

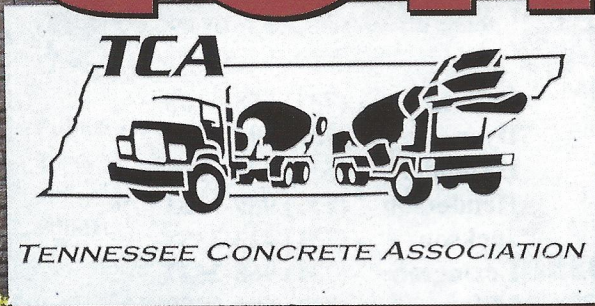
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Help for Pervious PCC Producers

Part 3: Fine Aggregate for Pervious PCC

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 third article, fine aggregate use in pervious PCC is explored. Part 4 in the series will examine:

4. Putting It All Together for a High Performance Pervious Concrete Mixture Design

Some Tennessee concrete producers have experimented with using fine aggregate in pervious PCC. Their experience and literature [1] both indicate that there are advantages and disadvantages in using fine aggregate in pervious PCC. Specifically, using fine aggregate increases compressive strength and decreases permeability. Increasing compressive strength will increase markets for pervious PCC if adequate permeability can be maintained. For example, the transportation research board recently extended a call for papers on pervious PCC uses in highway and street applications. Obviously, higher compressive strengths will be required in these applications. Parts 1 and 2 showed that supplementary cementing materials and chemical admixtures could be used to increase compressive strength of pervious PCC. If experience and literature are correct, 3000-psi pervious PCC with adequate permeability may be achievable with low compaction. This study is an attempt to quantify the effects of fine aggregate substitution on pervious PCC engineering properties.

MATERIALS

Type I Portland cement [2] was obtained from a local ready mix producer's bulk storage. A local limestone coarse aggregate close to but not meeting the ASTM C 33 [3] No. 89 gradation specification was obtained from a local quarry. The average results of a washed sieve analysis [4, 5] conducted in triplicate on the local limestone are shown in Table 1. TCA members donated two fine aggregates, river sand (a typical middle Tennessee concrete fine aggregate) and manufactured limestone sand (a typical East Tennessee concrete fine aggregate). The average results of a washed sieve analysis [4, 5] conducted in triplicate on both fine

aggregates are shown in Table 2. Chemical admixtures were provided by the local representative of an international chemical producer. Local tap water was used in all mixtures.

RESEARCH PLAN

The research team developed a pervious PCC mixture (see Table 3) to act as the control or standard for comparison for the project. Throughout the research, the amount of cement, water and admixtures was held constant for all mixtures. The volume of total aggregate remained constant, but the percentage of coarse and fine aggregates was varied. The control mixture contained no fine aggregate. For each fine aggregate, the variable mixtures contained 2, 4, 6, 8, or 10 percent fine aggregate by volume of total aggregate. Table 4 shows the coarse and fine aggregate proportions for each river sand variable mixture as well as the approximate effective void size, D_{10} , of the aggregate blend. Similarly, Table 5 shows the coarse and fine aggregate proportions for each limestone manufactured sand variable mixture as well as the approximate effective void size, D_{10} , of the aggregate blend. Eight batches of each mixture (control and variables) were produced and tested. The goal of the project was to quantify the effects of Tennessee fine aggregate on pervious PCC engineering properties.

PROCEDURE

All pervious PCC batches were 0.33-cubic feet in size. Each batch was mixed in a one-cubic foot capacity electric mixer. Four 4x8-inch cylinders were cast from each batch. Two of the cylinders were used for compressive strength and static modulus of elasticity determination and two were used to determine effective void content and permeability. 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 cylinders were de-molded and placed in a lime-water immersion tank. Permeability was determined on a pair of cylinders at 14 days as per the method described by Crouch [8]. Following permeability testing the cylinders were dried at 230°F for seven days. Twenty-one days after casting, effective void contents were determined as per ASTM D 7063 [9]. Compressive strength and static modulus

TABLE 1. COARSE AGGREGATE USED FOR THE PROJECT

Sieve Size	Sieve Size (mm)	Project Coarse Aggregate (% finer by mass)	ASTM No. 8 Stone (% finer by mass)	ASTM No. 89 Stone (% finer by mass)
1/2 inch	12.5	100	100	100
3/8 inch	9.5	99	85-100	90-100
No. 4	4.75	45	10-30	20-55
No. 8	2.36	3	0-10	5-30
No. 16	1.18	2	0-5	0-10
No. 50	0.3	1		0-5

TABLE 2. FINE AGGREGATES USED FOR THE PROJECT

Sieve Size	Sieve Size (mm)	River Sand (% finer by mass)	Limestone Mfg. Sand (% finer by mass)	TDOT PPC Fine Aggregate Requirements (% finer by mass) [6]
3/8 inch	9.5	100	100	100
No. 4	4.75	98	100	95-100
No. 8	2.36	91	96	
No. 16	1.18	82	66	50-90
No. 30	0.6	63	39	
No. 50	0.3	9	20	5-30
No. 100	0.15	1	10	0-10
No. 200	0.075	0.3	6.3	0-3*

*For manufactured limestone sand increase to 5%.

TABLE 3. CONTROL PERVIOUS PCC MIXTURE DESIGN

Component	Amount
Type I PC, lbs./CY	600
Limestone Coarse Aggregate, SSD, lbs./CY	2600
Water, lbs./CY	180
Hydration Stabilizer, oz./cwt.	4
Mid-Range Water Reducer, oz./cwt.	5
Viscosity Modifier, oz./cwt.	2

TABLE 4. AGGREGATE BLEND FOR RIVER SAND VARIABLE MIXTURES

Component	RS 2	RS 4	RS 6	RS 8	RS 10
Limestone Coarse Aggregate, SSD, lbs./CY	2549	2497	2445	2393	2341
River Sand, SSD, lbs./CY	50	101	152	203	254
Approximate Effective Void Size, D_{10} , mm	2.6	2.5	2.4	2.2	1.4

TABLE 5. AGGREGATE BLEND FOR MANUFACTURED LIMESTONE SAND VARIABLE MIXTURES

Component	RS 2	RS 4	RS 6	RS 8	RS 10
Limestone Coarse Aggregate, SSD, lbs./CY	2549	2496	2445	2392	2341
Manufactured Limestone Sand, SSD, lbs./CY	52	105	157	210	262
Approximate Effective Void Size, D_{10} , mm	2.6	2.5	2.4	2.1	1.7

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of elasticity were determined at 28 days using the other 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 [10] and subsequently tested in accordance with ASTM C 39 [11] and ASTM C 469 [12].

RESULTS

The results of the project are truly voluminous—176 compressive strengths, permeabilities and effective void contents. Average results are shown in this article; detailed information will be available in second author's thesis. Table 6 shows average engineering properties for the control and ten fine aggregate variable mixtures. Each compressive strength, permeability and effective void content result is the average of sixteen cylinders (8 pairs). Each static modulus of elasticity result is the average of eight cylinders.

ANALYSIS OF RESULTS

Table 7 shows the percentage reduction in average permeability, 28-day compressive strength and static modulus of elasticity compared to the control mixture average results. Yellow shading indicates the change from the previous fine aggregate percentage (the mixture with two percent less fine aggregate) was statistically significant in a paired t-test at the 95% level of significance. Figure 1 shows the very strong linear relationships ($R^2 > 0.95$) between effective void content and percent fine aggregate for both river sand and manufactured limestone sand. The effects of fine aggregate substitution on average permeability, 28-day compressive strength and static modulus of elasticity are described in the following paragraphs.

Permeability

Table 7 shows that in eight of the ten cases, the reduction in permeability was statistically significant when compared to the previous mixture. Permeability of pervious PCC is a function of both effective void content and effective void size. Fine aggregate substitution for coarse aggregate effects both effective void content and effective void size. Tables 4 and 5 show the effect of fine aggregate substitution on the effective void size D_{10} . Just as Figure 1 shows the effect of fine aggregate substitution on effective void content, Figure 2 shows the combined effects of void content and size on permeability. The very strong exponential relationships ($R^2 > 0.96$) for both fine aggregates indicate that permeability is a function of both variables. Figure 3 shows the very strong linear relationships ($R^2 > 0.98$) between permeability

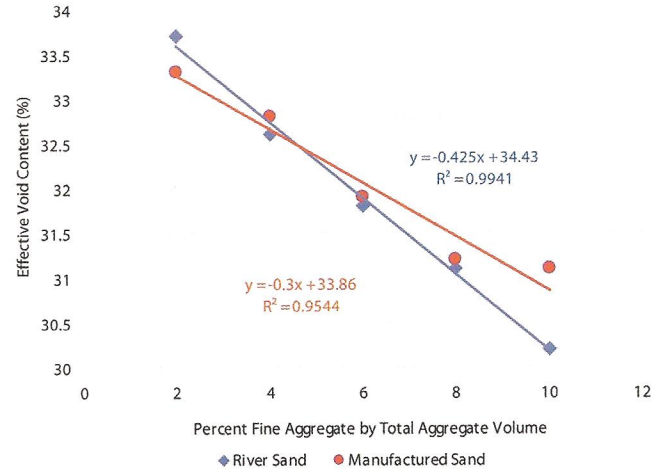


Figure 1. Effective Void Content vs. Percent Fine Aggregate

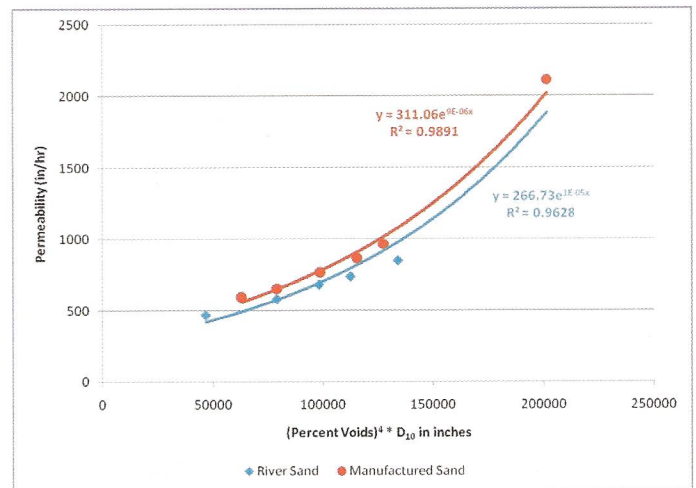


Figure 2. Permeability vs. (Percent Effective Voids)⁴ * Effective Void Size, D_{10}

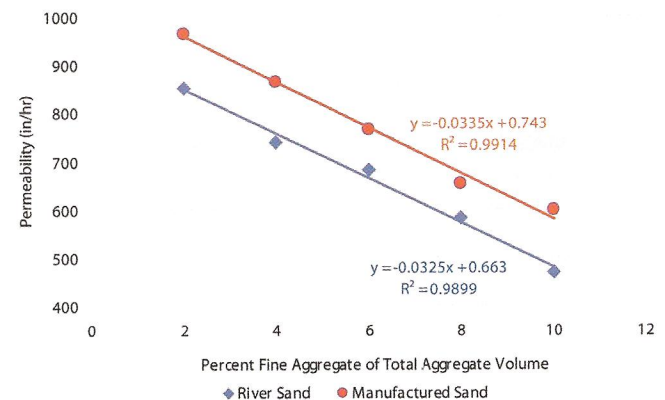


Figure 3. Permeability vs. Percent Fine Aggregate

TABLE 6. AVERAGE ENGINEERING PROPERTY RESULTS

Mixture	Mean Effective Void Content (%)	Mean Permeability (inches/hour)	Mean 28-day Compressive Strength (psi)	Mean 28-day Static Modulus of Elasticity (psi)
Control	37.0	2112	1450	1.45 x 10 ⁶
RS 2	33.7	850	2270	1.90 x 10 ⁶
RS 4	32.6	737	2520	2.10 x 10 ⁶
RS 6	31.8	680	2550	2.15 x 10 ⁶
RS 8	31.1	581	2660	2.25 x 10 ⁶
RS 10	30.2	468	2960	2.30 x 10 ⁶
MS 2	33.3	964	2440	2.00 x 10 ⁶
MS 4	32.8	865	2530	2.25 x 10 ⁶
MS 6	31.9	765	2560	2.25 x 10 ⁶
MS 8	31.2	652	2720	2.35 x 10 ⁶
MS 10	31.1	595	2640	2.30 x 10 ⁶

TABLE 7. PERCENTAGE CHANGE OF ENGINEERING PROPERTY FROM THE CONTROL MIXTURE

Mixture	Mean Permeability	Mean 28-day Compressive Strength	Mean 28-day Static Modulus of Elasticity
RS 2	- 60	+ 57	+ 31
RS 4	- 65	+ 74	+ 45
RS 6	- 68	+ 76	+ 48
RS 8	- 73	+ 83	+ 55
RS 10	- 78	+ 104	+ 59
MS 2	- 55	+ 68	+ 38
MS 4	- 59	+ 75	+ 55
MS 6	- 64	+ 77	+ 55
MS 8	- 69	+ 88	+ 62
MS 10	- 72	+ 82	+ 59

and percent fine aggregate for both river sand and manufactured limestone sand.

Compressive Strength

Table 7 shows that in only five of the ten cases (unlike permeability) were the increases in compressive strength statistically significant when compared to the previous mixture. In nine of ten cases an increase in fine aggregate substitution rate increased compressive strength. However, the magnitude of the increase was not constant. Producers should carefully consider if an increase in fine aggregate substitution rate will increase compressive strength enough to justify the almost certain significant loss in permeability.

Figure 4 shows a strong linear relationship ($R^2 > 0.90$) between fine aggregate substitution rate and compressive strength for river sand, the same relationship for manufactured sand is only fair ($R^2 > 0.74$). Figure 5 shows the strong linear relationships ($R^2 > 0.94$) between compressive strength and effective void content for both river sand and manufactured limestone sand when the control mixture data is included. It is important to note that the regression lines are almost identical, possibly indicating that the

gradation of the coarse aggregate is more important than that of the fine aggregate. Additional data will be required to confirm that possibility, but with at least nine times as much of coarse aggregate as fine aggregate it would not be surprising if the coarse aggregate gradation was more important.

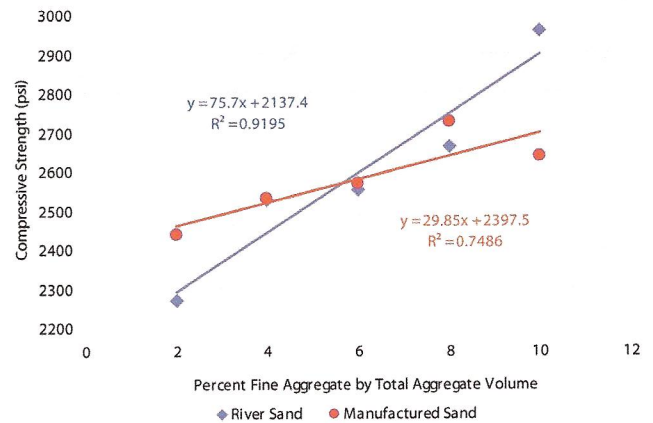


Figure 4. 28-day Compressive Strength vs. Percent Fine Aggregate

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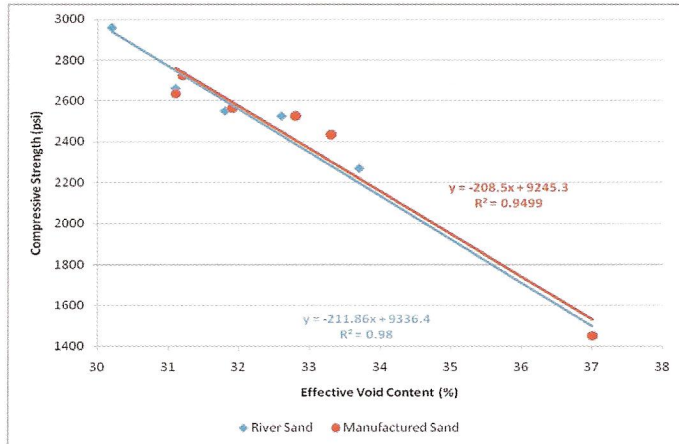


Figure 5. 28-day Compressive Strength vs. Effective Void Content

Static Modulus of Elasticity

Table 7 indicates that in only four of the ten cases was the increase in static modulus of elasticity statistically significant when compared to the previous mixture. In eight of ten cases (see Table 7) an increase in fine aggregate substitution rate increased static modulus of elasticity. However, the magnitude of the increase was typically small, except in going from the control mix to the average results for a mix with a two percent substitution rate. Figure 6 shows a very strong logarithmic relationship ($R^2 > 0.97$) between fine aggregate substitution rate and static modulus of elasticity for river sand, the same relationship for manufactured sand was only good ($R^2 > 0.81$).

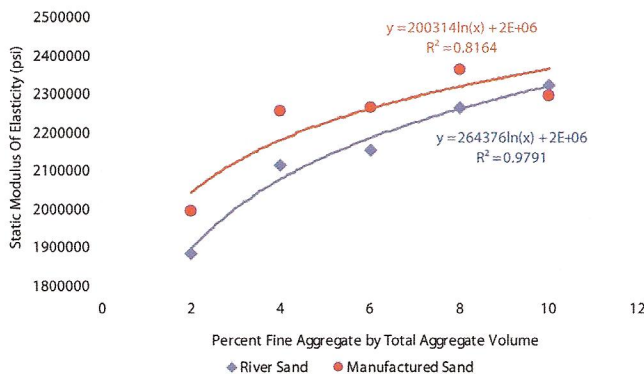


Figure 6. 28-day Static Modulus of Elasticity vs. Percent Fine Aggregate

FINE AGGREGATE FOR PERVIOUS PCC - HELP SUMMARY

Based on the results from this study, the following advice can be offered to pervious PCC producers.

1. In 4 of 5 cases, a two percent increase in substitution rate of either fine aggregate for coarse aggregate by volume between zero and ten percent, produced a statistically significant decrease in permeability. Percentage reductions ranged from 55 to 78 percent compared to the permeability of the control mixture with no fine aggregate.
2. In 3 of 5 cases, a two percent increase in substitution rate of river sand for coarse aggregate by volume between zero and ten percent, produced a statistically significant increase in compressive strength. For river sand substitution, percentage increases ranged from 57 to 104 percent compared to the control mixture with no fine aggregate. In 2 of 5 cases, a two percent increase in substitution rate of limestone manufactured sand for coarse aggregate by volume between zero and ten percent, produced a statistically significant increase in compressive strength. For limestone manufactured sand substitution, percentage increases ranged from 68 to 88 percent compared to the control mixture with no fine aggregate.
3. In the first two cases (from 0 to 2 and from 2 to 4 percent), a two percent increase in substitution rate of either fine aggregate for coarse aggregate by volume produced a statistically significant increase in static modulus of elasticity. Further increases in either fine aggregate substitution rate resulted in either no increase or no significant increase in static modulus of elasticity. Percentage increases ranged from 31 to 62 percent compared to the static modulus of elasticity of the control mixture with no fine aggregate.
4. Large increases in compressive strength are possible with fine aggregate substitution for coarse aggregate however Tennessee concrete producers considering fine aggregate use are cautioned that a significant decrease in permeability is much more likely than a significant increase in compressive strength or static modulus of elasticity. Trial placements and testing are recommended to avoid producing pervious PCC with inadequate permeability.

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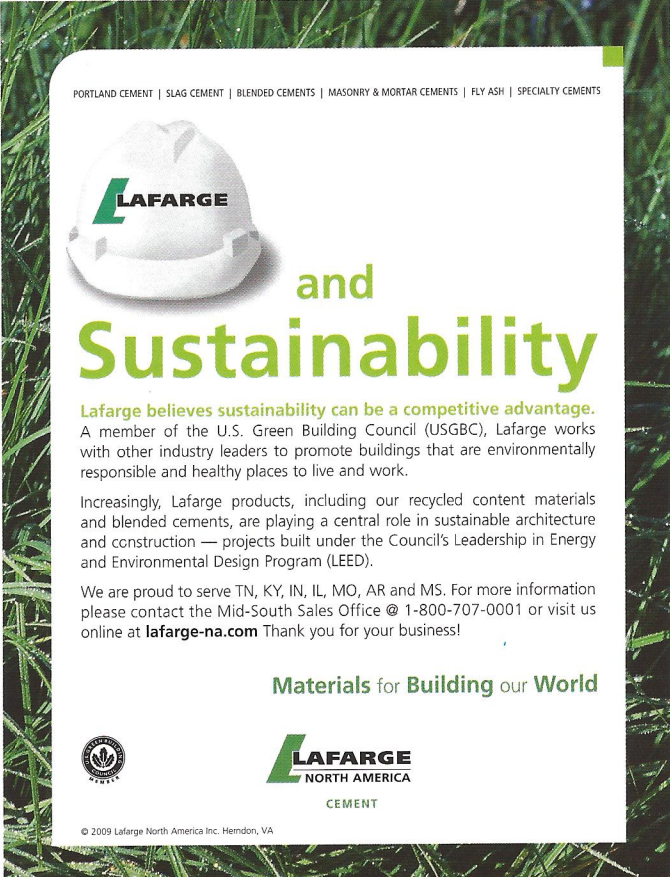
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AUTHOR INFORMATION

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

Cameron Williams, E.I. is an Agricultural Engineer with the Natural Resources Conservation Service and a graduate student in the Civil Engineering Department at Tennessee Technological University.

Daniel Badoe, Ph.D. is a professor of Civil Engineering at Tennessee Technological University.



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