Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

"EcoPad" In-Situ Mixed Concrete Pavement
With a 93% to 100% Total Recycled Content

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ABSTRACT

This paper presents research that identifies mixture proportions, construction methods, and performance of in-situ mixed concrete pavements constructed at various We Energies facilities located in Wisconsin, USA. The components of an EcoPad consist of recycled concrete or recycled crushed stone, bottom ash, Class C fly ash, and either portland cement or slag cement for a mixture that has up to a 100% recycled content in the concrete. The process for producing the in-situ mixed concrete includes the use of vane spreaders for distributing the cementitious materials, pulverizers for mixing the aggregates and binders, and conventional road building techniques for shaping and compaction of concrete. Compressive strength was targeted to achieve 21 MPA (3,000 psi) at 28 days to one year age depending on the planned final use. EcoPads provide a durable, highly utilitarian working surface for material handling yards and plant roadways at a low-cost while contributing to achieving sustainability goals.

Keywords: EcoPad, fly ash, bottom ash, in-situ mixing, pavement, slag cement

Figure 1. EcoPad 2012 Fuel Storage Building, Biofuel Power Plant, Rothschild, Wisconsin

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INTRODUCTION

Objective. The primary objective of this research project was to develop a "green" alternative industrial paving material and construction process for constructing environmentally friendly large outdoor storage area pavements. The term "EcoPad" was intended to illustrate the economic and environmentally friendly nature of this construction process. The EcoPad process was intended to maximize the recycled content of the concrete, to achieve a rate between 93% (with portland cement) and 100% (incorporating slag cement). Long term performance has been evaluated for this highly sustainable paving process.

Project Description. The original installation of an EcoPad, initiated in 2006, involved the development of an effective industrial-grade concrete pavement using a high recycled content, placed in-situ with conventional road building equipment typically used for roller compacted pavement. An important goal was to obtain field construction experience to guide and optimize the process.

The first installation in 2006 involved a 1.4 hectare (3.5 acre) outdoor storage pad. Three other installations were constructed in 2011 and 2012 which included a utility equipment storage pad at a service center, a fuel storage building for a biomass electric generating plant and a sealed dewatering pad at a power plant. Class C fly ash (FA) and bottom ash (BA) used in these projects was produced at We Energies power plants in Wisconsin. The fly ash was a by-product of Western USA sub-bituminous coal combustion. The fly ash was captured by electrostatic precipitators from flue gas and the bottom ash was collected from a wet bottom tangentially fired boiler. The bottom ash meets ASTM standards for fine aggregates. The 38 mm (1½ in) recycled concrete coarse aggregate (RC) was supplied from crushed and screened stockpiles from various paving recyclers in Wisconsin. All of the EcoPads at We Energies were designed with a 200mm (8 in) nominal pavement thickness with expected one year strength of 21 MPa (3000 psi).

Purpose of EcoPads. Owners, constructors, engineers and architects are specifying "green", environmentally-friendly materials and construction alternatives to meet sustainability requirements and to accommodate today's infrastructure needs while preserving natural materials for future generations. The high recycled content EcoPad, with its economic and environmental advantages, has been monitored for performance to determine if it is a long term solution for large storage areas such as manufacturing and commercial warehousing storage yards, terminals, dockyards, plant roads and other large pavements that do not require a hard troweled finish. In addition, the exposed aggregate appearance and durability may make it a viable alternative for natural settings like park roads compared with conventional asphalt paving.

Relevant Publications. A literature search was conducted, but rather than compiling an exhaustive review of roller compacted concrete literature, some pertinent publications were reviewed and are listed in the references for this paper.

LABORATORY TESTING

Complete laboratory testing for mixtures and analysis was performed to determine optimum mixture proportioning for the 2006 EcoPad construction. For this particular mixture analysis, the effectiveness of the proposed cementituous (PC and FA) mixture and aggregate (RC and BA) materials were assessed by evaluating the materials grain size analysis, aggregate blending proportions, moisture-density relationships, and moisture-strength relationships. This information was also utilized for mixture proportioning in more recent EcoPad projects.

Representative samples of the proposed materials included recycled concrete, bottom ash, Class C fly ash, and portland cement. Laboratory testing of the samples included moisture content testing (ASTM D2216), grain size analysis (ASTM D422), moisture density relationships by the modified proctor method (ASTM D1557), and compressive strength testing and analysis (ASTM D1633). The moisture density relationship for each mixture was determined in general accordance with ASTM D1557. A 100 mm (4 in) diameter split mold was used for compressive strength determination per ASTM D1633 to facilitate the removal of each specimen with minimal disturbance to the samples. Upon completion, the specimens were sealed in plastic bags and cured for seven (7) days at 100º F in accordance with ASTM C-593 to approximate conditions of 28-day cure periods. Following curing, the samples were capped with a gypsum mixture and the compressive strength was determined using a constant drive calibrated load frame. The testing provided a relative measure of the compressive strength between samples and was used to determine optimum mixture parameters.

In the first phase of testing, samples of the proposed recycled concrete (coarse aggregate) and the bottom ash (fine aggregate) were tested to determine their optimum blend for grain size distribution and density. The second phase consisted of mixing the selected aggregate blend with varying amounts of the blended cementitious binder material for determination of the mixture's optimum density and strength characteristics.

Laboratory Testing Results. Evaluation of the proposed concrete mixture was based upon coarse and fine aggregates consisting of 38 mm (1½ in) top size recycled concrete and bottom ash from We Energies. The blended cementitous material consisted of 50% PC and 50% FA based upon an optimized ratio determined from previous testing work on conventional concrete mixtures that worked well using fly ash/portland cement blends.

Table 1. Summary of Grain Size Analysis on Recycled Aggregates for EcoPad Pavement at Pleasant Prairie Power Plant, Kenosha, Wisconsin

	Bottom Ash (BA)		Recycled Concrete (RC)		
Sample No.	BA1	BA2	RC1	RC2	RC3 (field)
Size mm (inch or sieve #)	(% Finer)				
38.1 (1½)	-	-	100	-	-
25.4 (1)	-	-	95.7	100	100
19.05 (¾)	100	100	85.0	93.4	94.2
12.7 (½)	99.0	98.5	65.2	75.5	79.1
9.5 (3/8)	98.1	96.7	54.6	66.1	69.4
4.76 (#4)	95.6	94.0	33.5	48.4	51.8
2.0 (#10)	92.3	91.2	20.3	37.1	35.8
0.84 (#20)	83.5	83.8	12.1	27.9	24.2
0.42 (#40)	67.0	70.1	7.5	20.6	17.1
0.147 (#100)	26.7	36.1	3.5	9.4	8.7
0.074 (#200)	12.6	16.7	2.6	6.6	6.6

As shown in Table 1, the proposed recycled concrete coarse aggregate was a poorly to well-graded crushed concrete with about 48 to 66% gravel, 31 to 45% sand, and 3 to 7% silt/clay sized particles. Variations in gradations for recycled concrete were expected, and were observed during the second phase of the laboratory and field testing. The fine aggregate is described as bottom ash (BA) with about 4 to 6% gravel, 77 to 83% sand, and 13 to 17% silt/clay sized particles. Results of the unit weight tests on the coarse and fine aggregate indicated loose unit weights of 1584 to 1682 kg/m3 (99 to 105 pcf) and 1041 kg/m3 (65 pcf), respectively.

Results of the coarse/fine aggregate (RC/BA) blending tests are shown in Table 2. They generally indicate a poorly graded aggregate with about 35 to 54% gravel, 41 to 57% sand, and 5 to 8% silt/clay blends. The compacted unit weights of the blends ranged from 1,647 to 1,748 kg/m3 (102.8 to 109.1 pcf). The 60/40 blend was selected for the moisture-density and moisture strength testing to maximize bottom ash content while maintaining high density.

Table 2. Summary of Aggregate Trial Blending Tests

Sample No. Grainsize Analysis, mm (in/sieve #)	BA1	RC1	50/50 RC/BA	60/40 RC/BA	70/30 RC/BA	80/20 RC/BA
38.1 (1½)	-	100	100	100	100	100
25.4 (1)	-	95.7	97.6	97.4	97.0	96.6
19.05 (¾)	100	85.0	92.5	91.0	89.5	88.0
12.7 (½)	99.0	65.2	82.1	78.7	75.3	72.0
9.5 (3/8)	98.1	54.6	76.4	72.0	67.7	63.3
4.76 (#4)	95.6	33.5	64.6	58.3	52.1	45.9
2.0 (#10)	92.3	20.3	56.3	49.1	41.9	74.7
0.84 (#20)	83.5	12.1	47.8	40.7	33.5	26.4
0.42 (#40)	67.0	7.5	37.3	31.3	25.4	19.4
0.147 (#100)	26.7	3.5	15.1	12.8	10.5	8.1
0.074 (#200)	12.6	2.6	7.6	6.6	5.6	4.6
USCS	SM	GW	SP-SM	SP-SM	GP-GM	GP
Unit Weight (Loose), kg/m^3 (pcf)	1041.3 (65)	1586 (99)	-	-	-	-
Unit Weight Compact, kg/m^3 (pcf)	-	-	1646.9 (102.8)	1744.6 (108.9)	1747.8 (109.1)	1733.4 (108.2)

Notes for Table 2: Compacted unit weight based on modified proctor method (ASTM D1557) at moisture content of 15%. Loose unit weight is based on as-received moisture content. Aggregate blends are based on initial bottom ash and recycled concrete samples submitted.

Table 3. Summary of Density/Strength Tests of 60/40 RC/BA Aggregate Blend with Varying Cement Contents

	Moisture-Density		Moisture-Strength	
Mixture ID	Optimum Moisture %	Max Density, Dry kg/m3 (pcf)	Optimum Moisture %	Max Strength, MPa (psi)
60/40 RC/BA @12% PC/FA	15.5	1762 (110.0)	16.6	11 (1640)
60/40 RC/BA @15% PC/FA	16.5	1762 (110.0)	16.6	12.5 (1820)
60/40 RC/BA @18% PC/FA	14.5	1778 (111.0)	14.2	12.6 (1825)

Evaluation of the compressive strength potential of the preliminary selected aggregate blend 60/40 included performing moisture-density and moisture-strength relationship testing by modified Proctor method as previously described and shown in Table 3.

The test results indicated that the 18% cementitious blend content exhibited the highest compressive strength. However, since the strength was comparable to the 15% specimen, the 15% cementitious blend content was selected for economic and sustainability reasons. Due to a change in the source for aggregates for the project, a 70/30 aggregate blend was selected rather than the 60/40 blend tested to more closely match the original gradations and to achieve optimum densities. This is likely due to the material's dense graded nature which allows for a more compact arrangement of particles, with higher concrete strengths possible.
The EcoPad pavement was designed using a 125 mm (5 in) and 75 mm (3 in) thick recycled concrete/bottom ash aggregate blend (representing a 70/30 ratio) and a 15% blended cementitious content. These dimensions by volume were calculated to be similar to the ratios by weight performed in the preliminary lab testing phase and were used as a practical level of measurement in construction.

Table 4. Chemicals and Physical Composition of Cementitious Materials

Oxide Analysis	Class C Fly Ash	Slag Cement	Portland Cement
SiO_2 (silicon dioxide)%	40.3	35.7	20.7
Al_2O_3 (aluminum oxide)%	18.9	10.0	4.8
Fe_2O_3 (iron oxide)%	5.2	0.58	2.7
SiO_{2+} Al_2O_{3+} Fe_2O_3%	64.5	46.3	28.2
CaO (calcium oxide)%	21.6	38.6	65.4
MgO (magnesium oxide)%	3.8	11.2	2.5
SO_3 (sulfur trioxide)%	1.9	2.4	2.4
LOI (loss on ignition)%	0.4	-	1.61
Na_2O (sodium oxide)%	1.8	0.35	-
K_2O (potassium oxide)%	1.2	0.42	-
Available Alkalis (as equivalent Na_2O%)	1.3	-	0.53
Physical Data	**Class C Fly Ash**	**Slag Cement**	**Portland Cement**
Fineness, amount retained on #325 sieve%	13.6	1.0	5.3
Specific Gravity	2.52	2.95	3.15

Chemical and physical data available on the cementitious materials used on this project are shown on Table 4. The Class C fly ash was supplied from the We Energies Pleasant Prairie Power Plant. Fly ash, slag cement and portland cement mixtures were pre-blended at the supply terminal facility in Milwaukee.

ECOPAD CONCRETE MIXING AND CONSTRUCTION PROCESS

The mixing and compaction process for the EcoPad utilized common road-building equipment and the work was performed in-situ on the graded surface. A 300 mm (12 in) thick compacted bottom ash base was installed for the EcoPad. Sub-base areas were well compacted native soils, previously used as unpaved storage areas.

Pre-grading and compaction of the aggregates (without cementitious content) was necessary before final concrete mixing in order to attain correct final grades on the finished pad, which will closely match the pre-mixed elevations in the field.

Based upon the mixture proportions established by laboratory test data, an additional 75 mm (3 inches) of bottom ash fine aggregate and a 125 mm (5 in) thick layer of recycled concrete coarse aggregate was placed on the pad area. The aggregates were then premixed with a paving pulverizer (also referred to as a pavement reclaimer). A dry 50/50 blend of portland cement and Class C fly ash was placed with a vane feeder spreading truck over the previously mixed aggregates at a rate of 60 kg/m2 (110 pounds per square yard) corresponding to a 15% cementitious content in the concrete by dry unit weight. This rate was based upon the laboratory blended mixture shown in Table 3. Moisture conditioning was not required on this project due to relatively wet weather conditions. However, the watering feature is typically necessary for construction and requires the use of a tanker truck, which is attached to the pulverizer. A recommended mixture moisture content of 9% to 13% was specified based upon initial laboratory testing along with a limited short delay period for working and compacting the mixture. A higher actual moisture content (up to 16%) was experienced due to weather conditions at the time of construction. Higher moisture contents in the range of 14% to 16% were found to be necessary in the field. Due to the fact that the EcoPad concrete inherently involves a very low water/cementitious materials ratio to allow for mechanical placement and compaction, even relatively wet field conditions with this method favor strength development and stability. It also adds additional working time and plasticity for the mixture. Compaction of the in-situ mixture was specified at 95 percent of the maximum dry density as determined by the modified Proctor method.

After mixing, the aggregate and cementitious materials mixture was compacted with a vibratory sheepsfoot compactor, adjusted with a grader, and finished with a smooth drum roller (without vibration). Grading and thorough compaction are critical to obtaining full concrete strength and must begin directly after mixing since the mixed materials are undergoing final setting and hardening. Placed EcoPad concrete should be quickly finished and left undisturbed to ensure proper strength development. Of course, temperature conditions and moisture will affect the rate of hardening for this very low slump concrete. The mixed concrete has a limited working time during which it can be re-graded and rolled while in a semi plastic condition.

Prompted by a shortage of portland cement at the time of construction, a separate test section of the EcoPad was constructed with a Class C fly ash/ground slag mixture (SC), which did not include any portland cement. All other parameters were held constant, including the ratio of cementitious binder, moisture content ranges, and aggregate proportions. In effect, this test section represents a 100% recycled content mixture for the EcoPad.

Curing methods involved wetting, sealing, and protection of the EcoPad surface and then covering with bottom ash for protection from cold-weather conditions. Other curing methods such as plastic cover sheets or bedding materials could be utilized.

FIELD TESTING

Field testing of the EcoPad materials was performed in three stages. The initial stage consisted of performing grain size analysis on samples of the field blended aggregates. A laboratory mixture analysis of the field aggregate blend with 15% of the blended cementitious material was also performed to establish laboratory moisture-density and moisture-strength relationships.

The second stage of the testing was performed during the field mixing of the blended aggregate and cementitious materials. The field testing consisted of performing field density testing by nuclear gauge method (ASTM D2922) during the compaction phase to assess the in-situ moisture content and percent compaction achieved. In addition, samples of the in-situ mixture were obtained and compacted in the field by the modified Proctor method. The field molded specimens were delivered to the laboratory and cured for a period of 7 to 365 days to assess the compressive strength development of the mixture.

The third phase of the testing included obtaining in-situ drilled core specimens after approximately one year and 6 years to assess the in-place strength of the EcoPad pavement. The cores were obtained with a rotary type drill with a diamond impregnated core barrel in general accordance with ASTM D42. Samples were subsequently air dried for 7 days, capped with a gypsum capping compound and compressive strengths were determined in accordance with ASTM C39.

Results of Field Testing. Results of the grain size analysis are shown in Table 5 for the individual bottom ash and recycled concrete field samples that were used on-site. They were similar to the results obtained in the laboratory testing phase.

Results of the field moisture-density relationship testing in Table 6 indicate a higher maximum dry density than the preliminary laboratory mixture proportioning phase. This was likely due to a well-graded sample resulting in a more densely compacted mixture. The higher result in the compressive strength may also be due to the higher density characteristics and lower optimum moisture contents. Subsequently, two (2) additional samples of the previously sampled and combined field blended aggregate were mixed in the lab, one with 15% PC/FA and the other with 15% SC/FA cementitious blend to further assess the moisture-density and moisture-strength relationships. Results of the tests on the PC/FA blend showed similar results to those of the PC/FA blend of the first aggregate field blend mixture. Results of the SC/FA cementitious blend also provided results that were similar to those of the first aggregate field blend mixture.

Table 5. Comparison of Aggregate Field Blended Gradations

	60/40 Blend		70/30 Blend		70/30 Field Blend	
Aggregate Blend RC/BA	Sample 1 60/40-1	Sample 2 60/40-2	Sample 1 70/30-1	Sample 2 70/30-2	Sample 1 Field 1	Sample 2 Field 2
Grain Size mm	(in/sieve#)					
38.1 (1½)	100	100	-	-	-	-
25.4 (1)	97.4	97	100	100	100	100
19.05 (¾)	91.0	89.5	96	95.4	95.1	95.1
12.7 (½)	78.7	75.3	84.7	82.4	84.2	84.0
9.5 (3/8)	72.0	67.7	78.3	75.3	77.6	79.1
4.76 (#4)	58.3	52.1	66.6	62.1	63.6	65.0
2.0 (#10)	49.1	41.9	58.7	53.3	51.8	53.0
0.84 (#20)	40.7	33.5	50.3	44.7	40.7	39.1
0.42 (#40)	31.3	25.4	40.4	35.5	30.4	26.8
0.147 (#100)	12.8	10.5	20.1	17.4	14.2	13.0
0.074 (#200)	6.6	5.6	10.6	9.6	9.7	8.9

Results of the SC/FA cementitious blend resulted with similar moisture density relationships but with lower strengths, 11 MPa (1,600psi) vs. 15.3 and 18.6 MPa (2,225 and 2,700 psi). This is likely due to the fact that the slag cement usually contains less CaO and also generally develops its strength at a slower rate than portland cement.

The second phase of field testing included performance of field moisture and density tests during the placement and compaction phase of construction. In summary, the field blended aggregate had initial moisture contents of 14 to 19 percent, which was 0 to 5 percent above their recommended mixing range of 9 to 13 primarily due to wet weather conditions.

Table 6: Summary of Density/Strength Tests Based on Field Blended Aggregate

	Moisture-Density Relationship		Moisture-Strength Relationship	
Mixture ID	Optimum Moisture %	Maximum Dry Density, kg/m3 (pcf)	Optimum Moisture %	Maximum Strength, MPa (psi)
60/40 RC/BA @12% PC/FA	10.5	1986 (124.0)	10.3	19 (2700)
60/40 RC/BA @15% PC/FA	10.0	1986 (124.0)	10.6	15 (2225)
60/40 RC/BA @18% PC/FA	11.0	1954 (122.0)	10.3	13 (1920)

During the mixing process the moisture contents were generally found to range from 10 to 16 percent based upon in-place field density testing. Field density testing also indicated in-place compaction ranging from 92 to 99 percent with an average 96.5 percent.

Results of the field molded compressive strength specimens are summarized in Table 7 and Figure 2. In summary, the field molded samples of the 15% PC/FA (at 50%/50%) cementitious blend indicated compressive strengths of 16.8 MPa (2,440 psi) at 28 days and 17.4 MPa (2,525 psi) at 56 days which are similar to the laboratory mixtures with the field blend aggregates

Table 7. Field Molded and Cored Compressive Strength Test Results

Sample No.	FS-1 (PC/FA)	FS-2 (Slag/FA)	FS-3 (Slag/FA)
Sample Date	11-04-04	11-05-04	11-08-04
Continuous Blend	PC/FA	SC/FA	SC/FA
Field molded samples			
Moisture Content, %	13.6	14.9	13.1
Dry Density, kg/m3	1942-1956	1919-1948	1934-1954
(pcf)	(121.2-122.1)	(119.8-121.6)	(120.7-122)
Compaction, %	99-100	96-98	97-98
Field Molded Strength	MPa (psi)	MPa (psi)	MPa (psi)
7 day (air)	11.1 (1,620)	1.3 (185)	1.0 (145)
28 day (air)	16.8 (2,440)	1.3 (195)	1.2 (175)
56 day (air)	17.4 (2,525)	1.8 (265)	1.7 (240)
180 day (air)	22.6 (3,280)	6.8 (985)	6.2 (900)
365 day (air)	29.9 (4,325)	18.4 (2,675)	16.9 (2,455)
365 day (corrected)*	27.1 (3,930)	16.8 (2,435)	15.4 (2,235)
Field Core Strength			
365-day (air)	21.7 (3,150)	13.6 (1,970)	12.0 (1,735)

(15.3 MPa (2,225 psi) and 18.6 MPa (2,700 psi)) and somewhat higher than the laboratory blended aggregates (13.0 MPa (1,880 psi) and 13.2 MPa (1,920 psi)).

The field molded samples with the (Slag) SC/FA cementitious blend are presented in two segments in Table 7, FS-2 and FS-3 due to the fact they were placed on separate days. They had the same mixture proportion, but were subjected to slightly different weather conditions. FS-2 and FS-3 indicated compressive strengths on the order of 1.3 MPa (195 psi) and 1.2 MPa (175 psi) at 28 days which turned out to be much less than the laboratory mixture which yielded a strength of 11 MPa (1,600 psi) using the accelerated curing method. This is probably due to the much lower curing temperatures of the field samples and the fact that slag cement generally develops strength at a slower rate, especially at lower temperatures.

The 365 day test results indicated compressive strengths on the order of 27.1 MPa (3930psi) for the PC/FA blend and 15.4 MPa (2235 psi) for the SC/FA blend.

Field Core Sampling and Testing. The final phase of the field testing included obtaining field molded samples and field cored samples from the EcoPad pavement sections after one year, 2 years, and at 6 years of field curing. Results of the one year field cored strength tests in Table 7 and Figure 3 indicate an average compressive strength of 12.7 MPa (1,840 psi) for the PC/FA mixture and 12.8 MPa (1,852psi) averaged for the slag/FA mixture (FS2 & FS3).

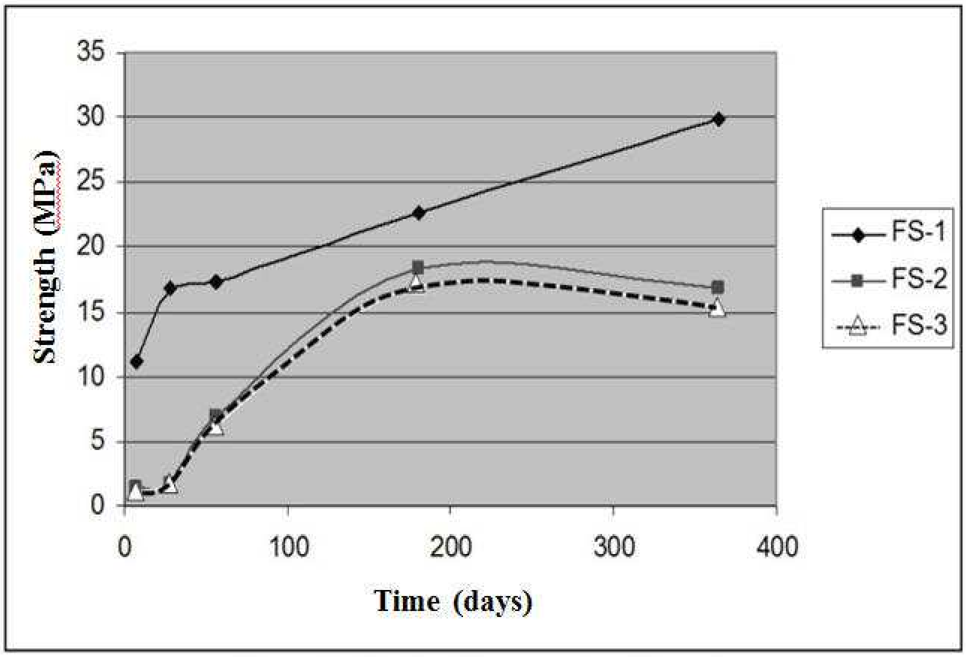

Figure 2: EcoPad Compressive Strength

**Figure 2 Notes: Molded field samples have a height/diameter ratio of 1.15:1 when compared to length to a ratio of 2:1 for field core samples. The 1.15 H/D samples, therefore, result in a somewhat higher strength than would be achieved with the 2 H/D core samples. A correction factor of 0.91 was applied, according to ASTM C 42, to obtain corrected strength values.*

Additional field testing was conducted after 2 years and after 6 years of service on the original 2006 EcoPad project. As indicated in Figure 3, the PC/FA blend exhibited a slight increase in strength over time averaging 23 MPa (3,300 psi) at 6 years. Slag cement blends (FS-2 & FS-3) were combined in Figure 3 to include both similar test sections with the same mixture proportions, and exhibited a slight decrease in strength from Year 2 but greater than Year 1 results. In the 6 year field core testing work, long term strength stability and strength increases were confirmed for PC/FA blends with strengths over 21 MPA (3,000 psi).

RECENT ECOPAD INSTALLATIONS AT WE ENERGIES

Since the original installation in 2006 of the P4 EcoPad, another EcoPad was constructed at We Energies in 2011 (Menomonee Falls Service Center EcoPad) and at two other facilities in 2012, using the same mixture proportions and design developed during the original installation. For these projects, the main focus was on higher strength concrete and, therefore, increased amount of PC/FA blends. An important modification to the process involved separate spreading of PC/FA in two lifts; thereby avoiding the need to obtain pre-blended powder binders and adding sustainability advantages due to less handling and shorter hauling distances. While this approach involved additional time for placement of materials, the materials and the process used were still capable of producing a uniformly mixed concrete with high strength. They did not present unmanageable logistical issues on site during construction. Average field core sample strengths for the Menomonee Falls Service Center EcoPad were 24 MPa (3,550 psi) at 8 months. Longer term testing is planned.

A finding in the 2011 project was the advantage of using two spreaders on larger projects, which could be coordinated with portland cement and fly ash deliveries as work progresses. Separate spreading of binder powders offers advantages compared with obtaining pre-blended powders that are subject to longer distance hauls and potential blending equipment reliability at the suppliers' terminal facility. The time limiting factor was found to be cementitious powder transfers from pneumatic tanker to powder spreader. Care should be taken to prevent vehicle tracking through spread powders as this could create objectionable dusting.

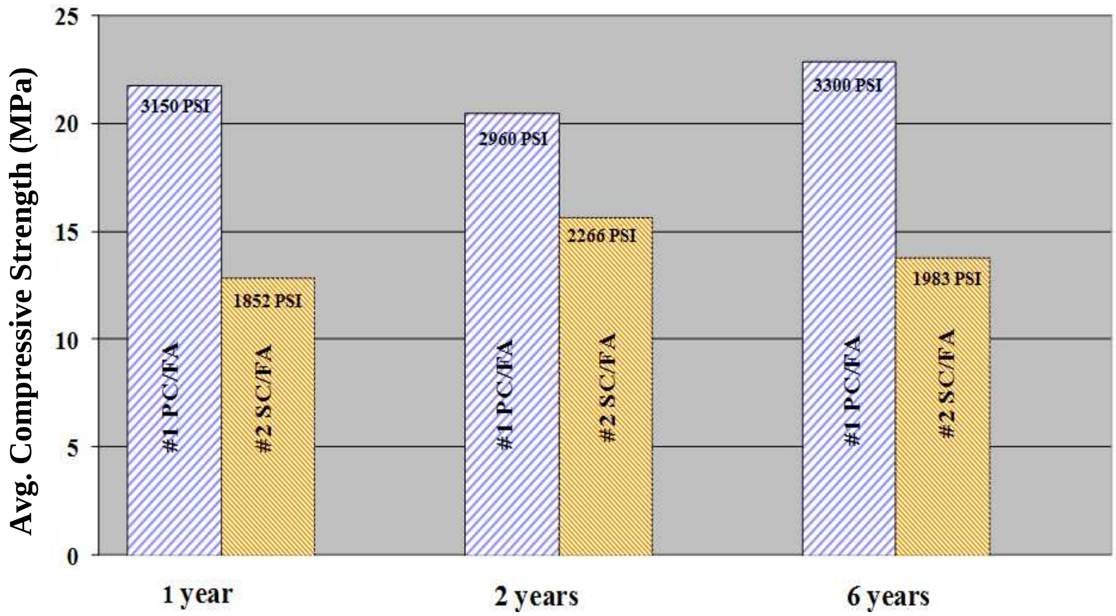

Figure 3: EcoPad Compressive Strength (Core Samples, Air Dried)

Another EcoPad installation at We Energies in 2012 involved a biofuel storage building pad at a power plant facility. This facility required an interior durable pad surface which could withstand material handling and woodchips with associated liquids. Similar mixture proportioning, ecopad design, and specifications were used for this installation. Nine month core samples showed an average strength of 12.8 MPa (1,858 psi). Lower strengths were likely due to the use of collected site aggregates (and soils) rather than recycled concrete. The pad, 0.41 hectare (44,000 sf), was installed within two days at a cost of half the alternative 125 mm (5 inch) asphalt paving with the much higher strength of a 200 mm (8 inch) concrete.

CONCLUSIONS

(1) As demonstrated by these projects, an in-situ mixed, high recycled content concrete may achieve one year strengths of 21.4 MPa (3,100 psi). Optimum mixture proportions were recycled concrete and bottom ash blended at a 70% - 30% ratio and placed in 125 mm (5 in) and 75 mm (3 in) thick layers, respectively with a 15% blended (50% portland cement/50% Class C Fly ash) cementitious material addition by dry weight placed on top of the layered aggregates and mixed in-situ with moisture adjusted to 12%.

(2) When the aggregate blend was mixed using slag cement to replace portland cement in the cementitious material blend, a lower compressive strength, 11.7 to 13.8 MPa (1,700 to 2,000 psi), in one year was attained. These mixture proportions provide 100% recycled content, but did not achieve the higher strengths found with the fly ash/portland cement mixtures.

(3) Long-term testing, at 2 years and 6 years confirmed the stability of the pavement and retained strength characteristics of portland cement/fly ash blends for in-situ, roller compacted concrete using recycled materials. Strengths reaching 23 MPa (3,300 psi) were observed. A similar result for slag cement/fly ash blended mixtures can be attained.

(4) Some variability in the test data due to variations of the individual materials was observed. Therefore, a mixture analysis for the specific ingredients of each mixture should be undertaken for each project using local sources. Use of aggregates other than recycled concrete should be carefully evaluated to avoid incorporation of soils or organic material in the mixture.

(5) The EcoPad is a "green" alternative paving material and construction process for environmentally-friendly and economic pavements with 93 to 100% recycled content. Long-term performance has been evaluated for this pavement. It shows a low-cost concrete pavement that was produced in an environmentally sustainable manner.

(6) Future work is planned to also measure the in-place flexural strength of the EcoPad.

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