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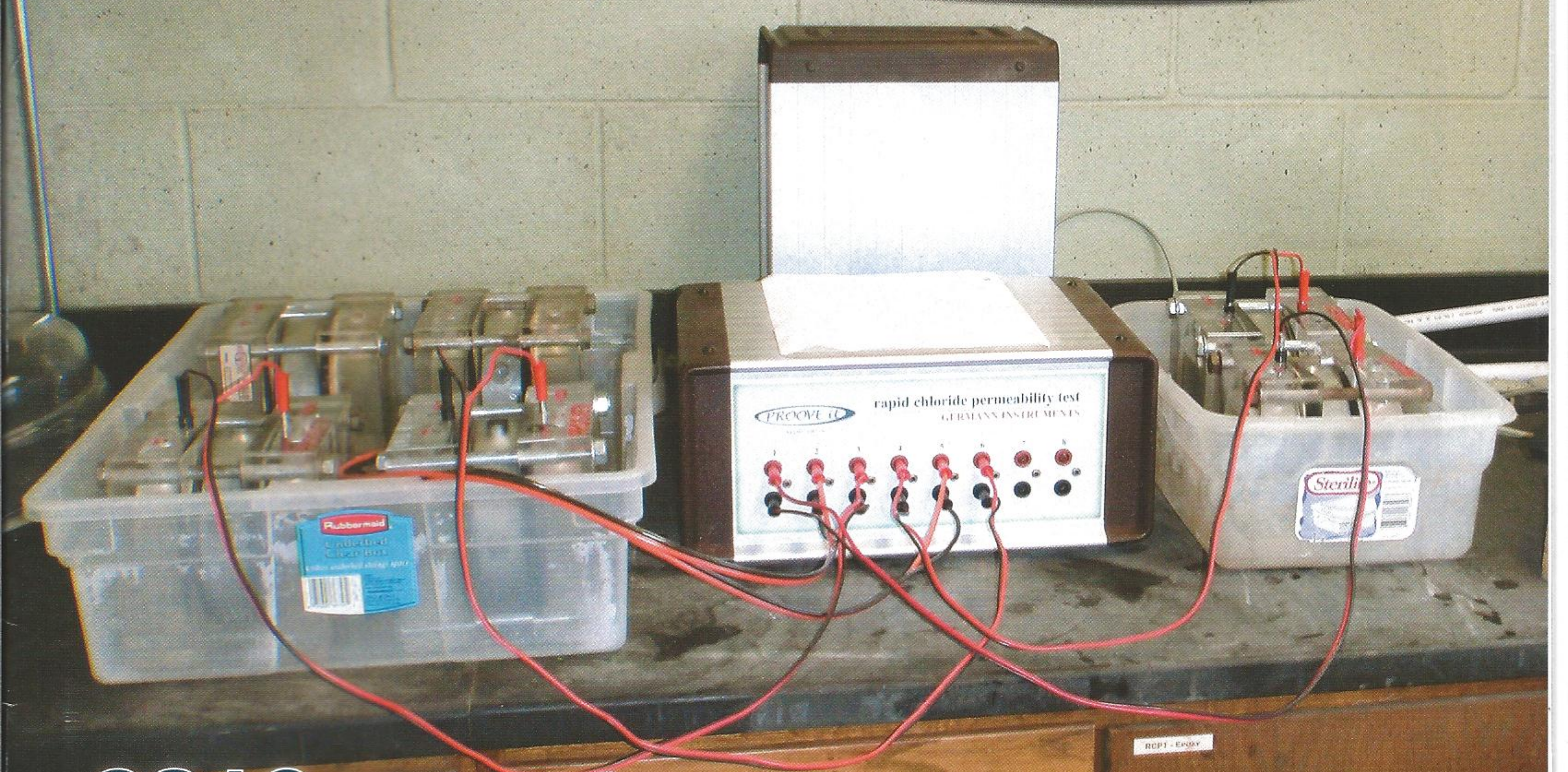

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by L. K. Crouch, Aaron Crowley, Lee Rogers, Heather P. Hall, and Daniel Badoe

Lowering the Chloride Permeability of a TDOT Class D PCC Mixture

Part 1: Developing an Informational Catalog

INTRODUCTION

The Tennessee Department of Transportation (TDOT) is considering a new Class D-LP (lower permeability) portland cement concrete (PCC) mixture specification. Currently, a limit of 1200-coulombs at 56-days, determined as per AASHTO T 277-07 [1], is under consideration. Tennessee Technological University (TTU) researchers are developing an informational catalog to support the possible new specification. The informational catalog is not a recipe book but rather information on mixture designs that have been successful in the laboratory at TTU. Hopefully, the mixture designs and resulting properties would be helpful to industry and municipal designers attempting to produce mixtures that meet the possible new specification. The new informational catalog is by no means exhaustive or exclusive; there are many ways to meet the possible new specification. The three mixtures covered in Part 1 are:

- Type I portland cement / Class F fly ash / Silica fume
- Type I portland cement / Class F fly ash / Metakaolin
- Type I portland cement / Grade 120 slag

Part 2, (Expanding the Informational Catalog) will cover the following four mixtures:

- Type I portland cement / Class C fly ash / Silica fume
- Type I portland cement / Class C fly ash / Metakaolin
- Type I portland cement / Undetermined SCM Replacements
- Type I portland cement / Undetermined SCM Replacements

STATISTICAL BACKGROUND

The goal of the research team was to produce mixtures with a very high probability of meeting the new proposed 1200-coulomb specification for rapid chloride permeability (RCPT). A design target value of 779-coulombs for RCPT at 56-days was calculated using the AASHTO T 277-07 multi-laboratory coefficient of variation of 18% and a three standard deviation safety margin. The safety margin produces a probability of less than one percent that the new proposed 1200-coulomb specification will not be met.

SUPPLEMENTARY CEMENTING MATERIAL DOSAGE CURVES

The RCP of a typical TDOT Class D mixture with 20% Class F fly ash was well established at 1536-coulombs at 56-days based on 100 samples from previous TDOT research at TTU [2]. In the summer of 2011, undergraduate lab assistants Samantha Pittman and Joshua Hogancamp generated dosage curves by substituting

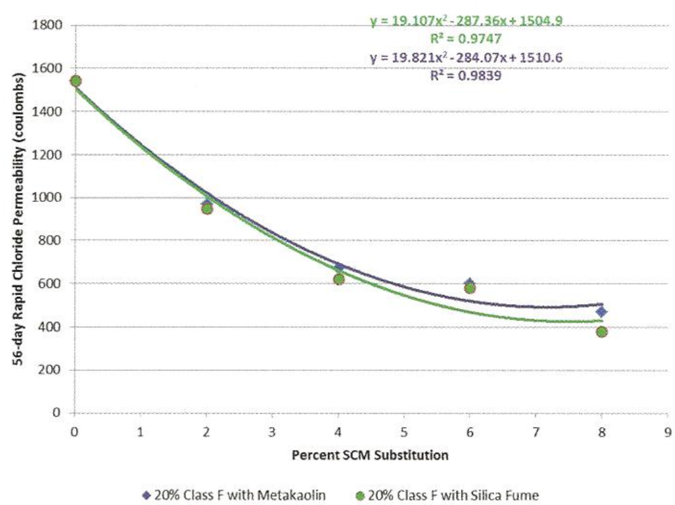

Figure 1. Dosage Curves for Metakaolin and Silica Fume in a Class F Fly Ash Class D Mix

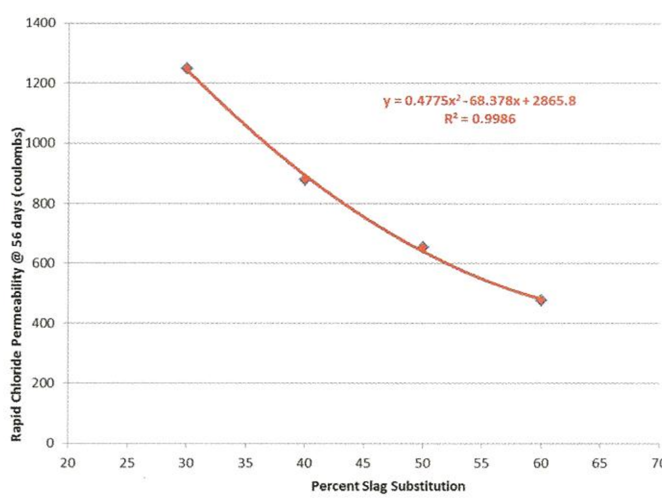

Figure 2. Dosage Curve for Grade 120 Slag in a Class D PCC Mixture

—Continued on page 10

TABLE 1. TRIAL CLASS D-LP MIXTURES

Component	45% Grade 120 Slag D-LP	3.5% SF 20% Class F D-LP	3.5% MK 20% Class F D-LP
Type I PC (lbs/CY)	341	474	474
Class F Fly Ash (lbs/CY)	0	124	124
Grade 120 Slag (lbs/CY)	279	0	0
Silica Fume (lbs/CY)	0	22	0
Metakaolin (lbs/CY)	0	0	22
No. 57 Limestone (lbs/CY SSD)	1921	1905	1909
River Sand (lbs/CY SSD)	1131	1124	1125
Water (lbs/CY)	229.5	229.5	229.5
Design Percent Air*	6	6	6
Air Entrainer, oz/cwt (oz/CY)	0.85 (5.3)	0.32 (2)	0.57 (3.5)
MRWR, oz/cwt (oz/CY)	3 (18.6)	2.4 (14.9)	2.4 (14.9)
HRWR, oz/cwt (oz/CY)	2.5 (15.5)	3.6 (22.3)	3.8 (23.6)

* - prior to 8/01/12 the design air content for a TDOT Class D mix was 6%

TABLE 2. COMPARISON OF D-LP MIXTURE DESIGN ATTRIBUTES WITH TDOT CLASS D REQUIREMENTS

Quantity/Ratio/Percentage	TDOT 604.03 Class D PCC Requirement (3)	45% Grade 120 Slag D-LP	3.5% SK 20% Class F D-LP	3.5% MK 20% Class F D-LP
Cementing Materials Content (lbs/CY)	620 minimum	620	620	620
Water-Cementing-Materials Ratio	0.40 maximum	0.37	0.37	0.37
Percent Fine Aggregate by Total Aggregate Volume	44 maximum	38	38	38
Percent Fly Ash Substitution (by weight) for PC	20 maximum for Class F	0	20	20
Percent Slag Substitution (by weight) for PC	35 maximum	45	0	0
Percent Silica Fume Substitution (by weight) for PC	Not allowed	0	3.5	0
Percent Metakaolin Substitution (by weight) for PC	Not allowed	0	0	3.5

TABLE 3. TESTING PROTOCOLS FOR CLASS D-LP MIXTURE DESIGNS

Property	Quantity Per Batch
Slump (AASHTO T 119) [11]	1 before HRWR; 1 after HRWR
Unit Weight and Gravimetric Air Content (AASHTO T 121) [12]	1
Air Content by Pressure Method (AASHTO T 152) [13]	1
Compressive Strength* @ 28 and 56-days (AASHTO T 22) [14]	(2) 6 x 12 per age
Static Modulus of Elasticity* @ 28 and 56-days (ASTM C 469) [15]	(1) 6 x 12 per age
Rapid Chloride Permeability @ 56-days (AASHTO T 277)	3 slices cut from separate 4 x 8 cylinders
Absorption and Voids in Hardened Concrete @ 56-days (ASTM C 642) [16]	3 slices cut from the RCP cylinders

* - with neoprene pads in steel retainers [17]

Continued from page 8—

by L. K. Crouch, Aaron Crowley, Lee Rogers, Heather P. Hall, and Daniel Badoe

Lowering the Chloride Permeability of a TDOT Class D PCC Mixture

Part 1: Developing an Informational Catalog

supplementary cementing materials (SCM) for portland cement in the mixture. Figure 1 shows the curves for metakaolin and silica fume. The regression equation for each curve was used to determine the dosage of 3.5% (for the 779-coulomb target value) for both silica fume and metakaolin.

A third dosage curve was generated using Grade 120 slag as the only SCM. The dosage curve for slag is shown in Figure 2. No RCP data was available for a straight portland cement (no SCM) TDOT Class D mixture. The regression equation for the curve was used to determine the dosage of 45% (for the 779-coulomb target value) for Grade 120 slag.

TRIAL CLASS D-LP MIXTURE DESIGNS

Table 1 shows the three D-LP trial mixture designs. Table 2 shows comparisons of the three D-LP mixture designs to current TDOT Class PCC requirements.

MATERIALS

Class F fly ash meeting ASTM C 618 [4] was obtained from a regional supplier. Grade 120 ground granulated blast furnace slag meeting ASTM C 989 [5] was obtained from a national cement manufacturer. Type I portland cement [6] was obtained from a national supplier. An ASTM C 33 [7] No. 57 limestone was obtained from a local quarry. River sand meeting TDOT 903.01 [8] was obtained from a ready mix producer. Chemical admixtures [9] and silica fume [10] were provided by the local representative of an international chemical producer.

PROCEDURE

All D-LP PCC batches were 1.33-cubic feet in size. Ten batches per mixture were produced and tested as per Table 3.

RESULTS AND ANALYSIS

Plastic property results and TDOT 604.03 requirements are shown in Table 4. All plastic properties met TDOT Class D PCC requirements. Table 5 shows comparison values from previous TDOT projects at TTU that will be used for D-LP comparisons in subsequent figures. Table 6 shows RCP results and statistical analysis of D-LP mixtures. The coefficients of variation (COV) met AASHTO T 277-07 requirements for a single operator of 12.3%. Figures 3, 4, 5, 6, and 7 show comparisons of RCP, compressive strength, static modulus of elasticity, ASTM C 642 absorption after boiling, and ASTM C 403 [18] time of set, respectively. The research team attempted to surgically reduce the

—Continued on page 12

Continued from page 10—

by L. K. Crouch, Aaron Crowley, Lee Rogers, Heather P. Hall, and Daniel Badoe

Lowering the Chloride Permeability of a TDOT Class D PCC Mixture

Part 1: Developing an Informational Catalog

RCP and do no harm to other engineering properties. Figures 3 through 7 indicate that this objective was accomplished with only minor exceptions.

COST ANALYSIS

Table 7 shows estimated material costs. Table 8 shows estimated costs per cubic yard. The numbers in Table 8 were determined using information from Tables 1 and 7.

SUMMARY COMPARISONS FOR PART 1

Table 9 shows a preliminary summary comparison of the current D-LP mixtures. Further comparisons will be provided in Part 2: Expanding the Informational Catalog.

REFERENCES

AASHTO T 277-07. "Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration". American Association of State Highway and Transportation Officials. Standard Specifications for Transportation Materials and Methods of Sampling and Testing Part 2A. 2011.

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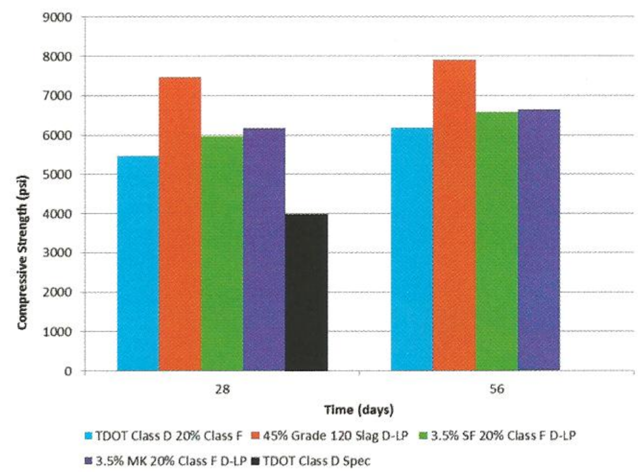

Figure 4. Comparison of D-LP and Class D Compressive Strengths

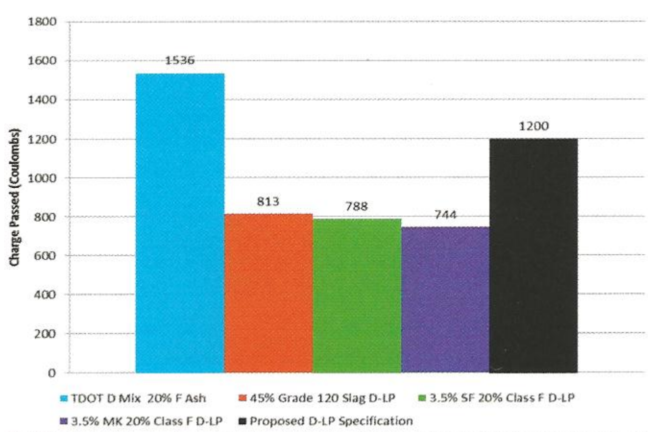

Figure 3. Comparison of D-LP and Class D Rapid Chloride Permeabilities

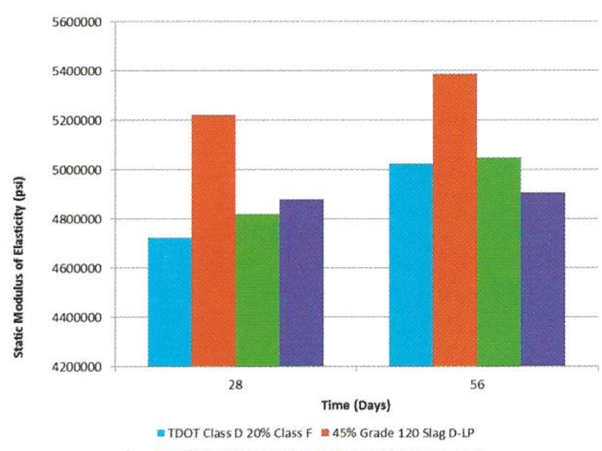

Figure 5. Comparison of D-LP and Class D Static Moduli

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TABLE 4. COMPARISON OF D-LP MIXTURE PLASTIC PROPERTIES WITH TDOT CLASS D REQUIREMENTS

Property	TDOT 604.03 Class D PCC Requirement (before 8/01/12)	45% Grade 120 Slag D-LP	3.5% SF 20% Class F D-LP	3.5% MK 20% Class F D-LP
Slump before HRWR (inches)	3 maximum	1.6	1.8	1.5
Slump after HRWR (inches)	8 maximum	7.1	6.9	7.3
Air Content by Pressure Method (%)	5 to 8.5	5.7	6.3	6.5
Air Content Gravimetric (%)	None	5.6	6.2	6.4
Unit Weight (pcf)	None	145.1	143.4	143.3
Temperature (°F) [19]	< 85	67	71	75

TABLE 5. COMPARISON VALUES (FROM PREVIOUS TDOT PROJECTS) FOR D-LP HARDENED PROPERTIES

Property	Mean Value	Specimen Size	Batches x Specimens	COV (%)
28-day Compressive Strength (psi)	5473	6 x 12	10 x 2	3.1
56-day Compressive Strength (psi)	6188	6 x 12	10 x 2	2.5
28-day Static Modulus of Elasticity (ksi)	4725	6 x 12	10 x 2	1.3
56-day Static Modulus of Elasticity (ksi)	5025	6 x 12	10 x 2	3.2
56-day RCP (coulombs)	1536	4 x 8 Slice	50 x 2	11.0
56-day absorption after boiling (%)	4.93	3 x 6	10 x 2	2.9

TABLE 6. D-LP RCP RESULTS (COULOMBS) AND STATISTICAL ANALYSIS

Property	45% Grade 120 Slag D-LP	3.5% SF 20% Class F D-LP	3.5% MK 20% Class F D-LP
Set 1	750	810	630
Set 2	830	770	700
Set 3	740	820*	790
Set 4	740	840*	780
Set 5	840	690	730
Set 6	940	730	820
Set 7	760	820	770
Set 8	850	780	730
Set 9	860	780	710
Set 10	820	840	780
Mean	813	788	744
Standard Deviation	65.2	48.7	55.4
COV (%)	8.0	6.2	7.5

* - test ran too long due to operator error

Continued from page 12—

by L. K. Crouch, Aaron Crowley, Lee Rogers, Heather P. Hall, and Daniel Badoe

Lowering the Chloride Permeability of a TDOT Class D PCC Mixture

Part 1: Developing an Informational Catalog

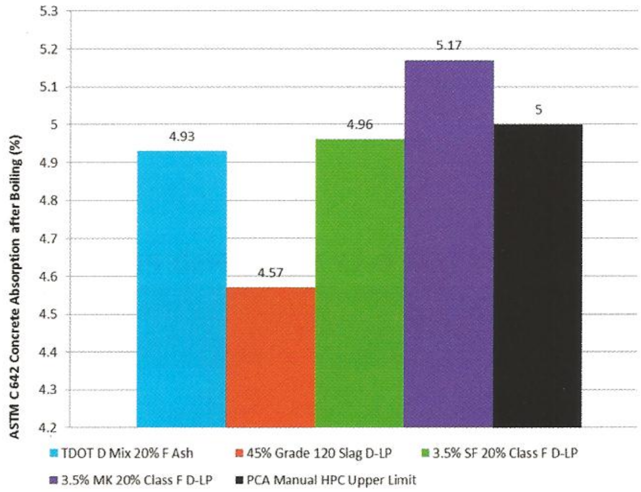

Figure 6. Comparison of D-LP and Class D ASTM C 642 Absorptions after Boiling

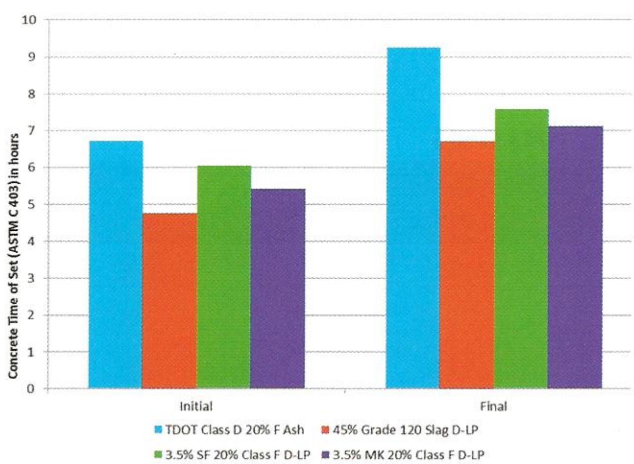

Figure 7. Comparison of D-LP and Class D ASTM C 403 Times of Set

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—Continued on page 16

TABLE 7. COST ASSUMPTIONS

Component	Assumed Cost Delivered to Ready Mix Producer
Type I portland Cement ($/ton)	110.00
Class F Fly Ash ($/ton)	30.00
Grade 120 Slag ($/ton)	85.00*
Silica Fume ($/ton)	1000.00*
Metakaolin ($/ton)	473.00*
No. 57 Limestone ($/ton)	18.00
River Sand ($/ton)	15.00
Air Entrainer ($/gallon)	4.50
MRWR ($/gallon)	8.50
HRWR ($/gallon)	12.00

* - plus freight

TABLE 8. ESTIMATED MATERIAL COSTS ($/CY)

Component	20% Class F TDOT Class D	45% Grade 120 Slag D-LP	3.5% SF 20% Class F D-LP	3.5% MK 20% Class F D-LP
Type I Portland Cement	27.28	18.76	26.07	26.07
Class F Fly Ash	1.89	0	1.86	1.86
Grade 120 Slag	0	11.86	0	0
Silica Fume	0	0	11.00	0
Metakaolin	0	0	0	5.21
No. 57 Limestone	17.14	17.29	17.15	17.19
River Sand	8.55	8.49	8.43	8.44
Air Entrainer	0.07	0.19	0.07	0.13
MRWR	1.24	1.24	0.99	0.99
HRWR	1.17	1.46	2.10	2.22
Total Material Cost (except water)	57.31	59.29	67.67	62.11

TABLE 9. CLASS D-LP PRELIMINARY SUMMARY COMPARISONS

	45% Grade 120 Slag D-LP	3.5% SF 20% Class F D-LP	3.5% MK 20% Class F D-LP
Relative Cost	Least	Most	Middle
How "green" is it?	Most	Middle	Least
How different is it from TDOT Class D?	Very	Not Much	Not Much
Main Advantage	Cheap & Green	Very Easy	Very Easy
Main Disadvantage	Must have Slag Silo	Expensive	Expensive

Continued from page 14—

by L. K. Crouch, Aaron Crowley, Lee Rogers, Heather P. Hall, and Daniel Badoe

Lowering the Chloride Permeability of a TDOT Class D PCC Mixture

Part 1: Developing an Informational Catalog

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