VOL. 24, NO. 2
SUMMER/FALL 2010

TENNESSEE CONCRETE MAGAZINE

2010 Membership Directory

Ready Mixed Concrete Producer Members

Associate Members

Affiliate Members

Contractor Members

ACI Certified Field Testing Technician, Grade I Sections

NRMCA Pervious Certified Installers/Technicians

ACI Certified Flatwork Technicians/Finishers by L. K. Couch—

Four-Part Series

Help for Pervious PCC Producers

Part 1: Supplementary Cementing Material Substitution Rates—It's Good to be Green!

INTRODUCTION

Tennessee Technological University (TTU) researchers have recently been exploring ways to improve conventional (compacted) pervious Portland cement concrete (PCC). The Tennessee Concrete Association (TCA) has provided materials and guidance for the research described in the articles. We hope you find the information presented helpful in producing improved pervious PCC mixtures. In the first article, making pervious "greener" is explored. Parts 2 through 4 in the series will examine:

2. Chemical Admixtures for Pervious PCC
3. Fine Aggregate for Pervious PCC
4. Putting It All Together for a High Performance Pervious Concrete Mixture Design

Pervious PCC is already "green" by application. Could it be made even "greener" with the use of supplementary cementing materials? Tennessee concrete producers are already familiar with some of the other benefits of supplementary cementing materials (SCMs) including increased compressive strength and reduced material costs. Former TTU Graduate Student Jason Phillips [1] explored SCM substitution rates for pervious PCC in order to maximize environmental benefits and compressive strength while reducing material costs.

MATERIALS

One Class F and two Class C fly ashes meeting ASTM C 618 [2] were obtained from regional suppliers. Grade 120 ground granulated blast furnace slag meeting ASTM C 989 [3] was obtained from a national cement manufacturer. Type I Portland cement [4] was obtained from a local ready mix producer's bulk storage. An ASTM C 33 [5] No. 8 limestone was obtained from a local quarry. The average results of a washed sieve analysis [6] conducted in triplicate on the local limestone are shown in Table 1. Chemical admixtures were provided by the local representative of an international chemical producer.

RESEARCH PLAN

The research team developed a pervious PCC mixture (see Table 2) to act as the control or standard for comparison for the project. Throughout the research, the volumes of paste, aggregates, and water were held constant for all variable mixtures. Only the volume of chemical admixtures (dosed by cementing materials weight) varied slightly for the mixtures due to the specific gravities of SCMs differing from that of Portland cement (PC). Cementing material composition was varied by substituting various SCMs on an equal volume basis for PC. SCM substitution rates ranged from 12.5 to 62.5 percent by volume of cementing materials. The control mixture was replicated three times. All other mixtures were only produced one time due to the large number (23) of variable mixtures in the study. The research team assumed that in the future, more promising variable mixtures could be further investigated. In order to compare cementing material costs, the following cost per ton assumptions were made: PC \$125, Class F fly ash \$27, Class C fly ash \$38, and Grade 120 slag cement \$80.

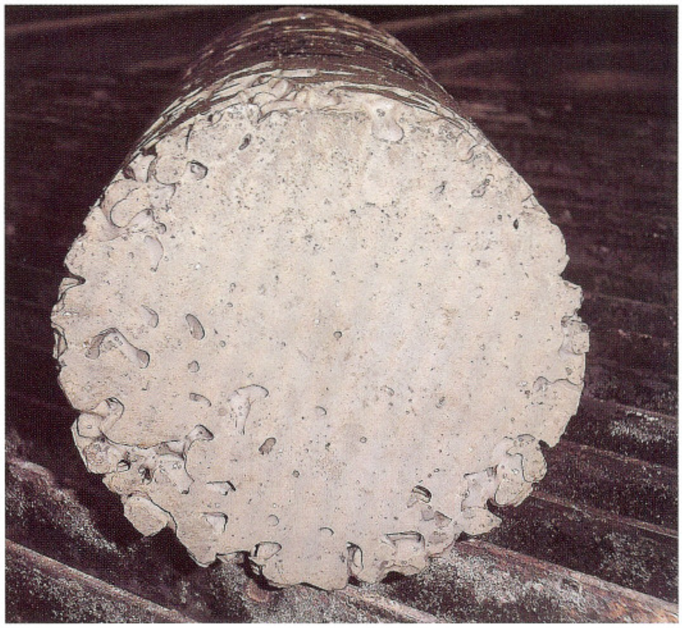

Figure 1. Severe Paste Drain Down

PROCEDURE

All pervious PCC batches were 0.65-cubic feet in size. Each batch was mixed in a one-cubic-foot capacity electric mixture. Ten 4x8-inch cylinders were cast from each batch. Eight of the cylinders were used for compressive strength determination and two were used to determine effective void content and to assess drain down of the paste. All cylinders were cast in two layers in reusable metal molds. Each layer received 4 blows from an AASHTO T 245 Marshall Hammer [7]. The Marshall Hammer is one of the compaction devices being considered by the ASTM Pervious PCC Standard Test Method Subcommittees. Following casting, each cylinder was covered with plastic and allowed to cure for approximately 24 hours. The next day, the

TABLE 1. COARSE AGGREGATE USED FOR THE PROJECT

Sieve Size	Sieve Size (mm)	Project Coarse Aggregate (%finer by mass)	ASTM C33 No. 8 Coarse Aggregate Requirements for % finer by mass
1/2 inch	12.5	100	100
3/8 inch	9.5	97	85–100
No. 4	4.75	10	10–30
No. 8	2.36	2	0–10
No. 16	1.18	1	0–5

TABLE 2. CONTROL PERVIOUS PCC MIXTURE DESIGN

Component	Amount
Type I PC, lbs./CY	600
ASTM No. 8 Limestone Coarse Aggregate, SSD, lbs./CY	2600
Water, lbs./CY	180
Mid-Range Water Reducer, oz./cwt.	5
Viscosity Modifier, oz./cwt	2

TABLE 3. AVERAGE EFFECTIVE VOID CONTENT FOR PERVIOUS PCC MIXTURES

Mixture(s)	SCM Substitution Rate for Type I PC by Volume (%)					
	0	12.5	25	37.5	50	62.5
Control	33.3					
Class F Fly Ash		32.4	32.7	33.3	31.9	
Class C Fly Ash No. 1		33.1	32.3	32.1	30.1	28.9
Class C Fly Ash No. 2		32.6	31.4	31	30.9	30.5
Grade 120 Slag		32.2	33.4	33.8	34.0	33.6
50PC/25Slag/25F					32.1	
50PC/25S/25C1					31.4	
50PC/35S/15F					31.7	
50PC/35S/15C1					31.6	

Slight Drain Down | **Moderate Drain Down** | **Slight Drain Down**

cylinders were de-molded and placed in a lime-water immersion tank. On the seventh day, the two effective voids cylinders were removed from the curing tank and dried at 230°F for seven days. Effective void contents were then determined as per ASTM D 7063 [8]. Paste drain down was determined by visual inspection. An example of severe paste drain down is shown in Figure 1. Compressive strengths were determined for each batch at 7, 28, 56, and 91 days using a pair of cylinders. On the day of a scheduled break the pair of cylinders was removed from the curing tank and capped with sulfur mortar as per ASTM C 617 [9] and subsequently tested in accordance with ASTM C 39 [10].

RESULTS

The results of the project are truly voluminous – 200+ compressive strengths and 50+ effective void contents. Average results are shown in this article, for more detailed information see Phillips [1]. Table 3 shows average effective void contents and paste drain down in four categories: minimal (no shading), slight (yellow), moderate (orange) and severe (red). Control compressive strength results are shown in Figure 2. Similarly, Class F, Class C No.1, Class C No.2, Grade 120 slag and tertiary

—Continued on page 12

Continued from page 9—

by L. K. Couch

Help for Pervious PCC Producers

Part 1: Supplementary Cementing Material Substitution Rates—It's Good to be Green!

mixtures compressive strength results are shown in Figures 3 through 7, respectively. Each result is the average of two compressive strength cylinders at the prescribed age.

ANALYSIS OF RESULTS

Effective Void Content

The variation in effective void content was small for the project. The small standard deviation suggests that there is no difference for results between 31.2 and 33.5 percent [1]. The vast majority of results fell within this range. High substitution rates of fly ashes tended to cause paste drain down rather than effective void contents that were too low.

Paste Drain Down

Class F and Class C fly ashes act as water reduces in conventional PCC mixtures [11]. It appears that is also true for pervious PCC mixtures. In particular, Kosmatka [11] shows that Class C fly ash is a more effective water reducer for conventional PCC. That also appears to be the case for pervious PCC in this project. At the same substitution rate, Class C fly ash caused more severe paste drain down than Class F fly ash (see Table 3). Paste drain down indicates that the mixture needs to be proportioned (probably with less water). Further, paste drain down will be less severe in the field than in the laboratory due to the voids in the underlying aggregate base. Grade 120 slag cement was not as effective as a water reducer as either fly ash in this study. No mixture containing only slag as an SCM, suffered paste drain down at any substitution rate.

Sustainability

How sustainable or "green" a PCC mixture is a function of the amount of recycled materials it contains. Since virgin aggregates were used throughout the project, the sustainability of mixtures in this project was a function of the SCM substitution rate (the higher – the greener). Since slag mixtures showed no paste drain down at 62.5 percent substitution, the research team decided to try a slightly modified (7 lbs/CY less water and 4 oz/cwt hydration stabilizer) mixture at 75 percent slag substitution by volume of cementing materials. The resulting mixture had an average effective void content of 33.3 percent, average compressive strengths of 1940 and 2090-psi at 7 and 28 days respectively and no paste drain down. Even higher substitution rates may be possible but were not explored in this project. Grade 120 slag cement allows the "greenest" pervious PCC mixtures.

Compressive Strength

Table 4 shows the average compressive strength of each fly ash and slag SCM mixture as a percentage of the average compressive strength of the control mixture at the same age. Since each variable mixture was only produced once, insufficient data was available for t-test comparisons to determine if differences observed were significant. Therefore, a ten percent difference from the average control mixture at that age was considered significant for this project. Table 4 is color coded for easier analysis: red shading indicates a twenty percent or more decrease in compressive strength; orange indicates a ten percent decrease; yellow indicates that the variable mixture strength is less than ten percent different from the average control compressive strength; Blue indicates a ten percent increase; and green indicates a twenty percent or more increase in compressive strength compared to the average control. Table 5 is very similar to Table 4 except that all tertiary variable mixtures had a fifty percent substitution rate. The color coding used is the same as Table 4.

All but three of the substitution-age combinations were neutral (no significant difference) or beneficial to compressive strength development. The three detrimental substitution-age combinations were all at seven days of age. The results of all three of the cases improved to neutral or beneficial at later ages. Neutral is actually a very positive result because the producer will be delivering a "greener" pervious PCC at lower cost (more in the following paragraphs) without a significant compressive strength reduction.

The compressive strength results shown here are from samples continuously cured in lime-water. Since adequate moisture and temperature for curing are not guaranteed in the field, it would take much longer for pervious PCC samples in the field to reach a 56 or 91 day laboratory curing level, if they ever reached that level. Seven and 28 day levels of laboratory curing are much more achievable in the field. Except in rare circumstances, pervious PCC producers should concentrate on the 7 and 28-day compressive strength results.

Class C fly ash was the most beneficial SCM to compressive strength improvement at almost all substitution rates and ages. For 50 percent or lower substitution rates, Class C fly ash was always neutral or beneficial at 7-days. Class C fly ash truly excelled in improving 28-day compressive strength, in ten cases the following results were obtained: six 20 percent or more benefits; three 10 percent or more benefits; and one neutral result. Twenty-eight days is the most common specification time and therefore the most important time to excel in improving compressive strength.

Cementing Material Cost

Table 6 shows cementing material costs based on the earlier stated cost-per-ton assumptions (PC $125, Class F fly ash $27, Class C fly ash $38, and Grade 120 slag cement $80). Table 6 is color coded for easier analysis: red shading indicates a twenty

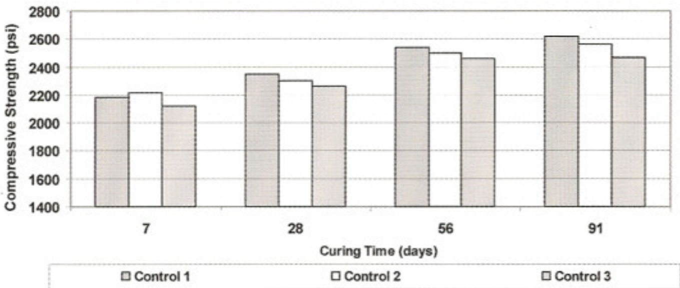

Figure 2. Control Mixture Compressive Strength Development

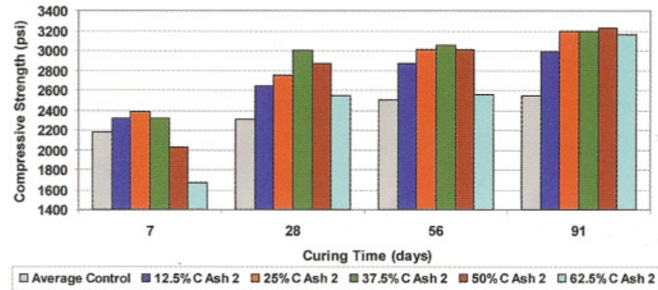

Figure 5. Compressive Strength Development of Class C Fly Ash Number 2 Mixtures

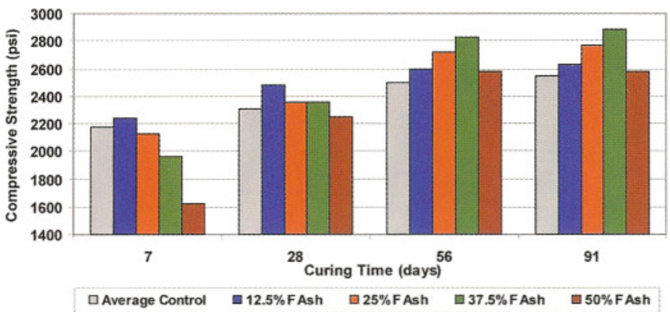

Figure 3. Compressive Strength Development of Class F Fly Ash Mixtures

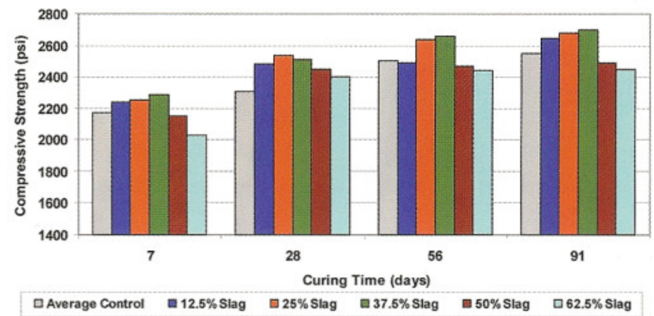

Figure 6. Compressive Strength Development of Grade 120 Slag Cement Mixtures

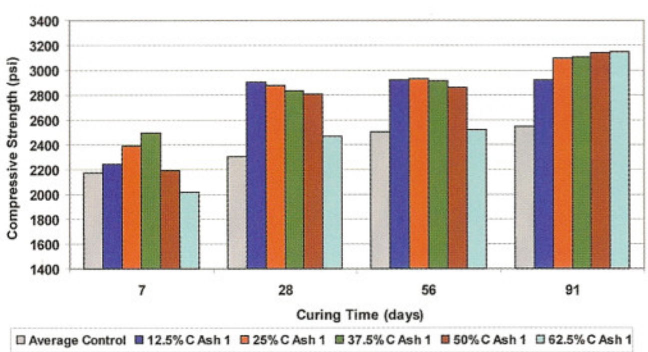

Figure 4. Compressive Strength Development of Class C Fly Ash Number 1 Mixtures

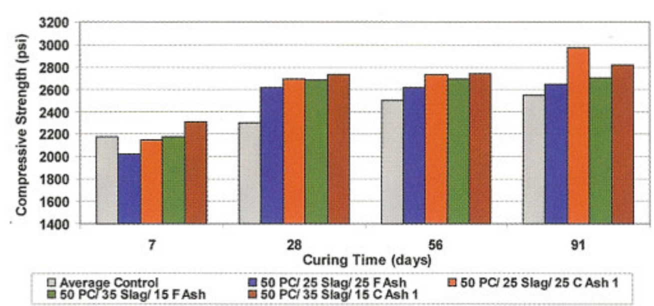

Figure 7. Compressive Strength Development of Tertiary Mixtures

percent or more increase in cost; orange indicates a ten percent increase; yellow indicates that the variable mixture cost is less than ten percent different from the control cost; Blue indicates a ten percent decrease; and green indicates a twenty percent or more decrease in cost compared to the control cost.

Class F fly ash was the clear winner in cementing material cost reduction for pervious PCC. Class F fly ash produces the maximum cost reduction for cementing materials at all substitution rates. Further, Class F fly ash significantly (10% or more) reduces cementing material costs at the lowest substitution rate tested (12.5%).

SCM SUBSTITUTION RATES FOR PERVIOUS PCC - HELP SUMMARY

The research presented herein is exploratory in nature, additional batches of the more promising mixtures should be produced to confirm the results obtained. Based on the results from this study, the following advice can be offered to pervious PCC producers.

1. SCM substitution in pervious PCC is almost always beneficial. It improves sustainability and

—Continued on page 14

Continued from page 11—

by L. K. Couch

Help for Pervious PCC Producers

Part 1: Supplementary Cementing Material Substitution Rates—It's Good to be Green!

reduces costs. Compressive strength can usually be maintained or improved.

2. For typical 28 day compressive strength specifications, 25 to 37.5 percent substitution by volume of a single SCM or a tertiary (50 percent substitution) mixture worked well. Consider higher substitution rates when longer curing periods are available.

3. Always make a trial batch of the pervious PCC mixture to check for SCM / admixture compatibility, compressive strength, effective voids and paste drain down.

4. Although each SCM contributed to improving pervious PCC. Each SCM excelled in a different area. Choose the appropriate SCM for the primary mixture purpose:

    - **Sustainability** - Grade 120 slag cement allows the "greenest" pervious PCC mixtures. Grade 120 slag cement can be substituted at the highest rates by volume of cementing materials without compromising pervious PCC properties. Substitution rates as high as 75 percent by volume can produce pervious PCC mixtures with adequate compressive strength and effective voids without paste drain down.
    - **Compressive Strength Improvement** - Class C fly ash was the most beneficial SCM to pervious PCC compressive strength improvement at almost all substitution rates and ages. Class C fly ash truly excelled in improving 28-day compressive strength, compressive strength was significantly (10% or more) improved in nine of ten cases. Twenty-eight days is the most common specification time and therefore the most important time to excel in improving compressive strength.
    - **Reducing Cementing Material Cost** - Class F fly ash was the clear winner in cementing material cost reduction for pervious PCC. Class F fly ash produces the maximum cost reduction for cementing materials at all substitution rates. Further, Class F fly ash significantly (10% or more) reduces cementing material costs at the lowest substitution rate tested (12.5%).

REFERENCES

1. Phillips, Jason B., **Pervious Concrete Paste Composition**, Master of Science Thesis, Tennessee Technological University, Cookeville, TN, May 2009.
2. ASTM C 618-03. "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete." American Society for Testing and Materials. **Annual Book of ASTM Standards**. Vol. 04.02. 2006. pp. 326-328
3. ASTM C 989-05. "Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars." American Society for Testing and Materials **Annual Book of ASTM Standards**. Vol. 04.02, 2006, pp. 530-534.
4. ASTM C 150-04a. "Standard Specification for Portland Cement." American Society for Testing and Materials. **Annual Book of ASTM Standards**. Vol. 04.01. 2005. pp. 144-151.
5. ASTM C 33-03. "Standard Specification for Concrete Aggregates." American Society for testing and Materials. Vol. 04.02, 2006, pp. 10-20.
6. ASTM C 136-06. "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates." American Society for Testing and Materials. Vol. 04.02, 2006, pp. 89-93.
7. AASHTO T 245-97. "Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus." American Association of State Highway and Transportation Officials. **Standard Specifications for Transportation Materials and Methods of Sampling And Testing Part II Tests**. 19th edition. 1998.
8. "Standard Test Method for Effective Porosity and Effective Air Voids of Compacted Bituminous Paving Mixture Samples[1]," (ASTM D 7063-05), available at www.astm.org.
9. ASTM C 617-98. "Standard Practice for Capping Concrete Specimens." American Society for Testing and Materials. **Annual Book of ASTM Standards**. Vol. 04.02, 2006. pp. 321-325.
10. ASTM C 39-01. "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." American Society for Testing and Materials. **Annual Book of ASTM Standards**. Vol. 04.02. October 2002. pp. 21-25.
11. Kosmatka, Steven H., Kerkhoff, Beutrix, Panareses William C., "Design and Control of Concrete Mixtures." 14th edition. Portland Cement Association. 2002.

TABLE 4. PERCENT OF AVERAGE CONTROL COMPRESSIVE STRENGTH AT SPECIFIED AGE

Supplementary Cementing	SCM Substitution Rate for Type I PC by Volume (%)				
Material/Age	12.5	25	37.5	50	62.5
Class F Fly Ash, 7 Days	103	98	90	75	
Class F Fly Ash, 28 Days	108	102	102	98	
Class F Fly Ash, 56 Days	104	109	113	103	
Class F Fly Ash, 91 Days	103	109	113	101	
Class C Fly Ash No. 1, 7 Days	103	110	115	101	93
Class C Fly Ash No. 1, 28 Days	126	125	123	122	107
Class C Fly Ash No. 1, 56 Days	117	117	117	114	101
Class C Fly Ash No. 1, 91 Days	115	122	122	123	124
Class C Fly Ash No. 2, 7 Days	107	110	107	93	77
Class C Fly Ash No. 2, 28 Days	115	119	130	124	111
Class C Fly Ash No. 2, 56 Days	115	121	122	121	102
Class C Fly Ash No. 2, 91 Days	117	126	126	127	124
Grade 120 Slag, 7 Days	103	104	105	99	93
Grade 120 Slag, 28 Days	108	110	109	106	104
Grade 120 Slag, 56 Days	100	105	106	99	98
Grade 120 Slag, 91 Days	104	105	106	98	96

TABLE 5. PERCENT OF AVERAGE CONTROL COMPRESSIVE STRENGTH AT SPECIFIED AGE

Tertiary Mixture	7 Days	28 Days	56 Days	91 Days
50PC/25S/25F	93	114	105	104
50PC/25S/25C1	99	117	109	117
50PC/35S/15F	100	117	108	106
50PC/35S/15C1	106	119	110	111

TABLE 6. CEMENTING MATERIAL COST PER CUBIS YARD ($)

Supplementary Cementing Material	SCM Substitution Rate for Type I PC by Volume (%)					
	0	12.5	25	37.5	50	62.5
Class F Fly Ash	37.50	33.55	29.60	25.65	21.71	
Class C Fly Ash	37.50	34.03	30.55	27.08	23.60	20.12
Grade 120 Slag	37.50	35.55	33.61	31.67	29.73	27.78
50PC/25S/25F					25.71	
50PC/25S/25C1					26.67	
50PC/35S/15F					27.31	
50PC/35S/15C1					27.89	

20% or more less than control	10% or more less than control	Less than 10% different from control	10% or more greater than control	20% or more greater than control

ACKNOWLEDGEMENTS

The work reported in this paper was Jason Phillips' Master of Science research topic. The author appreciates Jason's extensive work on this topic. I sincerely appreciate the assistance provided by former TTU students Derek Godwin and J. D. Self. I also greatly appreciate the materials provided by Denny Lind of BASF Admixtures, Inc., Brian Strevel of SEFA Group, Clark Simpson of Builder's Supply, Russell B. Stapp of Headwaters Resources, George C. Zima of Lafarge and Curtis Gould of Boral. I also gratefully acknowledge the financial support, financial project management, and computer assistance of the TTU Center for Energy Systems Research. Thanks to the TTU Department of Civil and Environmental Engineering for providing supplies and student salary for the project.

AUTHOR INFORMATION

L. K. Crouch, Ph.D., P.E. is a professor of Civil Engineering at Tennessee Technological University. ❖