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PART 2: Excavatable Flowable Fill (EFF) Mixtures

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Part 2: Excavatable Flowable Fill (EFF) Mixtures for 2006 TDOT 204.06

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Introduction

This paper is the second in a five part series of technology transfer articles on the new 2006 TDOT 204.06 CLSM Specification (1). We hope you find the information presented helpful in producing CLSM mixtures meeting the new specification. In the second article, a wide variety of example mixtures (Class F fly ash, Class C fly ash, air-entrained) are presented. The example mixtures are the top ten EFF mixtures from TTU research that are most likely to meet or close to meeting 2006 TDOT 204.06 EFF Specifications. Further, CLSM behavior trends that may help in designing CLSM mixtures meeting the 2006 TDOT 204.06 EFF Specifications are discussed. Future parts of the series will examine:

3. Early Strength Flowable Fill (ESFF) Mixtures for 2006 TDOT 204.06
4. Sustainable CLSM Mixtures for TDOT 204.06
5. The Future of CLSM in Tennessee

Table 1 shows performance-related property requirements of the 2006 TDOT 204.06 CLSM Specification. This article will be primarily concerned with the requirements for EFF mixtures. However, astute observers will quickly note that all CLSM mixtures meeting the EFF requirements also meet the "General Use" CLSM requirements. Further, many CLSM mixtures which do not meet the EFF compressive strength requirements will meet the "General Use" requirements.

Table 1. 2006 TDOT 204.06 Property Requirements

Performance–Related Property	General Use	Excavatable (EFF)	Early Strength (ESFF)
Consistency	8" min.	8" min.	8" min.
Load application (ASTM D 6024) (2)	24 hours max.	24 hours max.	6 hours max.
Air content, if air entrained (ASTM D 6023) (3)		30% max.	30% max.
Compressive Strength @ 24 hours (ASTM D 4832)* (4)			30-psi min.
Compressive Strength @ 28 days (ASTM D 4832)*		30-psi min.	
Compressive Strength @ 98 days (ASTM D 4832)*		140-psi max.	

* - may use 4x8 inch cylinder molds; preferred capping method is wet-suit neoprene in rigid retainers;

Example EFF Mixtures

Class F Fly Ash CLSM Mixtures Likely to Meet 2006 TDOT 204.06 EFF Specifications

The CLSM mixtures shown in Table 2(a) from research sponsored by TDOT, TCA, the Combustion Byproduct Recycling Consortium (CBRC) and the Kentucky Ready Mix Concrete Association (KRMCA) (5, 6, 7) meet all 2006 TDOT 204.06 EFF Specifications except load application. Recall from Part 1 that during suitability for load application testing, 1 drop of the Modified Kelly Ball was inadvertently performed rather than the ASTM required 5 drops per location. The authors consider it likely that the Class F fly ash CLSM mixtures shown below would meet the 2006 TDOT 204.06 EFF Specification. Mixture proportions, plastic properties, and compressive strength development of the promising Class F fly ash CLSM mixtures are shown in Tables 2(a), 2(b), and 2(c) respectively.

Table 2(a). Class F Fly Ash CLSM Mixtures (lbs/CY) Likely to Meet 2006 TDOT 204.06 EFF Requirements

Mixture	Type I PC	Class F Fly Ash	Aggregate	Water
F9	60	440	2492 - River Sand	498
TCA FScr	45	370	2611 - Limestone Screenings	448

Table 2(b). Plastic Properties of Class F Fly Ash CLSM Mixtures

Mixture	Flow (in)	Time to Pass the Ball Drop (1 Drop) in hours	Gravimetric Air Content (%)	Unit Weight (pcf)
F9	18	19	0	131.6
TCA FScr	10.5	23	0	135.2
Required	≥ 8	≤ 24 (5 drops)	≤ 30 if AE	--

Table 2(c). Compressive Strength Development (in psi) over Time (days) of Class F Fly Ash CLSM Mixtures

Mixture	7	28	63	98	182	364	728
TCA FScr	22.9	57.8	82.7	91.6	105	133.7	111
Required	--	≥ 30	--	≤ 140	--	--	--

Class C Fly Ash CLSM Mixtures Likely to Meet 2006 TDOT 204.06 EFF Specifications

The project to evaluate Class C Fly ash for use in EFF sponsored by TCA (8) was a laboratory only project. No field trenches were placed and therefore no suitability for load application testing could be performed. In an attempt to predict time of suitability for load application, compressive strength tests were performed on a pair of 4x8 cylinders for five Class F Fly Ash CLSM mixtures at the times corresponding to the CLSM mixture's field trench passing the ball drop test (1 drop). Figure 1 shows the average compressive strength of pair of cylinders for the five CLSM mixtures selected and the average compressive strength of all five CLSM mixtures at the time of passing the ball drop test. The authors reasoned that CLSM mixtures having a compressive strength greater than the average compressive strength value of all five mixtures had a good chance of passing the ball drop test.

The CLSM mixtures shown in Table 3(a) from research sponsored by TCA (8) meet all 2006 TDOT 204.06 EFF Specifications except load application. No air-entrained Class C fly ash mixtures were used in the study, therefore air content tests were not performed and the maximum air content specification does not apply. Mixture proportions, plastic properties, and compressive strength development of the promising Class C fly ash CLSM mixtures are shown

in Tables 3(a), 3(b), and 3(c) respectively. All one-day compressive strengths shown in Table 3(c) are greater than 6.1-psi. Therefore, the authors assumed that these CLSM mixtures had a good chance of passing the ASTM ball drop test in 24 hours.

Figure 1. Compressive Strength at the Time of Passing the Ball Drop Test (1 Drop)

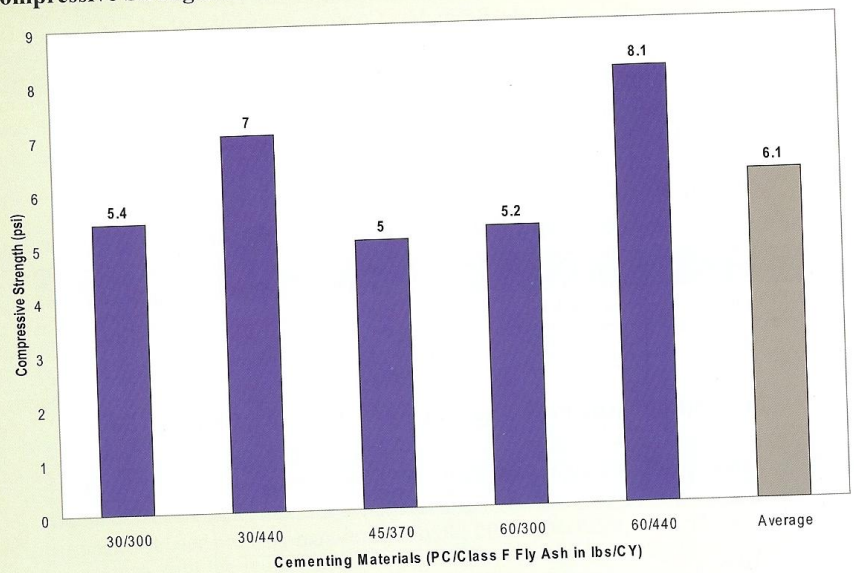


Table 3(a). Class C Fly Ash CLSM Mixtures (lbs/CY) Likely to Meet 2006 TDOT 204.06 EFF Requirements

Mixture	Type I PC	Class C Fly Ash	Aggregate (River Sand)	Water
C3	0	580	2417	530
TCA C	45	370	2605	520
C13	45	440	2538	520
C15	60	370	2542	539

Table 3(b). Plastic Properties of Class C Fly Ash CLSM Mixtures

Mixture	Flow (inches)	Unit Weight (pcf)
C3	19	129.9
TCA C	11	128.7
C13	14.5	131.9
C15	18	128.2
Required	≥ 8	----

Table 3(c). Compressive Strength Development (in psi) over Time (days) of Class C Fly Ash CLSM Mixtures

Mixture	1	7	28	98	182	364
TCA C	8	14.5	34	58	66.5	108.5
C13	14	23.5	46.5	94	105.5	138.5
C15	9.5	32.5	66.5	129	147	179
Required	--	--	≥ 30	≤ 140	--	--

CLSM Mixtures in Need of a Small Adjustment to Meet 2006 TDOT 204.06 EFF Specifications

The CLSM mixtures shown in Table 4(a) meet all 2006 TDOT 204.06 EFF Specifications except flow and/or load application. The authors consider it likely that the CLSM mixtures could meet the 2006 TDOT 204.06 EFF Specification with a small adjustment. Mixture proportions, plastic properties, and compressive strength development of the promising CLSM mixtures are shown in Tables 4(a), 4(b), and 4(c) respectively.

Air-entrained EFF mixtures set by cement hydration rather than dewatering, therefore air-entrained EFF mixtures require higher cement contents than non-air-entrained EFF mixtures. Air entraining admixtures entrain large quantities of stable air bubbles which limit compressive strength, minimize segregation, and virtually eliminate bleeding. Fly ash is typically not required in air-entrained EFF mixtures; the increase in paste volume required for sufficient workability, which is typically provided by fly ash in non-air-entrained EFF mixtures, is provided by air bubbles.

Mixture AE 100 needs an increase of 1.75-inches in flow to meet all 2006 TDOT 204.06 EFF requirements. A slight increase in water content should provide additional flow. Mixture AE 150 was not ball drop tested. Mixture AE 150 has a higher cement content, lower air content, and higher 7-day compressive strength than Mixture AE 100. Therefore, it is likely that Mixture AE 150 would pass the ball drop test more quickly than Mixture AE 100. Further, Mixture AE 150, with a 98-day compressive strength of 138.9-psi, is too close to the TDOT 98-day 140-psi maximum compressive strength. Increasing the air content into the low 20-percent range should reduce 140-day compressive strength without compromising Mixture AE 150's ability to pass the ball drop.

Mixture TCA CScr meets all 2006 TDOT 204.06 EFF Specifications except flow and was not tested for time of load application in this study. The TCA CScr mixture has a 1-day compressive strength over twice the average compressive strength needed to pass the ball drop (1 drop) shown in Figure 1. The flow deficiency can probably be corrected by slightly decreasing the aggregate content and slightly increasing the water content.

Mixture TDOT 95F meets all 2006 TDOT 204.06 EFF Specifications except flow. An increase in the total cementing materials would increase flow; however, the cement content is already very high for a non-air-entrained EFF mixture. A decrease in cement content and an increase in fly ash content would probably increase flow and reduce the later high compressive strengths. The rationale for the change will be discussed in the next section.

Table 4(a). CLSM Mixtures (lbs/CY) in Need of a Small Adjustment to Meet 2006 TDOT 204.06 EFF Requirements

Mixture	Type I PC	Fly Ash	Aggregate	Water
AE 100	100	0	2316 River Sand	270
AE 150	150	0	2450 River Sand	340
TCA CScr	45	370 Class C	2700 Screenings	506
TDOT 95F	100	250 Class F	2800 River Sand	500

Table 4(b). Plastic Properties of CLSM Mixtures in Need of a Small Adjustment

Mixture	Flow (inches)	Time to Pass the Ball Drop (1 Drop) in hours	Gravimetric Air Content (%)	Unit Weight (pcf)
AE 100	6.25	20	24.3	106.7
AE 150	8.5	Not Available	19.4	Not Avail.
TCA CScr	6.5	Not Available	Not Applicable	134.8
TDOT 95F	Shear	21	5	126
Required	≥ 8	≤ 24 (5 drops)	≤ 30 if AE	--

Designing a TDOT 204.06 EFF Mixture

There is currently no formal procedure available for designing 2006 TDOT 204.06 EFF mixtures. However, some of the lessons learned from TDOT, TCA, CBRC, and KRMCA sponsored research at TTU (5, 6, 7) can greatly reduce the time needed to proportion a successful 2006 TDOT 204.06 EFF mixture. The following paragraphs describe the EFF mixture lessons learned to date.

Figure 2 shows the probability of achieving a flow of 8-inches or more with non-air-entrained EFF mixtures using river sand aggregate. Mixtures utilizing each class of fly ash have a threshold value of total cementing materials above which, the probability of achieving the desired flow more than triples. The threshold values are 400 lbs/CY and 415 lbs/CY for Class C and Class F fly ashes, respectively. Aggregates other than river sand may require different amounts of cementing materials to achieve a high probability of obtaining the desired flow. In general more angular or finer aggregates may require more cementing materials.

Figure 3 shows correlations between cementing materials content and 28-day compressive strength for each class of fly ash using river sand aggregate. For early compressive strengths such as 28 days, the cement content is more important than the fly ash content. Therefore, cement weight cubed times fly ash weight correlated best with the 28-day compressive strengths. Figure 3 shows that for river sand aggregate, it is difficult to achieve the desired 28-day compressive strength of 30-psi with less than 45 and 60 lbs/CY of cement for Class C and Class F fly ash mixtures, respectively. It is important to note in the TDOT, TCA, CBRC, KRMCA sponsored study (5, 6, 7), limestone manufactured sand and limestone screenings had 28-day compressive strength 2.9 and 3.5 times that of river sand, respectively. Therefore, lower cement weights than those necessary for river sand aggregate may produce the desired 28-day compressive strength with limestone manufactured sand and limestone screenings aggregates.

Figure 4 shows correlations between cementing materials content and 98-day compressive strength for each class of fly ash using river sand aggregate. For compressive strengths at 98 days, the cement content remains more important than the fly ash content. Therefore, cement weight cubed times fly ash weight still correlated best with the 98-day compressive strengths. Figure 4 can be used to determine if the selected proportions for flow and 28-day compressive strength are likely to produce 98-day compressive strengths less than 140-psi with river sand aggregate. It is important to note in the TDOT, TCA, CBRC and KRMCA sponsored study, limestone manufactured sand and limestone screenings had 98-day compressive strength 4.1 and 4.4 times that of river sand, respectively. Therefore, lower cement and fly ash weights than those used with river sand aggregate are required to maintain compressive strengths less than or equal to 140-psi at 98-days with limestone manufactured sand and limestone screenings aggregates.

Experience from the TDOT, TCA, CBRC and KRMCA sponsored study and previous TTU lab studies indicates that cement weights of 100 to 150 lbs/CY give the best chance of meeting 2006 TDOT EFF requirements for air-entrained

EFF mixtures. At 100 lbs/CY of cement, air contents above 25-percent make it difficult to pass the ball drop test. As the cement content increases towards 150 lbs/CY, higher air content mixtures still have a chance of passing the ball drop test. Air-entrained EFF mixtures with cement contents near 150 lbs/CY should not have air contents less than 20-percent or difficulties may occur in meeting the 98-day compressive strength requirement. Water contents of air-entrained EFF mixtures are on the order of 60-percent of those for non-air-entrained EFF mixtures. Water contents of 250 to 350 lbs/CY are reasonable starting points for trial mixtures for air-entrained EFF mixtures.

Figure 2. Probability of Achieving ≥ 8-inch Flow with Type I PC and River Sand

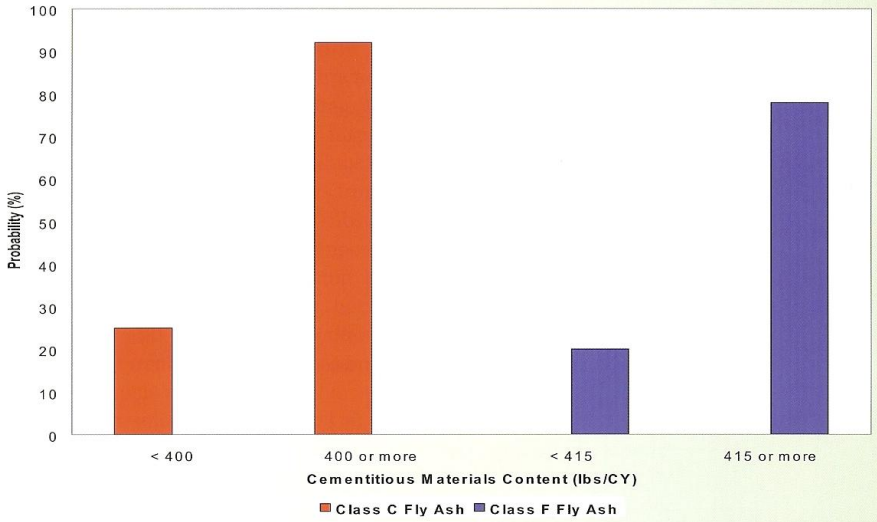


Figure 3. 28-day Compressive Strength with Type I PC and River Sand Aggregate

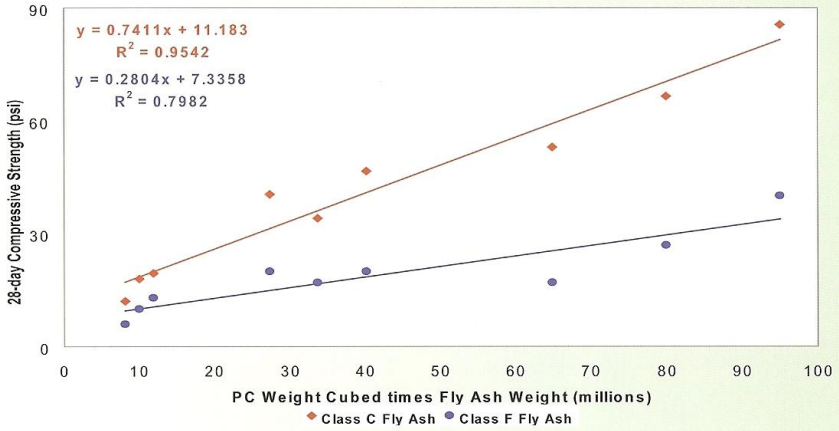
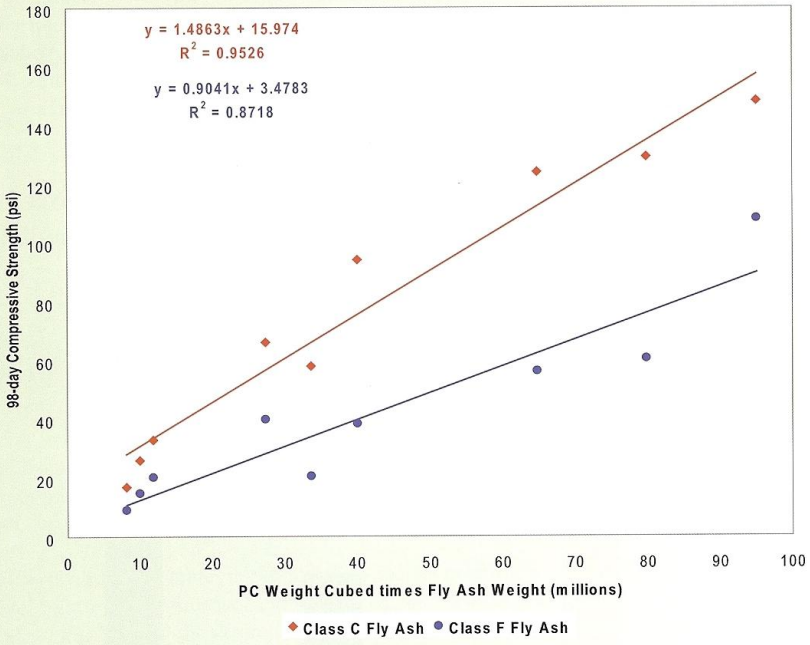


Figure 4. 98-day Compressive Strength with Type I PC and River Sand Aggregate



Summary

The following sources of information have been provided to help in meeting the 2006 TDOT 204.06 EFF Specification:

1. Examples of the top ten most promising TDOT, TCA, CBRC and KRMCA, and TTU research mixture proportions for EFF mixtures with performance-related properties;
2. Correlations between EFF mixture proportions and performance-related properties with trends noted and explained.

Further important sources of information for designing 2006 TDOT 204.06 EFF mixtures include:

1. Admixture representatives
2. Supplementary cementing materials representatives
3. TCA concrete producer members
4. TCA regional directors and executive director
5. TDOT Materials & Tests Division Personnel
6. National Ready Mix Concrete Association Publications
7. American Concrete Institute Publications

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