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RMC FOUNDATION: CONCRETE SUSTAINABILITY HUB

Renewal Ceremony Held in December

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LOWERING THE CHLORIDE PERMEABILITY OF A TDOT CLASS D PCC MIXTURE

Dr. Crouch Presents Part 2:
Expanding the Informational Catalog

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Lowering the Chloride Permeability of a TDOT Class D PCC Mixture

Part 2: Expanding the 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 1,200-coulombs at 56-days, determined as per AASHTO T 277-07 [1], is under consideration. Tennessee Technological University (TTU) researchers are now expanding [2] 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 informational catalog is by no means exhaustive or exclusive; there are many ways to meet the possible new specification. The four mixtures covered in Part 2 (hereafter referred to as catalog mixtures) are:

1. Type I Portland Cement / Class C Fly Ash / Silica Fume
2. Type I Portland Cement / Class C Fly Ash / Metakaolin
3. Type I Portland Cement / Grade 120 Slag / Class F Fly Ash
4. Type I Portland Cement / Class F Fly Ash / Metakaolin

STATISTICAL BACKGROUND

The goal of the research team was to produce mixtures with a very high probability of meeting the new proposed 1,200-coulomb specification for rapid chloride permeability (RCP). A design target value of 779-coulombs for RCP 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 1% that the new proposed 1,200-coulomb specification will not be met.

DOSAGE CURVES

The research team generated two dosage curves by substituting a second supplementary cementing material (SCM) for portland cement into a TDOT Class D mixture containing 25% Class C fly ash. A third dosage curve was also generated for substituting metakaolin into a Texas Department of Transportation inspired mixture containing 35% Class F fly ash. Figure 1 shows the curves for the resulting mixtures. The regression equation for each of the 25% Class C fly ash curves was used to determine the dosage of 5% (when rounding up to next whole number for the 779-coulomb target value) for both silica fume and metakaolin. The preliminary

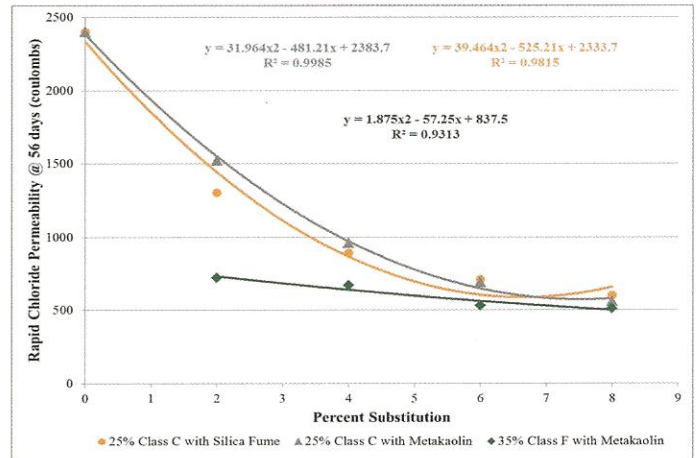


Figure 1. Dosage Curves for Catalog Mixtures Containing Metakaolin or Silica Fume

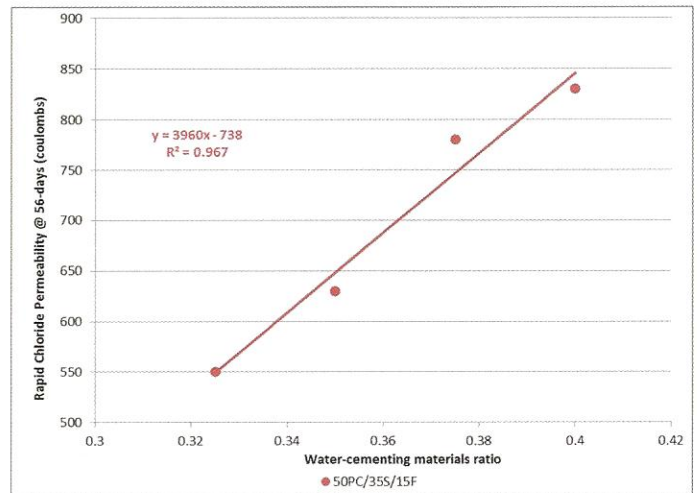


Figure 2. W/CM Curve for 35% Grade 120 Slag and 15% Class F Fly Ash Mixture

data for the Class F fly ash indicated that 2% metakaolin was adequate. However, due to the shape of the other metakaolin curve, a more conservative dosage of 3% metakaolin was chosen for the 35% Class F fly ash trial mixture.

A preliminary water-cementing-materials (w/cm) ratio selection curve was generated using 35% Grade 120 slag and 15% Class F fly ash trial mixture. The w/cm selection curve for 35% Grade 120 slag and 15% Class F fly ash mixture is shown in Figure 2. The regression equation for the curve indicated that a w/cm of 0.383 should be chosen (for the 779-coulomb target value). However,

TABLE 1. TRIAL CATALOG MIXTURES

| Component | 70PC / 25C / 55F Class D-LP | 70PC / 25C / 5MK Class D-LP | 50PC / 35SL / 15F Class D-LP | 62PC / 35F / 3MK Class D-LP |
|---------------------------------|--------------------------------|--------------------------------|---------------------------------|--------------------------------|
| Type I PC (lbs/CY) | 435 | 434 | 310 | 384.4 |
| Class F Fly Ash (lbs/CY) | 0 | 0 | 93 | 217 |
| Class C Fly Ash (lbs/CY) | 155 | 155 | 0 | 0 |
| Grade 120 Slag (lbs/CY) | 0 | 0 | 217 | 0 |
| Silica Fume (lbs/CY) | 31 | 0 | 0 | 0 |
| Metakaolin (lbs/CY) | 0 | 31 | 0 | 18.6 |
| No. 57 Limestone (lbs/CY SSD) | 1889 | 1897 | 1896 | 1880 |
| River Sand (lbs/CY SSD) | 1121 | 1124 | 1125 | 1118 |
| Water (lbs/CY) | 230 | 229.5 | 229.5 | 229.5 |
| Design Percent Air | 7 | 7 | 7 | 7 |
| Air Entrainment, oz/cwt (oz/CY) | 0.45 (2.8) | 1.5 (9.3) | 1.5 (9.3) | 0.7 (4.3) |
| MRWR, oz/cwt (oz/CY) | 2.0 (12.4) | 3.0 (18.6) | 1.0 (6.2) | 1.75 (10.9) |
| HRWR, oz/cwt (oz/CY) | 3.25 (20.2) | 3.0 (18.6) | 2.1 (13.0) | 2.5 (15.5) |

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

| Quantity/Ratio/Percentage | TDOT 604.03 Class D PCC Requirement [3] | 70PC / 25C / 55F | 70PC / 25C / 5MK | 50PC / 35SL / 15F | 62PC / 35F / 3MK |
|---|--|---------------------|---------------------|----------------------|---------------------|
| Cementing Materials Content (lbs/CY) | 620 minimum | 621 | 620 | 620 | 620 |
| W/CM Ratio | 0.40 maximum | 0.37 | 0.37 | 0.37 | 0.37 |
| Percent Fine Aggregate by Total Aggregate Volume | 44 maximum | 38 | 38 | 38 | 38 |
| Percent Fly Ash Substitution (by weight) for PC | 20 (25) maximum for Class F (C) | 25C | 25C | 15F | 35F |
| Percent Slag Substitution (by weight) for PC | 35 maximum | NA | NA | 35 | NA |
| Percent Silica Fume Substitution (by weight) for PC | Not allowed | 5 | NA | NA | NA |
| Percent Metakaolin Substitution (by weight) for PC | Not allowed | NA | 5 | NA | 3 |

TABLE 3. TESTING PROTOCOLS FOR CATALOG 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* at 28 and 56 days (AASHTO T 22) [14] | 2 - 6 x 12 per age |
| Static Modulus of Elasticity* at 28 and 56 days (ASTM C 469) [15] | 1 - 6 x 12 per age |
| Rapid Chloride Permeability at 56 days (AASHTO T 277) | 3 slices cut from separate 4 x 8 cylinders |
| Absorption and Voids in Hardened Concrete at 56 days (ASTM C 642) [16] | 3 slices cut from the RCP cylinders |

* with neoprene pads in steel retainers [17]

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

Lowering the Chloride Permeability of a TDOT Class D PCC Mixture



since other D-LP and catalog mixtures had all used a w/cm of 0.37, the first author chose to use the common w/cm of 0.37 for the 35% Grade 120 slag and 15% Class F fly ash trial mixture.

TRIAL CLASS CATALOG MIXTURE DESIGNS

Table 1 shows the four catalog trial mixture designs. Table 2 shows comparisons of the four catalog mixture designs to current TDOT Class D PCC requirements.

MATERIALS

Class F and C fly ashes meeting ASTM C 618 [4] were obtained from regional suppliers. Grade 120 ground granulated blast furnace slag meeting ASTM C 989 [5] was obtained from a national cement manufacturer. Type I portland cement conforming to ASTM C 150 [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. Metakaolin was provided by a regional supplier.

PROCEDURE

All Catalog PCC batches were 1.33-cubic feet in size. Eleven batches per mixture were produced and tested as per Table 3. AASHTO T-277-07 statistics are based on eleven batches. Therefore, eleven batches per mixture were chosen for the catalog project.

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 comparisons with the catalog mixtures in subsequent figures. Table 6 shows RCP results and statistical analysis of catalog mixtures. The coefficients of variation (COV) of three of the four catalog mixtures met AASHTO T 277-07 requirements for a single operator of 12.3%. Unfortunately, the COV of the 70PC / 25C / 5 SF mixture did not meet AASHTO T-277-07 requirements, due primarily to relatively higher values for sets 9 and 11. Figures 3, 4, 5, and 6 show comparisons of RCP, compressive strength, static modulus of elasticity, and ASTM C 642 absorption after boiling, respectively. The research team attempted to surgically reduce the rapid chloride permeability of the mixtures and do no harm to other engineering

properties. Figures 3 through 6 indicate that this objective was accomplished with only minor exceptions.

COST ANALYSIS

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

SUMMARY COMPARISONS

All catalog mixtures easily met the new proposed 1,200-coulomb at 56-day specification for rapid chloride permeability.

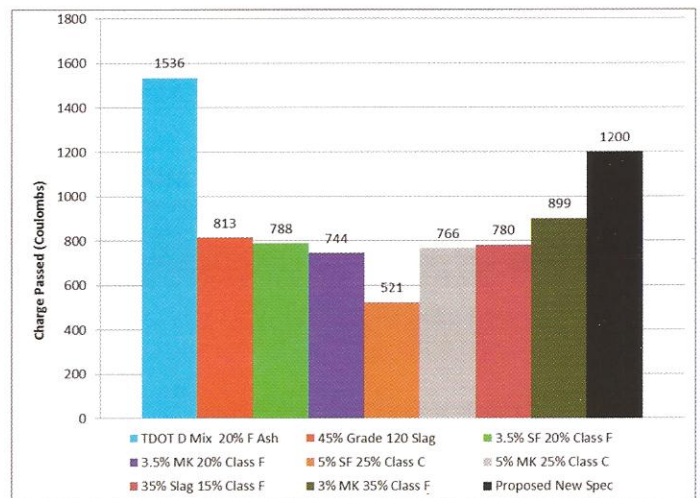


Figure 3. Comparison of Catalog, D-LP and Class D Rapid Chloride Permeabilities

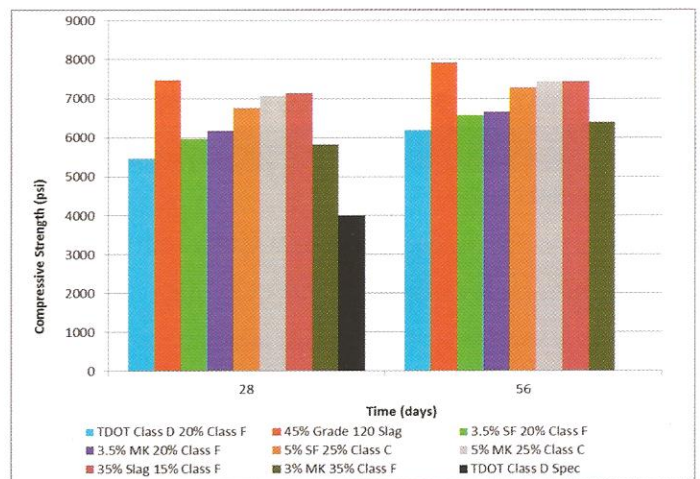


Figure 4. Comparison of Catalog, D-LP and Class D Compressive Strengths

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

| Property | TDOT 604.03 Class D PCC Requirement | 70PC / 25C / 55F Class D-LP | 70PC / 25C / 5MK Class D-LP | 50PC / 35SL / 15F Class D-LP | 62PC / 35F / 3MK Class D-LP |
|------------------------------------|-------------------------------------|-----------------------------|-----------------------------|------------------------------|-----------------------------|
| Slump before HRWR (inches) | 3 maximum | 1.8 | 1.3 | 1.7 | 2.3 |
| Slump after HRWR (inches) | 8 maximum | 6.8 | 5.6 | 7.6 | 7.2 |
| Air Content by Pressure Method (%) | 5.5 to 8.5 | 7.4 | 6.8 | 6.0 | 6.7 |
| Air Content Gravimetric (%) | None | 7.0 | 6.7 | 6.3 | 6.7 |
| Unit Weight (pcf) | None | 142.8 | 143.9 | 144.5 | 142.9 |
| Temperature (°F) [19] | < 85 | 72.8 | 78.7 | 76.6 | 74.9 |

TABLE 5. COMPARISON VALUES (FROM PREVIOUS TDOT PROJECTS) FOR CATALOG 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 |
| | 7472 | 6 x 12 | 10 x 2 | 2.7 |
| | 5974 | 6 x 12 | 10 x 2 | 3.3 |
| | 6177 | 6 x 12 | 10 x 2 | 4.1 |
| 56-day Compressive Strength (psi) | 6188 | 6 x 12 | 10 x 2 | 2.5 |
| | 7913 | 6 x 12 | 10 x 2 | 2.8 |
| | 6577 | 6 x 12 | 10 x 2 | 2.1 |
| | 6654 | 6 x 12 | 10 x 2 | 3.8 |
| 28-day Static Modulus of Elasticity (ksi) | 4725 | 6 x 12 | 10 x 1* | 1.3 |
| | 5220 | 6 x 12 | 10 x 1* | 5.6 |
| | 4820 | 6 x 12 | 10 x 1* | 3.1 |
| | 4880 | 6 x 12 | 10 x 1* | 5.6 |
| 56-day Static Modulus of Elasticity (ksi) | 5025 | 6 x 12 | 10 x 1* | 3.2 |
| | 5385 | 6 x 12 | 10 x 1* | 4.6 |
| | 5050 | 6 x 12 | 10 x 1* | 3.1 |
| | 4905 | 6 x 12 | 10 x 1* | 2.7 |
| 56-day RCP (coulombs) | 1536 | 4 x 8 Slice | 50 x 2 | 11.0 |
| | 813 | 4 x 8 Slice | 10 x 3 | 8.0 |
| | 788 | 4 x 8 Slice | 10 x 3 | 6.2 |
| | 744 | 4 x 8 Slice | 10 x 3 | 7.5 |
| 56-day Absorption after Boiling (%) | 4.93 | 3 x 6 | 10 x 2 | 2.9 |
| | 4.57 | 4 x 8 Slice | 10 x 3 | 5.5 |
| | 4.96 | 4 x 8 Slice | 10 x 3 | 5.6 |
| | 5.17 | 4 x 8 Slice | 10 x 3 | 1.8 |

*average of two runs on a single 6 x 12 cylinder

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

Lowering the Chloride Permeability of a TDOT Class D PCC Mixture

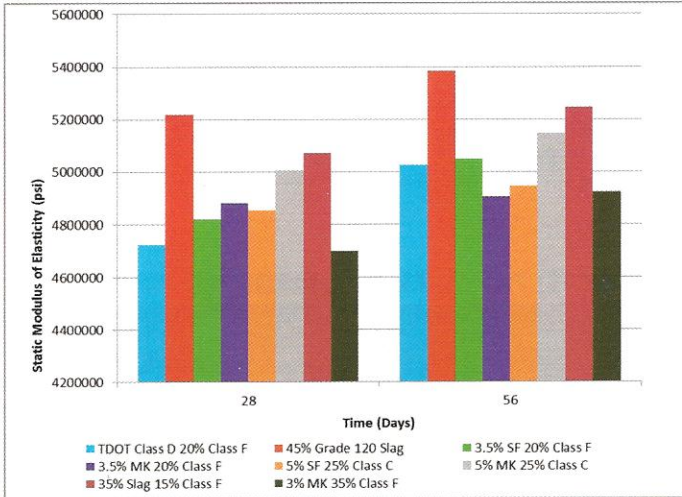
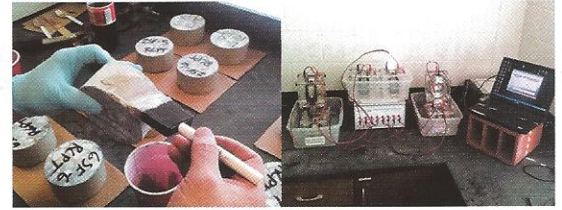


Figure 5. Comparison of Catalog, D-LP and Class D Static Moduli

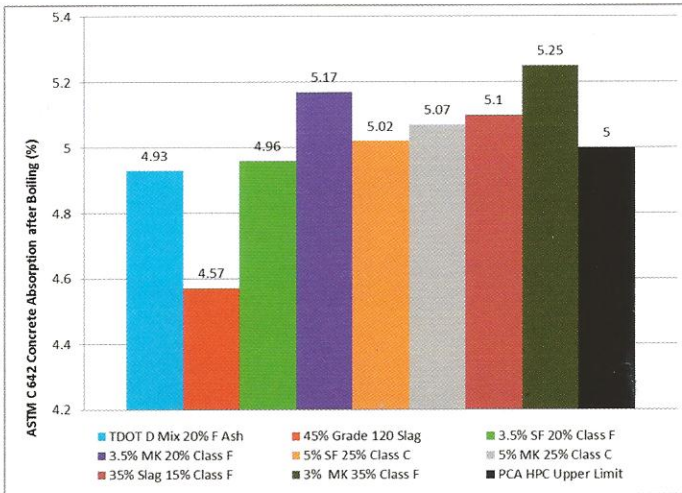


Figure 6. Comparison of Catalog, D-LP and Class D ASTM C 642 Absorptions after Boiling

Further, all catalog mixtures also met TDOT Class D plastic and hardened property specifications. Table 8 shows a summary comparison of other characteristics of the current catalog and D-LP mixtures.

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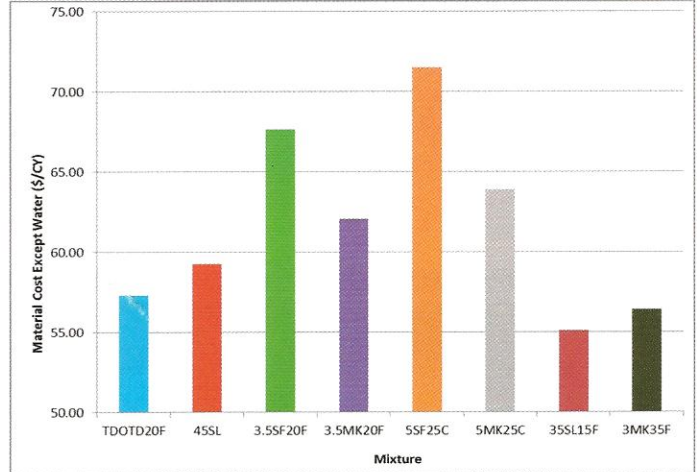


Figure 7. Estimated Material Costs of Catalog, D-LP and Class D Mixtures (\$/CY)

"Lowering the Chloride Permeability of a TDOT Class D PCC Mixture Part 1: Developing an Informational Catalog", L. K. Crouch, Aaron Crowley, Lee Rogers, Heather P. Hall and Daniel Badoe in *Tennessee Concrete* Fall 2013 Volume 27, Number 2.

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TABLE 6. CATALOG RCP RESULTS (COULOMBS) AND STATISTICAL ANALYSIS

| | 70PC / 25C / 5SF | 70PC / 25C / 5MK | 50PC / 35SL / 15F | 62PC / 35F / 3MK |
|--------------------|------------------|------------------|-------------------|------------------|
| Set 1 | 560 | 740 | 780 | 880 |
| Set 2 | 450 | 760 | 760 | 820 |
| Set 3 | 510 | 790 | 780 | 830 |
| Set 4 | 430 | 750 | 800 | 840 |
| Set 5 | 470 | 750 | 840 | 920 |
| Set 6 | 490 | 730 | 830 | 960 |
| Set 7 | 520 | 760 | 690 | 940 |
| Set 8 | 510 | 800 | 740 | 970 |
| Set 9 | 660 | 760 | 740 | 870 |
| Set 10 | 490 | 790 | 810 | 940 |
| Set 11 | 640 | 800 | 810 | 920 |
| Mean | 521 | 766 | 780 | 899 |
| Standard Deviation | 72.9 | 24.6 | 44.7 | 53.6 |
| COV (%) | 14.0 | 3.2 | 5.7 | 6.0 |

TABLE 7. COST ASSUMPTIONS

| Component | Assumed Cost Delivered to Ready Mix Producer |
|---------------------------|--|
| Type I PCC (\$/ton) | 110.00 |
| Class F Fly Ash (\$/ton) | 30.00 |
| Class C Fly Ash (\$/ton) | 50.00 |
| Grade 120 Slag (\$/ton) | 85.0* |
| 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. CLASS D-LP AND CATALOG SUMMARY COMPARISONS

| Mixture | Relative Cost | How "Green" is it? | How different is it from a TDOT Class D Mixture? | Main Advantage | Main Disadvantage |
|------------------|----------------|--------------------|--|-----------------|-------------------|
| 55PC/45SL | Third lowest | Second most | Very | Green | Need a slag silo |
| 76.5PC/20F/3.5SF | Second highest | Second least | Not much | Very easy | Very expensive |
| 76.5PC/20F/3.5MK | Middle | Least | Not much | Very easy | Expensive |
| 70PC/25C/5SF | Highest | Middle | Not much | Very easy | Very expensive |
| 70PC/25C/5MK | Third highest | Third least | Not much | Very easy | Expensive |
| 50PC/35SL/15F | Lowest | Most | Very | Cheap and green | Need a slag silo |

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DISCLAIMER

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