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..... Early TCA Experiments with
Self-Compacting Pervious PCC





by L. K. Couch, Marcus L. Knight and Alan Sparkman—

Early TCA Experiments with Self-Compacting Pervious PCC

INTRODUCTION

Pervious Portland Cement Concrete (PCC) is proportioned with aggregates, cement (possibly with supplementary cementing materials), water, and admixtures so that an open void structure (~25% by volume) is maintained throughout its cross section. The void structure is such that water can drain freely through the concrete without significant resistance.

Pervious PCC is very “green” (environmentally friendly) at a time when it is very important to be “green” from environmental stewardship and economic viewpoints. From an environmental perspective, pervious PCC, due to the typical open void structure, is one of the best management practices for control of storm water runoff in parking areas. The void structure allows much of the storm water to pass directly through a concrete parking slab into the sub-grade. This process, along with any filtering of the runoff that may occur in the pervious PCC and sub-grade,

may reduce the amount of pollutants and debris that eventually enters storm drains or receiving waters. This is especially true when compared to similar applications of impervious pavements that force storm water to cover great distances with the opportunity to gather contaminants (oil from parked cars) and debris (trash) along the way ultimately transporting these undesirable elements to receiving waters. Finally, pervious PCC provides another possible environmental benefit in that post industrial byproducts (i.e. fly ash) may be used in its production providing a possible reduction in the amount of material that must be transported to landfills.

From an economic viewpoint, pervious PCC is also attractive. Pervious PCC applications may provide several economic benefits for a particular application including a reduction in the number, size, and ultimately cost of storm water infrastructure

that is required to meet local standards. Its use may also lead to more development area on a given site, or a reduction in the size of site required for a particular development, as a possible reduction in the volume of retaining ponds may be achieved. Finally, the use of pervious PCC may provide an alternative to contractors and developers that need a competitive edge on projects where Leadership in Energy and Environmental Design (LEED) certification is desired or required.

Due in part to the environmental and economic considerations previously described, pervious PCC is one of the fastest growing markets for the ready mixed concrete industry. Unfortunately, pervious PCC engineering properties (compressive strength and effective void content) have been found to vary greatly from placement to placement and even within the same placement. Figure 1 shows compressive strengths and corresponding effective void contents for 103 cores from past Tennessee Concrete Association (TCA) pervious PCC placements.

Why is pervious PCC variability so high? American Concrete Institute (ACI) Committee 522 Report [1] indicates that pervious PCC engineering properties are dependent on compactive effort as well as mixture proportions. Further, previous research at Tennessee Technological University has shown that to achieve the desired pervious PCC engineering properties the mixture must be proportioned for a particular compactive effort application. If too much compactive effort is applied to a mixture proportioned for a low compactive effort, low effective voids, low permeability and paste drain down often result. If too little compactive effort is applied to a mixture proportioned for high compactive effort, low compressive strength and raveling of the surface aggregate often result. These facts leave the ready mix producer with few options. The ready mix producer must maintain several pervious mixture designs for different compactive efforts and spend much valuable time coordinating with placement contractors or share in the negative publicity of a placement with inadequate engineering properties.

Haselbach and Freeman [2] report that pervious PCC engineering properties even vary with depth in a single placement. The vertical variation in compressive strength, porosity and permeability was attributed to the surface compaction technique. The compaction was much more effective near the surface than at depth, even for six-inch deep slabs. Brown [3] states that an attempt to standardize compaction equipment for pervious PCC is an important research need. Can pervious PCC compaction equipment be standardized to provide effective, uniform compaction? Unfortunately, standardization of pervious PCC compaction is not likely. Economics (what equipment can be obtained cheaply and easily) and the desire for innovation do not favor standardization. Further, even if standardization could be achieved, all surface compaction techniques impart more stress to the near surface than to deeper portions of the pervious PCC. Past efforts have focused on many alternative surface

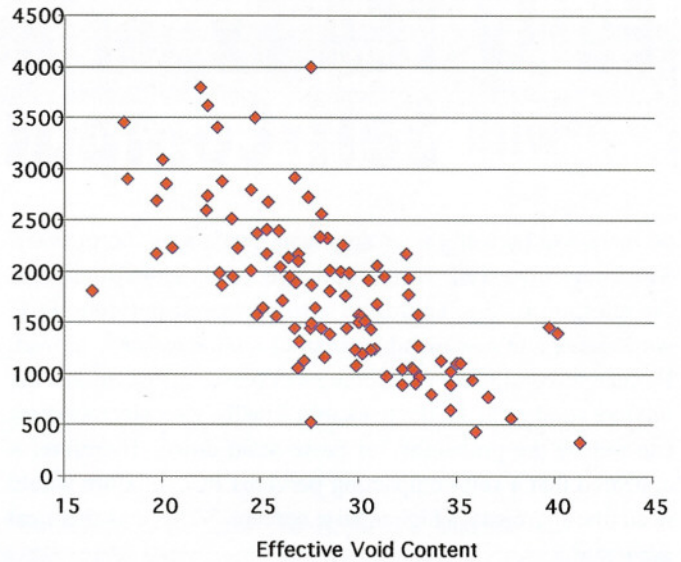


FIGURE 1: CORE COMPRESSIVE STRENGTH VS. EFFECTIVE VOID CONTENT OF TCA PLACEMENTS

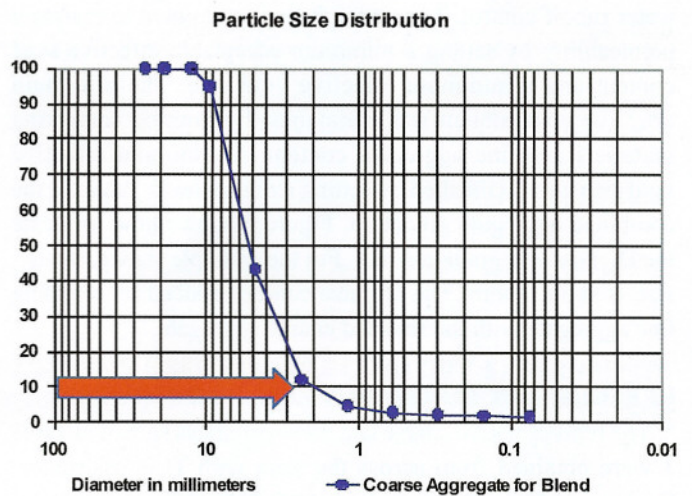


FIGURE 2: DETERMINING THE EFFECTIVE VOID SIZE (D₁₀)

compaction techniques including heavier rollers, high-density pavers, vibratory plate compactors, and counter-rotating rollers. What can be done to address these problems? Since compaction techniques cannot easily be standardized and are of questionable effectiveness, TCA researchers decided to try self-compacting pervious PCC.

BACK TO SIMPLE BASICS

When gluing wood pieces together for furniture, two factors are critical for the strength of the joint: the strength of the glue and the surface area available for gluing. Previous TTU research indicated that the addition of supplementary cementing materials (SCMs) and chemical admixtures increased the strength of the “glue” for pervious PCC [4]. Surface area for “gluing” can

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be increased by using finer aggregate gradations. Fortunately, Sparkman observed, in unpublished communications, that the addition of fine aggregate also increased pervious PCC workability and made ready mix trucks much easier to unload. Further, increasing the paste content of pervious PCC makes the mixture stronger and more workable. Finally, viscosity modifiers can reduce the probability of paste drain down. Therefore, it appeared that a self-compacting pervious PCC mixture would need fine aggregate, a higher paste content, SCMs and chemical admixtures.

Permeability is the unique feature of pervious PCC and the key feature that makes it a best management practice for storm water runoff control. The research team attempted to maintain permeability by setting a minimum acceptable effective void content and a minimum effective void size. The minimum effective void content was maintained by limiting cementing materials and fine aggregate content. A minimum effective void size was established by setting a minimum D_{10} size for the combined aggregate gradation. Figure 2 shows how to locate the D_{10} size on a gradation plot. For the example shown, the D_{10} size is about 2-mm. The D_{10} size can be reduced by blending fine aggregate with the selected coarse aggregate.

LABORATORY MATERIALS AND PROCEDURE

The representative coarse and fine aggregates shown in Table 1 were obtained from across the state with TCA assistance. Coarse and fine aggregates from each part of Tennessee were blended mathematically by trial and error to produce combined aggregate gradations with a D_{10} size close to 1-mm. The 1-mm D_{10} target size was chosen for these early self-compacting pervious PCC experiments. The value may need to be altered as more information becomes available. Combined aggregate gradations are shown in Table 2.

Initial mixture proportions were chosen based on prior experience with low compaction pervious PCC mixtures. Final self-compacting laboratory mixture proportions (shown in Table 3) were chosen by trial batches to produce mixtures with effective void contents between 23 and 32 percent and 28-day compressive strengths greater than 2500-psi that did not have excessive paste drain down. All trial batches were mixed in a one cubic foot electric mixer. The mixture was then placed without compaction in a 24-by-6-by-6-inch oiled wooden beam mold and struck off level (see Figure 3). The beam specimen was then covered with plastic until the next day. The following day, the beam forms

were wrecked and the beam was placed in lime-water curing tank. Four cores were extracted from the beam at seven or eight days in accordance with ASTM C 42 [5]. Two cores were used for compressive strength determination and two were used to determine the effective void content. Compressive strength as per ASTM C 39 [6] was determined using sulfur mortar capping as per ASTM 617 [7] following coring. The effective void content was determined as per ASTM D 7063 [8] after drying the cores at 230°F for three to seven days.

Each trial batch consisted of one beam specimen. However, when a beam specimen appeared likely to meet compressive strength (2500-psi @ 28-days) and effective void content goals (23 to 32%), four additional batches were fabricated and tested to confirm the results. Results of the final laboratory mixtures for each part of Tennessee are shown in Table 4. The compressive strengths shown in Table 4 were measured at 7 or 8 days rather than 28 days, due to the sponsor's desire to take the mixtures to the field as soon as possible. Effective void contents shown in Table 4 were typically measured 10 to 15 days after beam casting. Average compressive strengths and effective void contents for all three mixtures met project goals.



FIGURE 3: STRIKING OFF SELF-COMPACTING PERVIOUS BEAMS IN THE LABORATORY

FIELD EXPERIMENTS

General

Field experiments are far more important than laboratory results. Wonderful laboratory results are meaningless if they cannot be translated to the field. Five experimental field placements were conducted as part of this study. Field placement

TABLE 1. COARSE AND FINE AGGREGATES USED IN THE LABORATORY (PERCENT FINER BY MASS)

Sieve Size (mm)	East TN No. 8 Limestone	Middle TN No. 8 Limestone	West TN Gravel	East TN Limestone Sand	Middle TN River Sand	West TN Bank Sand
12.5	100	100	100	100	100	100
9.5	95	95	86	100	100	100
4.75	23	43	15	100	97	99
2.36	2	12	2	94	90	85
1.18	2	5	1	61	82	72
0.6	2	3	1	34	57	48
0.3	2	2	1	17	9	4
0.15	2	2	1	9	1	1
0.075	1	2	1	5.7	0.4	0.4

TABLE 2. LABORATORY COMBINED AGGREGATE GRADATIONS (PERCENT FINER BY MASS)

Sieve Size (mm)	East Tennessee	Middle Tennessee	West Tennessee
12.5	100	100	100
9.5	96	95	88
4.75	32	48	26
2.36	13	19	13
1.18	9	12	10
0.6	6	8	7
0.3	4	3	1
0.15	3	2	1
0.075	1.9	1.6	0.6

TABLE 3. SELF-COMPACTING PERVIOUS PCC MIXTURE DESIGNS USED FOR LABORATORY EXPERIMENTS

Component	East Tennessee	Middle Tennessee	West Tennessee
Type I PC, lbs/CY	540	486	445
Class F Fly Ash, lbs/CY	98	88	81
Coarse Aggregate, SSD, lbs/CY	2016	2181	1983
Fine Aggregate, SSD, lbs/CY	274	208	319
Water, lbs/CY	201	184	152
Design Percent Air Voids	25	25	25
Hydration Stabilizer, oz/CY	26	34	21
Mid-range Water Reducer, oz/CY	32	46	26
Viscosity Modifier, oz/CY	13	0	16

TABLE 4. RESULTS OF LABORATORY EXPERIMENTS

Core Set	Number of Cores	Mean Effective Voids (%)	Effective Voids Range (%)	Mean Compressive Strength (psi)	Compressive Strength Range (psi)
SC Lab East TN	10	26.1	24.4 - 27.6	2540	2230 - 2840
SC Lab Middle TN	10	24.3	21.9 - 26.5	3080	2590 - 4420
SC Lab West TN	10	27.1	25.0 - 28.9	2610	2450 - 2830
Average SC Lab Values	30	25.8	21.9 - 28.9	2740	2230 - 4420



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procedure was identical to laboratory procedure—place, strike-off, cover. The research team felt well prepared when field tests began, however, regardless of the level of preparation, life always manages to provide a few surprises. For example, the producer of the field mixture may not have the exact aggregates, fly ash, or chemical admixtures used to develop the mixture in the laboratory.

The results of three of the five field placements are shown in Table 5. The other two placements served well as lessons in humility for the designer (first author). Table 5 also shows several of the larger data sets used in Figure 1 to serve as a basis for comparison for the experimental self-compacting pervious PCC placements. Details are provided in the following paragraphs.

East Tennessee Mixture

The first field placement was in East Tennessee in September 2008. The coarse aggregates used were much finer than those used in the laboratory experiments and the mixture was obviously over-sanded. The resulting effective void contents were in the desired range, but the compressive strength results averaged 320-psi less than the minimum desired compressive strength. A second East Tennessee experimental placement with a mixture designed for the finer aggregates was discussed but has not been placed.

West Tennessee Mixture

The first West Tennessee experimental placement was also in September 2008. This mixture was obviously far too lean. The mixture designer leaned out the mixture too much to reduce



the possibility of paste drain down. The placement (humility lesson 1) resulted in a low strength (770-psi), high void content (40%) mixture that raveled easily. A subsequent experimental placement with materials similar to those in West Tennessee occurred at TCA headquarters in Nashville in November 2008. The mixture was revised to increase Portland cement (+9 lbs/CY), fly ash (+16 lbs/CY) and water (+8 lbs/CY). The results (see Table 5) met all project goals.

Middle Tennessee Mixture

The first Middle Tennessee experimental placement was at TCA headquarters in Nashville in October 2008. This mixture was far too wet and was removed without coring (humility lesson 2). The next middle Tennessee placement was still a little wet and over-pasted. However, it was a tremendous improvement over the first placement. The results (see Table 5) easily met compressive strength goals, but fell approximately 1 percent below the target effective void content range.

Analysis of Field Results

The purpose of Table 5 is not to show that self-compacting pervious is superior to compacted pervious PCC. The number of self-compacting data points is very small and the results of the humility lessons are not shown. Rather, comparisons were performed to determine the potential of self-compacting pervious PCC mixtures. Are self-compacting pervious PCC mixtures promising enough to pursue? Some of the advantages and disadvantages are listed below.

1. **Simplicity** – place, strike-off, and cover. The procedure is more attractive to customers and contractors.
2. **Increased producer control** – producers now control the level of compaction (none).
3. **Higher compressive strength potential** – the average compressive strength of the three more successful self-compacting pervious PCC placements was 62 percent higher than the average compressive strength of the compacted pervious PCC placements in Table 5.

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TABLE 5. RESULTS OF TCA FIELD PLACEMENTS

Core Set	Number of Cores	Mean Effective Voids (%)	Effective Voids Range (%)	28-day Mean Compressive Strength (psi)	Compressive Strength Range (psi)
Chattanooga	18	32.0	28.5 - 35.8	1230	940 - 1760
Williamson C	5	25.9	22.2 - 28.5	2200	1870 - 2600
Williamson F	6	28.2	24.8 - 31.4	1300	970 - 1570
Burgess Falls	5	27.2	24.7 - 29.2	2790	2260 - 3500
Tunica	6	18.8	16.4 - 20.5	2610	1810 - 3450
Kingsport	6	23.6	21.9 - 25.4	2980	1950 - 3790
Knoxville	10	28.3	25.9 - 32.9	1370	530 - 2400
Erwin	5	28.5	19.7 - 41.3	1790	330 - 2860
Average Compacted Field Values	61	27.1	16.4 - 41.3	1820	330 - 3790
SC Field East TN	4	28.3	23.6 - 31.6	2180	2140 - 2250
SC Field Middle TN	4	22.3	22.0 - 22.9	3280	2960 - 3680
SC Field West TN	4	24.7	23.4 - 25.8	3420	2850 - 4690
Average SC Field Values	12	25.1	22.0 - 31.6	2960	2140 - 4690

- 4. Water content sensitivity** – this is actually neither an advantage nor a disadvantage, all pervious PCC is sensitive to water content.
- 5. Gradation sensitivity** – self-compacting pervious PCC is more sensitive to aggregate gradation than compacted pervious PCC.
- 6. Paste content sensitivity** – self-compacting pervious PCC typically needs a high paste content due to the additional surface area of the fine aggregate. Caution must be exercised to not over or under paste the mixture (the first author learned this in the humility lessons).
- 7. Aesthetics** – the third author expressed some concern that self-compacting is not as aesthetically pleasing as typical compacted pervious PCC.

RECOMMENDATIONS FOR FUTURE SELF-COMPACTING PERVIOUS PCC RESEARCH IN TENNESSEE

Self-compacting pervious PCC had some start up problems but showed great potential for increased compressive strength and simplicity of placement. The three major difficulties (paste content sensitivity, gradation sensitivity, and aesthetics) can all be addressed by increasing the D_{10} target size from 1-mm to 1.5 to 2-mm. The target compressive strength of 2500-psi will probably still be achievable depending on the aggregates, chemical admixtures and SCMs available to the local producer.

In many cases a 2000-psi target compressive strength may be adequate. Another major lesson learned from the early self-compacting pervious PCC experiments is that these mixtures should be designed and trialed with the specific materials that will be used in the field placements.

One possibility not explored in this research, is the use of self-compacting pervious PCC as a wearing course. The increased compressive strength (a 3000-psi minimum is possible with the right materials) and higher paste content of self-compacting pervious PCC may open up new applications for the material. The TCA research team and the Transportation Research Board are interested in highway applications of pervious PCC. If the asphalt folks can produce an open-graded friction course to reduce splash, spray and noise, the PCC folks can make a stronger, more durable, and longer lasting one.

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