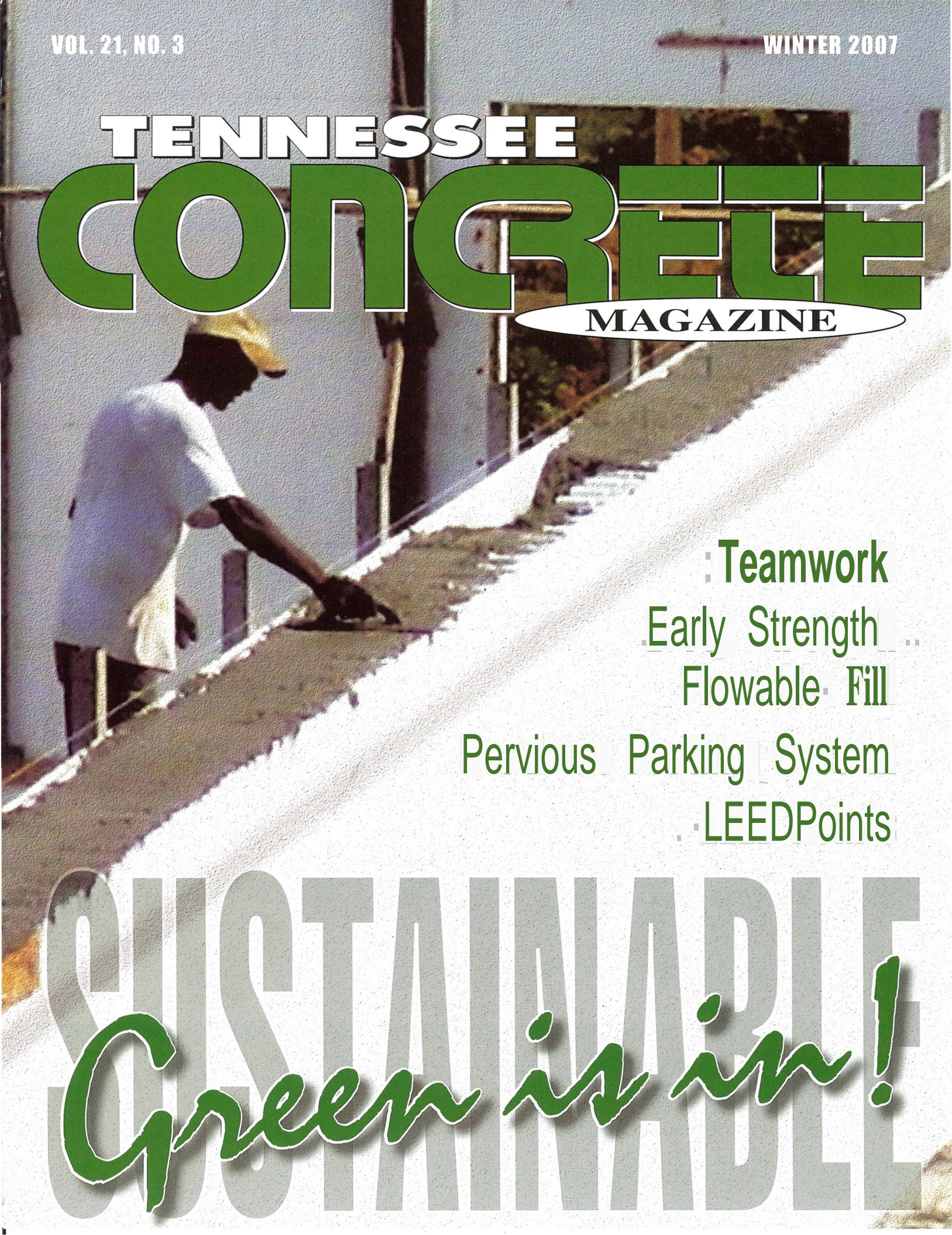


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## Part 3:

## Early Strength Flowable Fill (ESFF) Mixtures for 2006 TDOT 204.06

*L. K. Crouch, V. James Dotson, Brian Egan, Steve M. Hall and Larry Clouse*

### INTRODUCTION

This paper is the third 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 controlled low-strength material (CLSM) mixtures meeting the new specification. In the third article, several examples of ESFF mixtures are presented. Further, ESFF performance-related properties (from the laboratory, several field demonstrations, and the first field use) that may help in designing CLSM mixtures meeting the 2006 TDOT 204.06 ESFF Specifications are discussed. Future parts of the series will examine:

4. Sustainable CLSM Mixtures for TDOT 204.06
5. The Future of CLSM in Tennessee

Table I shows performance-related property requirements of the 2006 TDOT 204.06 CLSM Specification. This article will be primarily concerned with the requirements for ESFF mixtures. Observers will quickly note that all CLSM mixtures meeting the ESFF requirements also meet the "General Use" CLSM requirements. However, the additional cost of ESFF mixtures will generally preclude their use as "General Use" CLSM mixtures.

**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 ESFF Mixtures

Laboratory CLSM Mixtures Close to Meeting 2006 TDOT 204.06 ESFF Specifications

Mixture proportions, plastic properties, and compressive strength development of the promising laboratory ESFF mixtures are shown in Tables 2(a), 2(b), and 2(c) respectively. The ESFF mixtures shown in Table 2(a) from research sponsored by TDOT, TCA, and KRMCA (5,6,7) are close to meeting 2006 TDOT 204.06 ESFF Specifications except for load application. No field trenches were placed and therefore no suitability for load application testing was performed. Recall from Part 2, that a compressive strength greater than 6.1-psi from a pair of 4x8 cylinders indicated a good chance of passing the suitability for load application test. The authors consider it likely that the laboratory CLSM mixtures shown below would meet the 2006 TDOT 204.06 ESFF load application specification. The limestone manufactured sand laboratory ESFF needs a slight adjustment to the air content.

Table 2(a). Laboratory Mixtures Close to Meeting 2006 TDOT 204.06 ESFF Requirements

Component	River Sand ESFF	High-fines Limestone Screenings ESFF	Limestone Manufactured Sand ESFF
Type I PC (lbs/CY)	300	350	300
Water (lbs/CY)	317	375	317
Aggregate (lbs/CY)	2425	2335	2582
Air-entrainer (oz/CY)	70	105	70
HRWR (oz/CY)	30	45	30
WR Accelerator (oz/CY)	225	225	225

Table 2(b). Plastic Properties of Laboratory ESFF Mixtures

Component	River Sand ESFF	High-fines Limestone Screenings ESFF	Limestone Manufactured Sand ESFF	TDOT 204.06 ESFF Requirements
Flow (inches)	8.5	9.5	9.5	2;8
Bleed Time (min)	4.5	No Bleed	No Bleed	
Shrinkage	Minimal	No Shrinkage	No Shrinkage	
Air Content (%)	25.7	22.0	32.9	22;30
Unit Weight (pcf)	104.6	110.6	99.4	

Table 2(c). Compressive Strength Development (in psi) over Time of Laboratory ESFF Mixtures

	6 hours	9 hours	24 hours	7 days	28 days	56 days
River Sand ESFF	10	27	71	188	299	349
Screenings ESFF	30	64	179	444	621	703
LS Manuf., Sand ESFF	11	20	60	149	226	305
ESFF Requirements			2;30			

*Field Demonstration ESFF Mixtures Likely to Meet 2006 TDOT 204.06 ESFF Specifications*

The three promising laboratory ESFF mixtures were further investigated through three field demonstrations. Demonstrations were conducted at Algood (near Cookeville), Knoxville, and Nashville. Figures 1, 2, and 3 show the ESFF field demonstrations. The demonstration ESFF mixtures are shown in Table 3(a). Tables 3(b) and 3(c) show plastic and hardened properties, respectively, of the demonstration ESFF mixtures. The ball drop test could not be performed on the limestone screenings ESFF mixture at Algood due to a high water level in the trench. The other ESFF demonstration mixtures met all TDOT 204.06 ESFF Specifications except load application, since only one drop of the ball was inadvertently used rather than the required 5 drops. Recall from Part 1 that upon passing a one drop ball drop tests the Algood trench was immediately able to support a full size club-cab pickup truck. Therefore, the authors assumed that these ESFF mixtures had a good chance of passing the ASTM ball drop test (5 drops) in 6 hours.

**Table 3(a). Field Demonstration Mixtures Likely to Meet 2006 TDOT 204.06 ESFF Requirements**

Location	Algood, TN	Algood, TN	Knoxville, TN	Nashville, TN
Producer	Plateau	Plateau	Rinker	IMI
Type I PC (lbs/CY)	350	300	312	297
Water (lbs/CY)	Not Available	Not Available	Not Available	Not Available
Aggregate Type	Screenings	River Sand	LS Man Sand	River Sand
Aggregate (lbs/CY)	2335	2340	2614	2555
Air-entrainer (bags)	1	1	1	1
HRWR (oz/CY)	45	30	30	30
WR Accelerator (oz/CY)	225	225	230	225

**Table 3(b). Plastic Properties of Field Demonstration ESFF Mixtures**

Location	Algood, TN	Algood, TN	Knoxville, TN	Nashville, TN	204.06 Requirements
Demo Date	9/23/02	9/23/02	11/01/02	11/08/02	
Aggregate Type	Screenings	River Sand	LS Man Sand	River Sand	
Flow (inches)	11.3	13.5	12	8.6	2-8
Bleeding	No Bleed	No Bleed	Minimal	Minimal	
Shrinkage	None	Minimal	Minimal	Minimal	
Air Content (%)	23.3	22.9	26.0	28.2	22-30
Unit Weight (pcf)	108	108	110	104	
Pass Ball Drop (1 Drop) Time in hours	Not Available	2.5	5.5	6.0	2-6

**Table 3(c). Compressive Strength Development (in psi) over Time (days) of Field Demonstration ESFF Mixtures**

	1	7	28	56
Limestone Screenings @ Algood, TN	168	356	513	617
River Sand @ Algood, TN	96	108	329	432
LS Manufactured Sand @ Knoxville, TN	97	249	371	426
River sand @ Nashville, TN	102	232	324	381
TDOT 204.06 ESFF Requirements	2-30			



Figure 1.  
Fluid Consistency of the River Sand  
ESFF Mixture at the Algood, Tennessee  
Demonstration 9/23/02.

Figure 2.  
Knoxville ESFF Demonstration at  
Rinker Materials 11/01/02



Figure 3.  
Nashville ESFF Demonstration at TDOT  
Region 3 Headquarters 11/08/02

*First Field Use of an ESFF Mixture Likely to Meet 2006 TDOT 204.06 ESFF Specifications*

TDOT ESFF mixtures went from concept to field use in 13 months. This may not be a new world record, but it is certainly an example of rapid development and implementation. Metro Ready Mix of Nashville placed ESFF for a rapid road repair application on Robertson Road in Nashville on 5/30/03. Information provided by Metro Ready Mix on the mixture proportions and compressive strength development of the first field placement are shown in Tables 4(a) and 4(b) respectively. Although the authors were not present, Metro Ready Mix Quality Control Personnel reported that the ESFF mixture performed well in both the plastic and hardened states.

Table 4(a). First Field Use of a Mixture Likely to Meet 2006 TDOT 204.06 ESFF Requirements

Location	Robertson Road Nashville, TN
Concrete Producer	Metro Ready Mix
Date	5/30/03
Type I PC (lbs/CY)	300
Water (lbs/CY)	317
Aggregate Type	River Sand
Aggregate (lbs/CY)	2435
Air-entrainer (oz/CY)	70
HRWR (oz/CY)	60
Accelerator (oz/CY)	225

Table 4(b). Compressive Strength Development over Time of the First Field Use ESFF Mixture

	6 hours	9 hours	24 hours	4 days	7 days
Robertson Road Nashville, TN	18	42	110	410	450
204.06 ESFF Requirements			2:30		

### Designing a TDOT 204.06 ESFF Mixture

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

The ESFF mixtures described in this article have all been air-entrained. Air-entrained ESFF mixtures set by cement hydration rather than dewatering, therefore air-entrained ESFF mixtures are not affected by poor drainage conditions. However, most air-entrained ESFF mixtures will not meet TDOT 204.06 Specifications if placed in standing water since set will be delayed. Although air-entrained ESFF mixtures are not adversely affected by poor drainage conditions, they are susceptible to retardation by low temperatures. The combination of low mixture temperatures and air contents approaching the TDOT 204.06 specified limit make it very

difficult to meet 204.06 load application requirements. ESFF mixtures for placement in cold weather should be proportioned with an air content as low as possible to provide adequate flow. A good target air content would be in the low twenties. Higher air contents and thus greater flows can be used in warmer weather.

Non-air-entrained ESFF mixtures are less temperature sensitive than air-entrained ESFF mixtures. Fly ash or slag is used to replace the large volume of air needed to provide the additional paste volume necessary to achieve the required flow. It would be helpful to have an air-entrained and a non-air-entrained ESFF mixture available. The appropriate mixture for each application could be selected based on drainage and temperature conditions anticipated at the time and location of placement. TTU researchers have been attempting to develop non-air-entrained ESFF mixtures. The progress to date on these attempts will be discussed in Part 5 of the series.

The ESFF mixtures presented do not meet TDOT 204.06 ESFF Specifications. In fact, most ESFF mixtures surpass the limits of excavatability with a backhoe in less than 28 days. It is very difficult to design a CLSM mixture which will meet both TDOT 204.06 ESFF and ESFF Specifications. TTU researchers have been attempting a CLSM mixture that will meet both parts of the new TDOT 204.06 Specification. The progress to date on these attempts will be discussed in Part 5 of the series.

## Summary

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

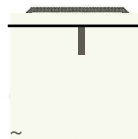
1. Examples of the most promising TDOT, TCA, KRMCA, and TTU research mixture proportions for ESFF mixtures with performance-related properties;
2. Mixture proportions and compressive strength development for the first field use of a TDOT ESFF mixture in Tennessee.

Further important sources of information for designing 2006 TDOT 204.06 ESFF Mixtures include:

1. Admixture representatives
2. TCA concrete producer members
3. TCA regional directors and executive director
4. TDOT Materials & Tests Division Personnel
5. American Concrete Institute Publications

*See page 26 for  
References, etc.*

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## Disclaimer

The opinions and assertions contained herein are the private ones of the authors and are not to be construed as reflecting the official views of the Tennessee Valley Authority.

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