored By

UWM Center for By-Products Utilization, Milwaukee, WI
Combustion By-Products Recycling Consortium, Morgantown, WV

Co-Sponsored By

Holcim (US) Inc.; Marquette University; Northeast Asphalt, Inc.; Peters Concrete Co.; We Energies;
WPS Resources Corporation; and Zenith Tech, Inc.

September 19, 2002, Green Bay, WI

Workshop Description

The purpose of the workshop is to present important technical information and review production and construction aspects for a new type of concrete and base course material for roads, highways, airfield pavements, parking lots, and other pavements. Permeable base is a type of concrete that is an agglomeration of coarse aggregates coated with a paste consisting of cement, fly ash, and water. A properly designed and constructed porous base eliminates pavement distress caused by pumping, faulting, and cracking. Use of a permeable base is estimated to provide up to a 70% increase in the service life of concrete or asphalt pavements. Such permeable concrete is generally roller-compacted. It is cost competitive; has a long-life; and is durable.

The workshop will present case histories of successful installations. It will include a demonstration of permeable concrete base production and placement. Handout materials will be provided. The workshop will be of interest to those associated with pavement design, engineers, engineering technicians, engineers working in governmental agencies, industry and private practice, engineering faculty and students, as well as ready mixed concrete producers, aggregates suppliers, and contractors. Knowledgeable professionals engaged in specifying, approving, marketing, and using coal ash and permeable concrete base course will present state-of-the-art information.

PROGRAM

Workshop and Field Demonstration for Use of Permeable Concrete in Base Course – A Solution for Pavement Drainage Management

Thursday, September 19, 2002, Green Bay, WI

- 8:00 a.m. Registration**
- 8:45 Welcome and Introduction**
Lori-Lynn C. Pennock, Fossil Fuel and Combustion By-Products Analyst, WPS Resources Corporation, Green Bay
- 9:00 What is a permeable concrete and its use in base course, engineering properties and mixture proportions of permeable concrete made with coal ash (physical & chemical properties of coal ash, strength, shrinkage, permeability, etc.)**
Tarun R. Naik
- 10:15 Break**
- 10:35 Field applications of permeable base course materials containing high- or variable-carbon coal ash and FGD Materials.**
Bruce W. Ramme
- 11:30 Design and Construction Considerations for Asphaltic Concrete Pavements with Open-graded Base Course**
Professor James Croveti, Marquette University, Milwaukee
- 12:15 p.m. Lunch**
- 1:15 Adjourn to the construction demonstration location.**
- 1:30 Field Demonstration: Permeable base course placement process; and Questions and Answers**
Philip M. Hayes, Project Management Group Leader, WPS Resources Corporation, Green Bay; and Tarun R. Naik
- 3:30 p.m. Adjourn**

SPEAKER INFORMATION

The program is scheduled to include the following speakers:

Tarun R. Naik, Ph. D., P. E.

Director, UWM Center for By-Products Utilization, Milwaukee, Wisconsin.

Dr. Naik has over 35 years of experience in the use of cement, aggregates, admixtures, and by-products in concrete. His contribution in teaching and research has been well recognized nationally and internationally. His research has resulted in over 250 technical reports and papers in ACI, ASCE, ASTM, RILEM, etc. He is a member of ACI, ASCE, ASEE, ASTM, RILEM, NSPE, and WSPE. He is also a member of technical committees of several of these organizations. He has served as a president of WI-ACI, WSPE, and other organizations.

Bruce W. Ramme, P. E.

Principal Engineer, Combustion Products Utilization, We Energies, Milwaukee, WI. Mr. Ramme has worked for about 20 years with We Energies and is currently working towards the goal of 100% utilization of We Energies coal combustion products. He is a member of ACI, ASCE, and other professional organizations. He was chairman of ACI Committee 229 on CLSM; and ACI 213B on By-Product Lightweight Aggregate, and a member of other technical committees of ACI. He is also a past-president of the Wisconsin Chapter of ACI and the Southeast Branch of the Wisconsin Section of ASCE.

The UWM Center for By-Products Utilization at the University of Wisconsin-Milwaukee (UWM-CBU) is an outstanding example of a successful public/private partnership. The UWM-CBU is dedicated to preserving the environment by finding practical uses for what is otherwise considered waste. It does so through research on a variety of materials. The end result is the creation of cost-effective products that are economically viable and environmentally sound. UWM-CBU's activities are satisfying existing needs and bringing about a significant decrease in the volume of materials going to landfills. Research is not the UWM-CBU's only function, however. It also gathers and distributes information about by-products utilization. Closing the recycling loop through reduction and reuse is a much-discussed ideal. The UWM-CBU is doing it.

The UWM-CBU was established in 1988 by a generous grant from Dairyland Power Cooperative, La Crosse; Madison Gas & Electric Company, Madison; National Minerals Corporation, St. Paul, MN; Northern States Power Company, Eau Claire; We Energies, Milwaukee; Wisconsin Power & Light Company, Madison; and WPS Resources Corporation, Green Bay. With their financial support and support from other organizations including Illinois Clean Coal Institute, Manitowoc Public Utilities, US-DOE, UWS Applied Research Council and Solid Waste Recovery Research Program, WI-DNR, Wisconsin Recycling Market Development Board, and others, the UWM-CBU is developing low-cost, high-quality construction materials from coal fly ash, bottom ash, FGD materials (a.k.a. clean-coal ash), used foundry sand and slag, wood ash, pulp- and paper-mill residuals, de-ink solids, used tires, discarded plastics and glass, and other recyclable products.

**THE UWM CENTER FOR BY-PRODUCTS UTILIZATION MISSION
STATEMENT:**

“To collect and analyze data, and disseminate information regarding the beneficial use of presently discarded by-products from industrial, commercial, and public sector operation