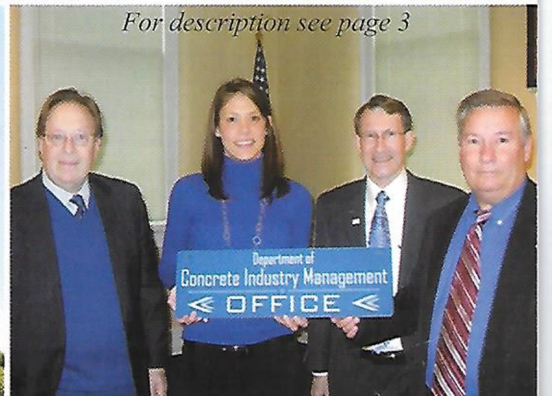
TENNESSEE CONCRETE MAGAZINE

Winter 2015/16
VOL. 29, NO. 3

CELEBRATING 20 YEARS

For description see page 3



by L. K. Crouch, James Locum, Caleb Smith, Blakeslee Eagan, Sarah Dillon, Daniel Badoe and Heather P. Hall

BAD ASH FLOWABLE FILL

INTRODUCTION

The old proverb states "You can't make a silk purse from a sow's ear." However, recent graduate Sarah Dillon had considerable success using substandard materials in both her master's and doctoral research (1, 2, 3, 4). The first author was inspired to see if performance requirements for flowable fill in the new Tennessee Department of Transportation (TDOT) Standard Specifications for Road and Bridge Construction (5) could be met with substandard materials.

MATERIALS (SOW'S EAR)

Figure 1 shows fine aggregate washing as per ASTM C 117 (6). Table 1 shows average results from the triplicate washed sieve analysis (6, 7). Table 1 also shows TDOT specifications for flowable mortar aggregate (8), TDOT No. 10 coarse aggregate (screenings) specification (9), TDOT fine aggregate for concrete specification (8), and a typical middle Tennessee river sand gradation for comparison. The project screenings did meet TDOT specification for No. 10 coarse aggregate (screenings). However, the project screenings failed to meet the TDOT Specifications for fine aggregate for flowable mortar or concrete. The high fines content of the screenings, determined by the amount of material passing the No. 200 (0.075-mm) sieve, makes them undesirable for most applications and therefore underutilized.

Table 2 shows project fly ash chemical composition. Table 2 also shows ASTM C 618 requirements (10), AASHTO M 295 requirements (11), and a typical middle Tennessee Class F fly ash for comparison. TVA was contacted and requested to provide the highest loss-on-ignition (LOI) fly ash available. TVA provided a fly ash from the Colbert Plant in Northwestern Alabama that is reported to have an LOI that sometimes reaches 12%. The project fly ash failed to meet the ASTM or AASHTO specifications. The high LOI of the fly ash makes it unacceptable for most applications and is therefore underutilized (aka bad ash).

Other materials used that were not substandard included portland cement and water. Type I portland cement for the project was donated by the Tennessee Concrete Association. Local tap water was also used for all mixtures in the study.

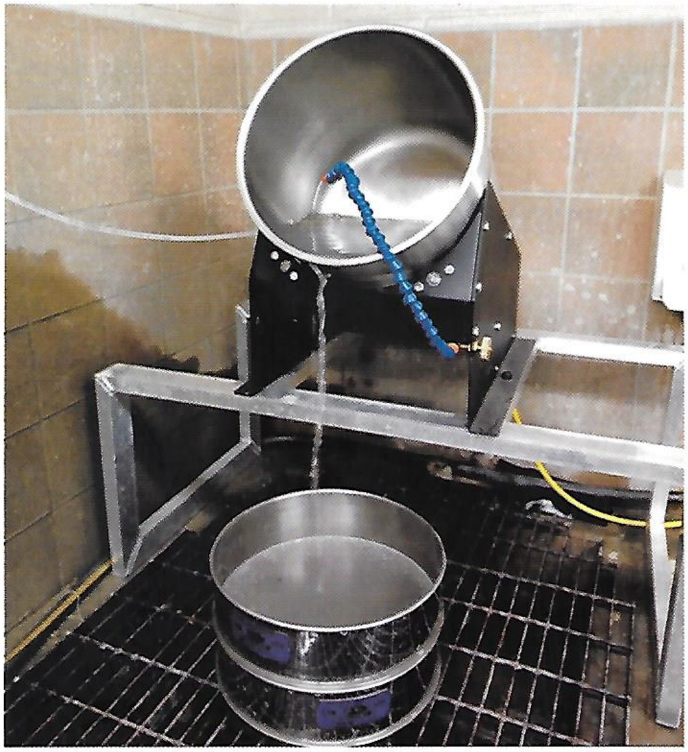


Figure 1: Washing Screenings for Sieve Analysis

PROCEDURE

TDOT Specification Selection

Three types of controlled low-strength materials (CLSM) mixtures are specified by TDOT depending on the specific application: General Use Flowable Fill, Excavatable Flowable Fill (EFF), and Early Strength Flowable Fill (ESFF). The required proportions for the 2015 General Use Flowable Fill Specification are shown in Table 3. Table 4 shows property requirements for TDOT General Use CLSM. The General Use Property Requirements were chosen as the easiest of the three to meet with substandard materials.

The 24-hour maximum suitability for load application requirement ASTM D 6024 (12) presented a small problem since space or materials were not available for test trenches. However, previous Tennessee Technological University (TTU) research (13) showed that there was a good chance of passing the ball drop test if compressive strength was between 6 and 10-psi. Therefore, the research team assumed that there would be a very good chance of the mixture meeting the suitability for load application requirement if the compressive strength exceeded 10-psi.

TABLE 1. AVERAGE RESULTS FROM WASHED SIEVE ANALYSIS

Sieve Size	Sieve Size (mm)	Project Screenings Percent Passing	TDOT 903.01 Flowable Mortar Aggregate Specification	TDOT 903.22 No. 10 Coarse Aggregate (Screenings) Specification	Typical River Sand Percent Passing	TDOT 903.01 Fine Aggregate for Concrete Specification
0.5 in.	12.7	100	100	-	-	-
0.375 in.	9.5	100	-	100	100	100
No. 4	4.75	95	-	85-100	97	95-100
No. 8	2.36	53	-	-	91	-
No. 16	1.18	31	-	-	83	50-90
No. 30	0.6	25	-	-	65	-
No. 50	0.3	23	-	-	9	5-30
No. 100	0.15	23	-	10-30	1	0-10
No. 200	0.075	23	0-20	-	0.3	0-3

TABLE 2. CLASS F FLY ASH CHEMICAL COMPOSITION

Component	Bad Ash Percent Composition	Typical Tennessee Class F Fly Ash Percent Composition	ASTM C 618-08a Requirements	AASHTO M 295-07 Requirements
Silicon Dioxide	47.5	47.6	-	-
Aluminum Oxide	21.3	18.8	-	-
Iron Oxide	8.7	17.3	-	-
$SiO_2 + Al_2O_3 + Fe_2O_3$	77.5	83.8	70% minimum	70% minimum
Calcium Oxide	6.8	7.9	-	-
Magnesium Oxide	2.4	1.0	-	-
Sulfur Trioxide	0	2.4	5% maximum	5% maximum
Moisture Content	26.0	0.1	3% maximum	3% maximum
Alkalis as Na_2O	1.3	0.8	-	1.5% maximum
Loss-on-Ignition	11.1	1.0	6% maximum	5% maximum

TABLE 3. 2015 TDOT 204.06B GENERAL USE FLOWABLE FILL PROPORTIONS

Component	Amount
Portland Cement, Type 1	100 lbs.
Fly Ash, Class C of F	250 lbs. minimum
Fine Aggregate	2800 lbs.
Water	60 gallons (approximate)

TABLE 4. 2015 TDOT 204.06B GENERAL USE FLOWABLE FILL PROPERTY REQUIREMENTS

Property	General Use Flowable Fill
Consistency by Inverted Slump Flow (inches)	15 minimum
Load Application by ASTM D6024 Ball Drop (hours)	24 maximum

Continued from page 8—
Bad Ash Flowable Fill
by L. K. Crouch, James Locum, Caleb Smith, Blakeslee Eagan, Sarah Dillon, Daniel Badoe and Heather P. Hall

Bad Ash Flowable Fill (BAFF) Mixture Designs

Table 5 shows proportions of the mixtures used in this study. Both mixtures were designed by trial batching. The mixture designs should be considered approximate since the fly ash moisture content (added at the facility to minimize wind erosion and transport) probably varied by location in the sample and over time. Percent paste values in the table were calculated as the sum of the volumes of portland cement, fly ash, and water by total mixture volume expressed as a percent.

Figure 2: Loading PC and Bad Ash into the Mixer

Mixing, Sample Fabrication, and Testing

Ten 0.55-cubic foot validation batches of each mixture were produced in a 1-cubic foot electric mixer. Material addition and mixing procedure were as per ASTM C 192 (14). Figure 2 shows the addition of the portland cement and bad ash to the mixture. The TDOT inverted slump flow test was performed on each batch. Figure 3 shows the inverted slump cone full, lifting the inverted slump cone, and measurement of the resulting patty.

Seven 4x8-inch cardboard cylinders were fabricated from each batch of BAFF as per ASTM D4832 (15). Only six cylinders (three per testing date) were required. However, an extra cylinder was made since demolding at 24-hours can prove challenging. Three cylinders were tested at 24-hours (as a substitute for suitability for load application) and three cylinders were tested at 28 days. The 28-day compressive strength test is not required by TDOT General Use CLSM Specifications but might provide insight into the later possibility of excavatability. The cylinders were tested in accordance with ASTM D 4832 with the following exception: TDOT preferred wet suit neoprene in steel retainers was used for capping. Compressive strength testing is shown in Figure 4.

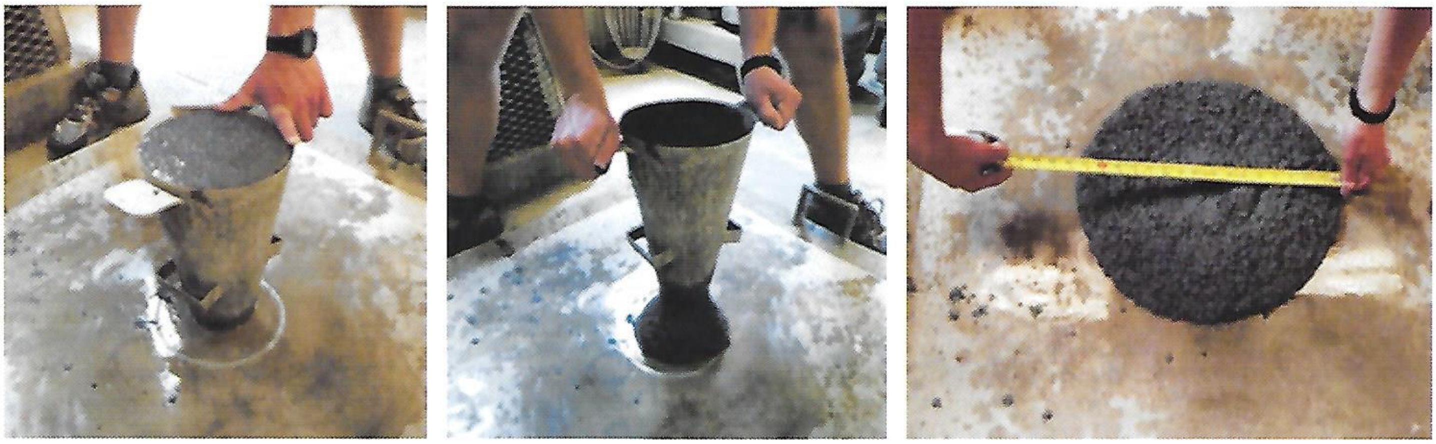


Figure 3: Inverted Slump Flow Testing of Bad Ash Flowable Fill

TABLE 5. BAD ASH FLOWABLE FILL MIXTURE DESIGNS

Component	General Use BAFF	Lower PC BAFF
Type I PC (dry lbs./CY)	104	62
Bad Ash (wet lbs./CY)	466	455
Screenings SSD (lbs./CY)	2517	2596
Water (lbs./CY)	466	455
Total Cementing Materials (dry lbs./CY)	477	426
Percent Paste	43.9	42.2

TABLE 6. GENERAL USE BAD ASH FLOWABLE FILL TEST RESULTS

Batch	TDOT Inverted Slump Flow (inches)	24-hour Mean Compressive Strength (psi)	28-day Mean Compressive Strength (psi)
1	18.50	18	283
2	18.25	18	261
3	18.75	18	283
4	17.75	21	305
5	18.75	20	298
6	18.50	20	305
7	18.75	20	340
8	18.75	20	324
9	18.75	19	301
10	19.25	18	303
Mean	18.6	19.2	300.3
Range	1.5	3	79
Std. Dev.	0.40	1.14	21.95
COV (%)	2.1	5.9	7.3

Continued from page 10—
Bad Ash Flowable Fill
by L. K. Crouch, James Locum, Caleb Smith, Blakeslee Eagan, Sarah Dillon, Daniel Badoe and Heather P. Hall

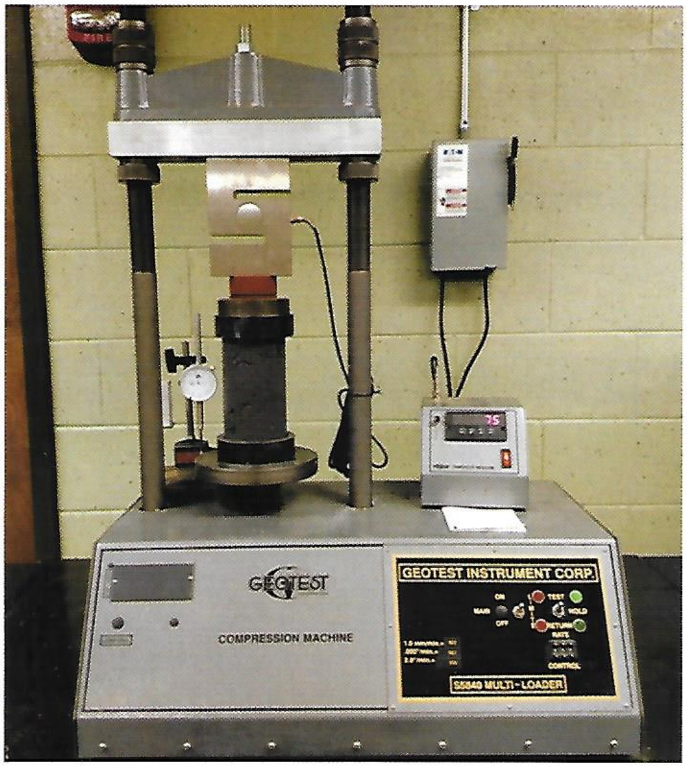


Figure 4: Compression Testing of Bad Ash Flowable Fill

RESULTS (SILK PURSE?)

Table 6 shows results for inverted slump flow, 24-hour compressive strength, and 28-day compressive strength for General Use BAFF. Similarly, Table 7 shows test results for Lower PC BAFF. ASTM D 4832-07 states that no precision information is currently available since a ten laboratory test is either not feasible or too expensive. These results show that the estimated coefficient of variation (COV) for each investigated property of the General Use Bad Ash Flowable Fill was below 8% while those for the Lower PC Bad Ash Flowable Fill were below 9%. This suggests that for both mixtures, the sample values for each property and for each mixture were clustered closely about the mean value. In particular, the estimated COV for the Inverted Slump Flow for both mixtures showed the lowest relative dispersion of the three properties for which COVs were determined.

ANALYSIS

TDOT's requirement on the Inverted Slump Flow for Generable Flowable Fill, as stated earlier in Table 4, is a minimum of 15 inches. Both mixtures had mean Inverted Slump Flows that were significantly greater than the 15-inch minimum at the 5 percent level of significance.

Because of the findings of earlier TTU research (13) which showed that there was a good chance of passing the ball drop test if the 24-hour mean compressive strength was between 6 and 10-psi, a statistical test was conducted to determine whether the 24-hour mean compressive strength of the two mixes exceeded 10 psi. The results showed both mixtures had a 24-hour mean strength that significantly exceeded 10 psi at the 5 percent level of significance.

OBSERVATIONS (NO FIELD DATA FOR CONCLUSIONS)

Based on the limited data available from this preliminary study, the following observations are offered:

1. Bad ash (substandard fly ash) and screenings can be used in flowable fill mixtures to meet the 2015 TDOT 204.06B General Use Flowable Fill Specification for inverted slump cone flow.
2. Bad ash (substandard fly ash) and screenings can be used in flowable fill mixtures that have a good chance of meeting the 2015 TDOT 204.06B General Use Flowable Fill Specification for suitability for load application.
3. Bad ash (substandard fly ash) and screenings can be economically attractive if the ready mix producer is located close to sources for these materials.
4. The use of bad ash (substandard fly ash) and screenings in flowable fill mixtures is environmentally friendly (green) since these materials have very few (if any) current applications and tend to accumulate or require disposal and subsequent monitoring (bad ash).

DISCLAIMER

The opinions expressed herein are those of the authors and not necessarily the opinions of the Tennessee Department of Transportation or the Tennessee Concrete Association.

ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge the support of TVA, Denny Lind of BASF, and Alan Sparkman of the Tennessee Concrete Association for their extensive donations of materials to the project.

In addition, the authors would like to thank Mark Davis and Perry Melton for their patience and skill in fabrication, maintenance, and repair of the equipment.

Further, we appreciate the support of the TTU Department of Civil and Environmental Engineering.

TABLE 7. LOWER PC BAD ASH FLOWABLE FILL TEST RESULTS

Batch	TDOT Inverted Slump Flow (inches)	24-hour Mean Compressive Strength (psi)	28-day Mean Compressive Strength (psi)
1	17.50	17	135
2	18.00	19	135
3	18.25	17	126
4	18.50	19	144
5	18.25	16	137
6	17.75	19	154
7	17.50	20	162
8	17.75	19	161
9	18.00	19	145
10	18.75	16	139
Mean	18.0	18.1	143.8
Range	1.125	4	36
Std. Dev.	0.42	1.45	11.90
COV (%)	2.3	8.0	8.3

Continued from page 12—
Bad Ash Flowable Fill
by L. K. Crouch, James Locum, Caleb Smith, Blakeslee Eagan, Sarah Dillon, Daniel Badoe and Heather P. Hall

Finally, the authors appreciate the administrative and information technology support provided by the TTU Center for Energy Systems Research, particularly Tony Greenway, Robert Craven, Etter Staggs and Linda Lee.

REFERENCES

Crouch, L. K., Dillon, Sarah., and Knight, Marcus L., **"Tennessee Lime-Fly Ash-Stabilized Base Using a High Loss-on-Ignition Fly Ash,"** *Lime: Building on the 100-Year Legacy of The ASTM Committee C07, ASTM STP 1557*, Margaret L. Thomson, and Joseph H. Brisch, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2012, pp. 60-75.

Dillon, Sarah, Crouch, L. K., Browning, Allen, and Badoe, Daniel, "Modification of an East Tennessee High Plasticity Silt with Lime and Substandard Fly Ash", Transportation Research Board 2015 Annual Meeting Compendium of Papers, January 2015.

Dillon, Sarah, Crouch, L. K., and Ferguson (Kelly), Kayla, "High Volume Substandard Fly Ash Roller-Compacted Concrete," Ash Library Website www.flyash.info, May, 2015. Downloaded 5/05/15

Dillon, Sarah, Crouch, L. K., and Young, Kevin, "Full-Depth Reclamation with Lime and Substandard Fly Ash," Ash Library Website www.flyash.info, May, 2015. Downloaded 5/05/15

Tennessee Department of Transportation, **Standard Specifications for Road and Bridge Construction (Section 204.06B)**, March 1, 2015.

ASTM C 117-13, "Standard Test Method for Material Finer than 75-µm (No. 200) Sieve in Mineral Aggregate by Washing[1]," **2014 Annual Book of ASTM Standards**, V.04.02, ASTM, West Conshohocken, PA, 2014, pp. 69-71.

ASTM C 136-06, "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates[1]," **2014 Annual Book of ASTM Standards**, V.04.02, ASTM, West Conshohocken, PA, 2014, pp. 100-104.

Tennessee Department of Transportation, **Standard Specifications for Road and Bridge Construction (Section 903.01)**, January 1, 2015.

Tennessee Department of Transportation, **Standard Specifications for Road and Bridge Construction (Section 903.22)**, January 1, 2015.

ASTM C 618-12a, "Standard Specification for Coal Fly Ash and Raw or Calcined Pozzolan for Use in Concrete[1]," **2014 Annual Book of ASTM Standards**, V.04.02, ASTM, West Conshohocken, PA, 2014, pp. 347-351

AASHTO M 295-11, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete[1]," **Transportation Materials and Methods of Sampling and Testing, 33rd Edition**, Part 1B Specifications, AASHTO, Washington, D.C., 2013.

ASTM D 6024-07, "Standard Test Method for Ball Drop on Controlled Low Strength Material (CLSM) To Determine Suitability for Load Application[1]," **2008 Annual Book of ASTM Standards**, V.04.09, ASTM, West Conshohocken, PA, 2008,, pp. 226-228.

"Five Part Series on the New TDOT 204.06 CLSM Specification Part 2: Excavatable Flowable Fill (EFF) Mixtures for 2006 TDOT 204.06", L. K. Crouch, V. James Dotson, and Adam C. Walker, *Tennessee Concrete*, Vol. 21, No. 2, Summer 2007.

ASTM C 192/C192M-14, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory[1]," **2014 Annual Book of ASTM Standards**, V.04.02, ASTM, West Conshohocken, PA, 2014, pp. 144-151.

ASTM D 4832-10, "Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders[1]," **2012 Annual Book of ASTM Standards**, V.04.08, ASTM, West Conshohocken, PA, 2012, pp. 958-963.

AUTHOR INFORMATION

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

James Locum, E.I. is a graduate research assistant in civil engineering at Tennessee Technological University.

Caleb Smith, E.I. is a graduate teaching assistant in civil engineering at Tennessee Technological University.

Blakeslee Eagan, E.I. is a recent M.S. graduate in civil engineering at Tennessee Technological University.

Sarah Dillon, PhD., E.I. is a recent doctoral graduate in engineering at Tennessee Technological University.

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

Heather P. Hall, P.E. is an assistant director of the TDOT Materials & Tests Division.