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Production and Quality Control for Controlled Low Strength Materials

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ABSTRACT

This paper presents the critical attributes of Controlled Low Strength Material (CLSM) structural fill which are essential for quality control during production for a significant project. The CLSM mixture proportions included Portland cement, fine aggregate with 30% material passing No 200 sieve, and an air entraining admixture. The CLSM mixture was mixed in a truck mixer using a minimum 150 drum revolutions at mixing speed.

The CLSM mixture was designed to produce a flowable mixture for placement without compaction. The flow consistency of the mixture was 6-9 inches (ASTM D6103), while the unit weight (ASTM C138) was 112-115 lb/ft^3. CLSM mix proportions were designed to produce a compressive strength of 30-200 psi at 28-days. The CLSM compressive strength was determined using a site developed testing procedure, which produced reliable results at early ages.

INTRODUCTION

Controlled low-strength material (CLSM) is a self-compacted, cementitious material primarily used as a backfill in place of compacted fill. CLSM (also known as flowable fill) is a cementitious material manufactured using cement, fines (fly ash, sand or native granular materials), and water mixed in a concrete plant or a truck mixer. The combined ingredients produce a flowable mixture that can be installed without compaction. The CLSM, due to its flowability and low placement costs, is being increasingly used for structural backfill, pavement bases, subbases and subgrades, bedding for pipes, electrical and conduits, erosion control and nuclear facilities and waste disposal sites, where construction schedules are critical and the conventional compacted backfill methods pose delays. In addition, the consistent quality of the CLSM offers a distinct technical advantage over the conventional marginal backfill materials, such as silty sands, which require greater compactive effort to meet the ASTM C1557 Proctor acceptance criteria, referenced in earthwork specifications. Use of CLSM can be justified by ease of placement in inaccessible areas and faster construction schedule. Testing for CLSM mixtures is performed in accordance with ASTM test standards.

American Concrete Institute report ACI 229 R (Ref 1) provide guidelines for CLSM applications, including materials, mixing, placing and quality control requirements.

CLSM MIX PROPORTIONS

CLSM mixture proportions are established from trial batches performed on-site, using cement, fine aggregate, water, and air-entraining admixture. Fly ash, if locally available, may be substituted for cement. All material sources, once the CLSM mixture are established, should not be changed without performing additional tests to verify the physical properties.

The CLSM mix proportions for 30-200 psi compressive strengths range are presented in Table 1.

Table 1: CLSM Mixture Proportions (pounds per cubic yard)

Material/Mix	CLSM-1 (30-50 psi)	CLSM-2 (150-200 psi)
Cement (Type I/II)	94 lbs.	188-235 lbs.
fine aggregate	2230-2400 lbs.	2400 lbs.
Water	563 lbs. (67.5 gallons)	625 lbs. (75 gallons)
Air entraining admixture	3 oz.	5 oz.

CLSM-1 mixture with 30-50 psi compressive strength at 28 days, is recommended for backfilling around pipes and conduit trenches, and around manholes, large voids and other non-structural fill applications. The specific mix proportions should be verified by site tests, and as a minimum include flowability, unit weight, and compressive strength tests.

CLSM-2 is recommended as structural backfill within the footprints of buildings, subbases for slabs on grade and pavements, and for foundation support.

CRITICAL ATTRIBUTES

Batching and Mixing

CLSM materials should be batched at a central batching facility to assure uniform quality and consistency of mixture between successive batches. The central batch plant should meet the NRMCA certification requirements in accordance with ASTM C94. For truck-mixed CLSM, a minimum of 150 revolutions at mixing speed are considered necessary, after batching, to assure proper dispersing and mixing of cement and to minimize any lumping of the material.Batch tickets showing the amount of cement, fines, water and admixtures should accompany each batch delivered, similar to delivery of concrete, for documentation

Bleeding

Due to large amount of water in CLSM mixtures required to provide flowable consistency, there is inherent bleeding and settlement prior to hardening. Published data on bleeding of the CLSM mixtures is limited. Air entraining admixtures, conforming to ASTM C260 should be used in CLSM mixtures to reduce bleeding and segregation. The amount of air entrainment is established from CLSM trial mixtures testing. Bleeding of the CLSM mixture is determined in the laboratory using a 1-liter (1000cc) graduated cylinder. The amount of bleed water is measured with time, at 30-minute interval until no further bleeding is observed.

Settlement

ACI 229R-99 (Ref 1) states "Subsidence deals with reduction in volume of CLSM as it releases water and entrapped air through consolidation of the mixture. Most of the subsidence occurs during placement and the degree of subsidence is dependent upon the quantity of free water released. Typically, subsidence of 3 to 6 mm (1/8 to 1/4 inch) per foot of depth is reported. This amount is generally found with mixtures of high water content. Mixtures of low water content undergo little or no subsidence."

Settlement of CLSM may be determined by 6x12-inch cylindrical specimens, to verify settlement characteristic after hardening. The specimens, after casting, are stored on-site and field cured without protection for four (4) days then transported to the laboratory for environmentally controlled curing . The vertical settlement of the CLSM-2 mixture is determined from readings taken on the cylindrical specimens as required after placement. The maximum settlement generally occurs in the first 6-12 hours after placement ranges from 0.10-0.15 inch.

For the CLSM-2 mixture, based on measurements taken on 6x12 inch cylinders, the average settlement was 0.11 inch after 28 days.

Shrinkage and Cracking

According to Ref. 1, shrinkage and cracking cracks do not affect the performance of CLSM. Ultimate linear shrinkage is reported to be in the range of 0.02-0.05%. Minor linear shrinkage cracking was observed in the surface of the first lift ranging in width from about 1/8-inch to 1/4-inch. The measure depth of the cracks was about 3 5/8-inches. Negligible linear hairline cracking was observed in the surface of the bull floated final lift.

Compressive Strength

CLSM compressive strength is determined in accordance with ASTM D4832. The compressive strength of the CLSM mixture is a function of the cement content and water to cement ratio. For CLSM-1, containing 1-sack cement, the 28-day compressive strength is 30-50 psi. Addition of fly ash to the CLSM mixture is expected to improve the long term compressive strength, which would typically produce strengths 25% higher (at 90-days) than the 28-day values.

For CLSM-2 mixture, the average 7-day compressive strength was 110 psi, while the average 28-day compressive strength was 200 psi. The 7-day strength is about 55% of the 28-day strength. Since no fly ash is included in this mixture, significant strength gain beyond 28-day age is not anticipated.

The CLSM mixtures with compressive strengths up to 200 psi are considered excavatable using hand equipment, but at higher strength, the CLSM requires heavy equipment (a backhoe) for excavation (Ref 1). New Mexico DOT limits the 28-day compressive strength for CLSM to150 psi maximum where used for backfill in culvert installations or backfilling pipes.

CLSM Modulus, k_U

The bearing capacity of CLSM-2 mixture is considered equivalent to a well compacted backfill. The CLSM modulus of soil reaction (k_{U}), tested in accordance with AASHTO T222, equals or exceeds the k_U values of conventionally compacted soils. Reference 2 provides results of the plate load tests performed on CLSM-2 mixture and conventionally compacted Silty Sand backfill; CLSM k_U: 625 -780 pounds per cubic inch (pci), and compacted backfill k_U:320-425 pci.

CLSM QUALITY CONTROL

CLSM quality control should focus on the critical attributes of the raw materials and the final product that influence mixture consistency and compressive strength. The specifier should specify the extent of quality control during production.

Fine Aggregate

Fine aggregates should conform to ASTM C33. Using sand as fine aggregate in CLSM mixture is recommended, since the fines content passing No. 200 sieve is less than 3%. Other materials, including native granular soils and quarry waste products, which may contain up to 30% fines passing No. 200 sieve have proven satisfactory, should be tested prior to use and during production to verify workability and effect on compressive strength.. Tests for gradation and the amount of fines passing No. 200 sieve should be performed daily during production. If the test results are satisfactory, or if variation in the test results are minimal, testing frequency may be reduced.

A typical gradation of fine aggregate (source: Slaton Pit, Texas) is shown in Table 2.

Table 2: Fine Aggregate Testing Summary

Test Attribute	Specification	Slaton
Sieve Analysis		
3/8 inch (9.5 mm)	100	100
#4 (4.75 mm)	95-100	100
#8 (2.36mm)	80-100	88
#16 (1.18mm)	50-85	71
#30 (600um)	25-60	58
#50 (300um)	5-30	25
#100 (150um)	0-10	4
#200 (75um)	0-3	0.6
Other Characteristics		
FM	2.3-3.1	2.54
Specific Gravity		2.61-2.62
Absorption, %		1.5
Organic Impurities		None
Soundness, %		9

A typical gradation of the crusher fines, processed from production of crushed base course material, used for the CLSM mixes is shown on Table 3

Table 3: Crusher Fines Gradation Summary

Test Attribute	**ASTM C33 Specification**	**Crusher Fines**
Sieve Analysis		
3/8 inch (9.5 mm)	100	100
#4 (4.75 mm)	95-100	88
#8 (2.36mm)	80-100	70
#16 (1.18mm)	50-85	58
#30 (600um)	25-60	50
#50 (300um)	5-30	44
#100 (150um)	0-10	34
#200 (75um)	0-3	29
Other Characteristics		
FM	2.3-3.1	2.56
Specific Gravity		2.35
Absorption, %		3.4
Organic Impurities		None
Soundness, %		9

Admixture

Air-entraining admixture, should conform to ASTM C260. Air entraining admixtures provide improved workability to the CLSM mixtures, with reduced bleeding and segregation, as well as lowering the water demand.

Cement

The cement should conform to ASTM C150 Type I or II. Other cement types, including Type V or blended cements, can be used. A typical certified mill certificate from a specific Type II / V Portland cement source is presented in Table 4.

Table 4: Cement Mill Test Results

Requirements	ASTM C150 Type II	ASTM C150 Type V	Specific source
Chemical Requirements			
SiO2, %	20.0 min.		21.2
Al2O3, %	6.0 max		4.5
Fe2O3, %	6.0 max		4.4
CaO, %			63.8
MgO, %	6.0 max	6.0 max	0.8
SO3, %	3.0 max	2.3 max	2.9
LOI, %	3.0 max	3.0 max	1.1
Insoluble Residue, %	0.75 max	0.75 max	0.28
Na2O equivalent, %	0.60 max	0.60 max	0.39
C3S, %			55
C2S, %			19
C3A, %	8.0 max	5.0 max	5
C4AF, %			13
C4AF+2C_3A, %		25	22
Physical Requirements			
Blaine Fineness, m^2/kg (air permeability)	280 min	280 min	382
Minus 325 mesh, %			96.7
Vicat Set time			
Initial, minutes	45 min	45 min	89
Final, minutes	375 min	375 min	182
False Set, %	50 min	50 min	81
Air Content, %	12 max	12 max	6.0
Autoclave Expansion, %	0.80 max	0.80 max	0.003
Compressive Strength, psi			
1 Day			2120
3 Day	1450 psi	1160 psi	3810
7 Day	2470 psi	2180 psi	5020
28 Day		3050 psi	6640

Sampling and testing of CLSM mixture for flow (ASTM D6103) and unit weight (ASTM D6103) should be performed every 50 cubic yards at the end of truck chute discharge or at the end of the pump line discharge. Testing for compressive strength should be performed daily during production, or every 100 cubic yards, whichever is greater.

CLSM strength specimens should be placed into 6x12-inch, pre-split and taped cylinder molds without rodding or tapping, in accordance with ASTM D 4832. The cylinders should be slightly heaped off above the molds to allow for the initial settlement, and left undisturbed for 24-36 hours after casting at the site testing agency laboratory. The cylinders should be tested for compressive strength at 7-day, 28-day or 56- day ages. At the required age, the specimens should be carefully removed from the molds, allowed to dry at room temperature for 4 hours, and the ends of specimens were ground prior to testing. Since CLSM specimens may be fragile at early ages, 1-day and 3-day strength tests are not recommended.

For CLSM-1, the 7-day and 28-day compressive strength for all 97 tests averaged 27 psi , and 39 psi, respectively. The standard deviation for all the 7-day and 28-day tests was 4.0 psi and 6.25 psi, respectively.

For CLSM-2, the 28-day compressive strength for laboratory cured tests averaged 198 psi, while the 28-day compressive strength for field cured tests averaged 216 psi.

REFERENCES

ACI 229R-99, Controlled Low-Strength Materials, Reported by ACI 229 Committee.

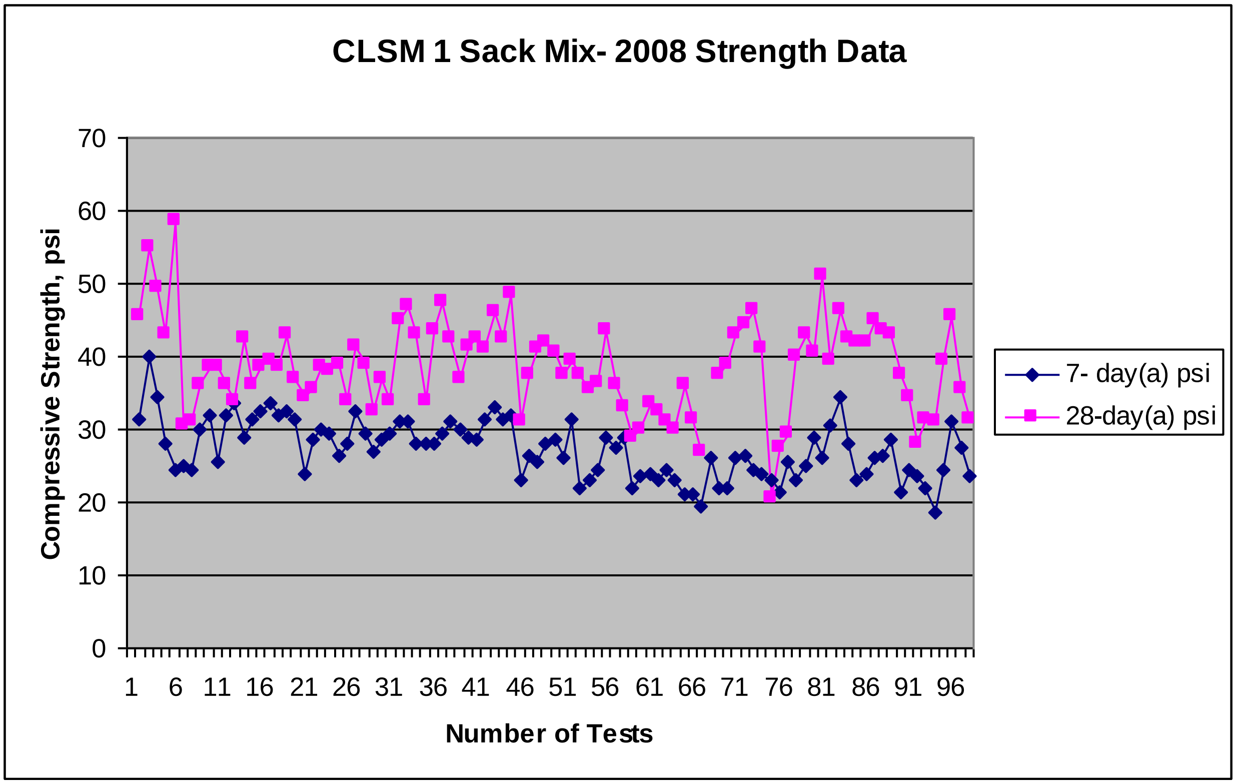

Figure 1: CLSM-1 7-Day and 28-Day Compressive Strength During Production

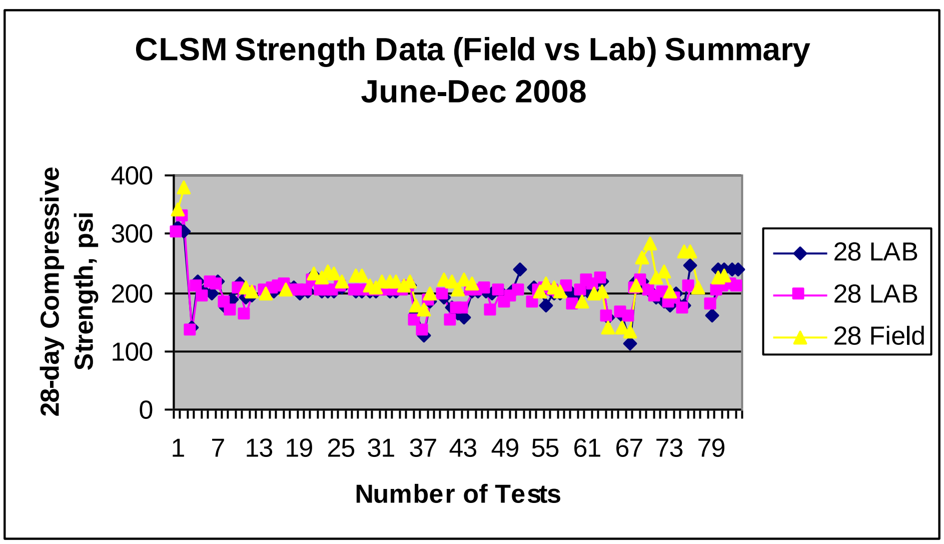

Figure 2: CLSM-2 28-Day Compressive Strength During Production

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