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Development of Soil-Based Controlled Low-Strength Materials

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DEVELOPMENT OF SOIL-BASED CONTROLLED LOW-STRENGTH MATERIALS

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Abstract

Initial research has been conducted on the feasibility of developing soil-based controlled low-strength material (CLSM) mixtures that could be used to backfill large excavations at construction sites. Often the excavated material at a construction site contains soils that are not suitable for use as compacted backfill. This paper discusses the feasibility of the use of soil-based CLSM to lower cost and to use the materials normally disposed into a spoil pile. By incorporating such materials into a CLSM mixture, the land area needed for spoil-pile disposal may be reduced, therefore reducing real estate costs and providing good land-stewardship practices.

The CLSM mixtures investigated include replacement of portland cement by Class C fly ash, replacement of Class F fly ash with a soil classified by the Unified Soil Classification System[1] (USCS) as a ML or CL soil, replacement of Class F fly ash with sand, and replacement of Class F fly ash with a mixture of soil and sand. The consistency and the unconfined compressive strength of the CLSM mixtures was measured.

Introduction

The U. S. Army Corps of Engineers (CE) is investigating innovative construction techniques for future Civil Works construction. One of these investigations concerns the use of controlled low-strength materials (CLSM) as a backfill material. CLSM is defined as "...materials that result in a compressive strength of 1200 psi (8.3 Mpa) or less[2]. " CLSM is described in ACT 229R[3] as self-compacting, cementitious material used primarily as a backfill in lieu of compacted fill. Unlike compacted backfill, CLSM mixtures do not require compaction after placement. This allows for a more economical approach to backfilling in that the equipment and labor required to place and compact conventional fill are eliminated.

Previous Research on Soil-Based Controlled Low-Strength Material

Adaska in 1997[4] reported that the use of soil-based CLSM goes back to work reported by the U.S. Bureau of Reclamation in 1964. Amster (1995) described this material as “soil-cement slurry.” It was used for pipe bedding on 515 km (320 miles) of the Canadian River Aqueduct Project, which runs from north of Amarillo to south of Lubbock, Texas. Following the successful evaluation of some test sections, the soil-cement slurry was used which incorporated “local blow sand” (sic) deposits[5].

CLSM is delivered to the job site in truck mixers. CLSM mixtures normally do not use soil as a constituent material. However, the use of the excavated soil is mentioned in ACI229R[3] Chapter 3. of this report, “Materials,” the use of granular excavation materials are listed as potential sources of CLSM materials[3].

CLSM has evolved into a deliverable product by ready-mix concrete producers, with the materials used to produce it being ones readily available to the producer. These materials are usually some combination of portland cement, fly ash, fine aggregate, and water. The producer is able to maintain a quality-controlled mixture with known properties by using constituent materials normally used to produce mortor. Soils can have variable properties that these producers do not want to contend with unless more assurance can be given of a technically usable and marketable product. The use of excavated materials is not widespread because of the logistics of getting the soil into the truck mixer at the job site. Many ready-mix concrete companies also do not have extra storage bins and other ancillary equipment needed to incorporate soil into the mixture at the batch plant. However, we believe the incorporation of soil into a CLSM has its place and is a viable option in many cases.

On large CE projects, a concrete batching and mixing plant is usually set up onsite for the production of concrete for the project. In this situation, the use of the excavated soil is possible since the soil would be readily available in the same area as the concrete batching and mixing equipment.

Significance of Research

This project is significant because there is very little information on the feasibility and use of a soil-based CLSM. Previous work in this area focused on the use of sandy soils. Not enough is known about the use of a soil-based controlled low-strength material which incorporates silty and clayey soils. The research was intended to determine the feasibility of soil-based CLSM and if a satisfactory strength could be obtained with some combination of Class F and C fly ashes, portland cement, a CL or ML-classified soil, a SP-classified sand-size material, and water.

Materials Used to Produce a Soil-Based Controlled Low-Strength Material

The materials used to produce the soil-based CLSM contained some combination of the following:

- Class C Fly Ash
- Class F Fly Ash
- Portland Cement
- CL- or ML Soil
- SP Sand-Size Material
- Water

The ASTM Class C fly ash was obtained from the Pleasant Prairie Power Plant, located near Kenosha, Wisconsin which is owned by the Wisconsin Electric Power Company. This plant burns lignite from the Powder River Basin in Wyoming. Chemical and physical analysis results are given in Tables 1 and 2. The ASTM Class F fly ash was obtained from the John E. Amos Power Plant located near St. Albans, West Virginia. The John E. Amos Power Plant produces Class F fly ash from the burning of bituminous coal. Chemical and physical analysis results are given in Table 3 and Table 4.

The portland cement was manufactured by the Blue Circle Cement Company, Calera, AL. Chemical and physical analysis results on the cement are given in Table 5 and Table 6.

Soil was obtained from a local source in Mississippi and was classified as a clayey silt, ML using the USCS, with 99.9% of the soil passing the 75 •m (No. 200) sieve. The liquid limit of this soil was 33, the plastic limit was 26, and the plasticity index was seven (7). The SP sand-size material was obtained from a sand and gravel pit in Mississippi. This material was non-plastic and had a specific gravity of 2.70.

Mixture Proportions

The baseline mixture, (6),[*] was a combination of portland cement, Class F fly ash, and water. The amount of portland cement was decreased with Mixture 7 and increased with Mixture

[*] Mixtures 1-5 were preliminary trial batches, data on which are not reported here.

8. Class C fly ash was substituted for the portland cement in amounts of 10-, 20-, 40-, 60-, and 80-% replacement for Mixtures 9 through 13. The next class of mixtures replaced ASTM Class F fly ash with varying amounts of the ML-classified soil (Mixtures 14 through 18), sand (Mixtures 19 through 25), and a combined ML-soil and sand (Mixtures 26 through 30). The amounts of replacement of each of these three classes was 10-, 20-, 40-, 60-, and 80-% of the ASTM Class F fly ash.

Table 1

Chemical Analysis of ASTM Class C Fly Ash from
Wisconsin Electric Power, Pleasant Prairie, WI

Chemical Analysis, %		ASTM C 618 Spec Limits Class C
SiO_2,	34.5	-
Al_2O_3,	18.7	-
Fe_2O_3,	6.2	-
Sum,	59.5	50.0 min
CaO,	34.0	-
MgO,	4.7	-
SO_3,	2.4	5.0 max
Moisture content,	0.2	3.0 max
Loss on ignition,	0.3	6.0 max
Available alkalies (28-day),	0.99	1.5 max

Table 2

Physical Analysis of ASTM Class C Fly Ash from
Wisconsin Electric Power, Pleasant Prairie, WI

Physical Tests		ASTM C 618 Spec Limits "Class C"
Fineness % retained on 45-•m sieve	16	34 max
Water requirement, %	94	105 max
Density, Mg/m^3	2.58	-
Autoclave expansion,	0.05	0.80 max
Strength activity index w/cement, 7-d, %	98	75 min
Strength activity index w/cement, 28-d, %	97	75 min

Table 3

Chemical Analysis of ASTM Class F Fly Ash from
American Electric Power, St. Albans, WV

Chemical Analysis, %		ASTM C 618 Spec Limits Class F
SiO_2,	50.2	-
Al_2O_3,	24.9	-
Fe_2O_3,	3.8	-
Sum,	78.9	70.0 min
CaO,	1.0	-
MgO,	0.8	-
SO_3,	0.2	
Moisture content,	0.1	3.0 max
Loss on ignition,	0.6	6.0 max
Available alkalies (28-day),	0.55	1.5 max

Table 4

Physical Analysis of ASTM Class F Fly Ash from
American Electric Power, St. Albans, WV

Physical Tests		ASTM C 618 Spec Limits Class F
Fineness % retained on 45-•m sieve	27	34 max
Water requirement,	99	105 max
Density, Mg/m^3	2.20	-
Autoclave expansion, %	-0.02	0.80 max
Strength activity index w/cement, 7-d, %	76	75 min
Strength activity index w/cement, 28-d, %	80	75 min

Table 5

Chemical Analysis of ASTM Type I Portland Cement from
Blue Circle Cement Company, Calera, AL

Chemical Analysis, %		ASTM C 150 Spec Limits Type I
SiO_2,	21.1	-
Al_2O_3,	4.6	-
Fe_2O_3,	3.0	-
CaO,	62.3	-
MgO,	2.2	6.0 max
SO_3,	2.6	3.0 max
Loss on ignition,	1.7	3.0 max
Insoluble residue,	0.29	0.75 max
Na_2O,	0.04	-
K_2O,	0.69	-
Alkalies-total as Na_2O,	0.49	0.60 max
TiO_2,		-
P_2O_5,		-
C_3A,	7	-
C_3S,	50	-
C_2S,	22	-
C_4AF,	9	-

Table 6

Physical Analysis of ASTM Type I Portland Cement from
Blue Circle Cement Company, Calera, AL

Physical Tests		ASTM C 150 Spec Limits Type I
Surface area, m^2/kg (air permeability)	373	280 min
Autoclave expansion, %	0.01	0.80 max
Initial set, min. (Gillmore)	145	60 min
Final set, min. (Gillmore)	330	600 max
Air content, %	6	12 max
Compressive strength, 3-day, psi	3660	1,740 min
Compressive strength, 7-day, psi	4500	2,760 min

Water content was held constant for Mixtures 6 through 13. It was found necessary to vary water contents for Mixtures 14 through 30 to maintain a flowable consistency equal to or greater than the baseline mixtures while at the same time minimizing segregation of the solid particles. Mixtures 14 through 18 water content increased as the soil content increased. Water contents decreased as the sand contents increased in Mixtures 19 through 25. Except for Mixture 27, the water contents decreased for the soil/sand combination mixtures. All of these CLSM mixtures were mixed in a laboratory mixer. The mixture proportion matrix developed for this work is given in Table 7.

Table 7

CLSM Mixture Proportions

Mixture Number	Water lb	Cement lb	Class F Fly Ash lb	Class C Fly Ash lbs	Soil (Loess) lb	Sand lb
6	17.2	1.5	40	0	0	0
7	17.2	1	40	0	0	0
8	17.2	2	40	0	0	0
9	17.2	1.35	40	0.165	0	0
10	17.2	1.2	40	0.33	0	0
11	17.2	0.9	40	0.66	0	0
12	17.2	0.6	40	0.99	0	0
13	17.2	0.3	40	1.32	0	0
14	18.6	1.5	36	0	4	0
15	20	1.5	32	0	8	0
16	20	1.5	24	0	16	0
17	21	1.5	16	0	24	0
18	21	1.5	8	0	32	0
19	17.2	1.5	36	0	0	4
20	15.2	1.5	32	0	0	8
21	15.4	1.5	36	0	0	8
22	15.4	1.5	32	0	0	16
23	14.2	1.5	28	0	0	24
24	12.9	1.5	24	0	0	32
25	12.2	1.5	20	0	0	40
26	17.2	1.5	36	0	2	2
27	18.2	1.5	32	0	4	4
28	16.2	1.5	24	0	8	8
29	15.2	1.5	16	0	12	12
30	14.2	1.5	8	0	16	16

Tests of Unhardened Materials

After mixing, the unhardened CLSM mixtures were sampled and tested in accordance with applicable ASTM Standards as follows: D5971[8], D6103[6], l6023[7], and C1064[9]. Cylinders were cast for compressive strength testing at 7, 28, 91, and 182 days age. Results are given in Table 8.

These fresh property measurements are given in Table 8.

Table 8

Fresh Property Test Results

Mixture Number	Temperature, °F Air	Temperature, °F Water	Temperature, °F CLSM	Flow Consistency 1st Measure	Flow Consistency 2nd Measure	Unit Weight of CLSM lb/ft³	Measured Air Content %	Yield of CLSM ft³
6	73.4	68.6	71.6	11 ¼	11 3/4	100.7	1.70	0.583
7	72.8	68.4	71.2	11 7/8	12 7/8	99.9	1.80	0.583
8	72.9	68.7	71.2	11	11	101.1	1.70	0.586
9	72.2	--	--	11 3/4	11 3/4	100.3	1.90	0.585
10	72.9	68.9	73.5	11 3/4	11 3/4	100.3	1.70	0.586
11	72.3	68.5	72.1	13 ½	12 3/4	100.3	1.65	0.586
12	67.5	65.4	67.8	13	13 ¼	100.3	1.55	0.586
13	71.6	65.8	70.5	13 3/4	14	99.9	1.70	0.589
14	70.7	67.3	68.9	12	12 ¼	98.2	1.45	0.612
15	64.3	68.3	66.2	14 ½	13 3/4	94.6	1.20	0.650
16	69.1	70.5	65.6	15	14 3/4	96.2	1.00	0.639
17	69.4	70.1	65.6	14 ¼	14	95.8	1.80	0.654
18	73.4	66.8	68.9	13 ½	13	100.3	0.60	0.623
19	72.2	64.6	68.5	15 ¼	16	100.3	0.30	0.585
20	72.2	64.6	67	15	15 ¼	103.7	1.20	0.547
21	71.4	70	70.4	12	12	105.5	1.25	0.577
22	66.6	68.2	68.5	13 3/4	13 ½	109.2	0.90	0.594
23	71.5	68.3	70.3	13 ½	12 ¾	114.2	1.00	0.593
24	70.5	66.7	70	11 ¾	12	119.3	0.75	0.590
25	70.1	69.6	68.5	12	12	124.1	0.70	0.594
26	75.1	66.4	69.5	11	11 ¼	101.3	1.30	0.579
27	72.7	66.9	66.8	> 16	> 16	99.1	0.90	0.602
28	72.5	66.9	69.5	12 ¾	12 ¼	103.1	0.90	0.560
29	76.1	65.8	68.6	12 ½	12 ¼	105.1	0.65	0.539
30	73	71	72	13	12 ¾	107.7	0.65	0.517

Twelve cylinders, 76 by 152-mm (3 x 6-in) were molded from each batch of CLSM. These cylinders were covered and stored in laboratory until the test date. On that date, three specimens from each batch were demolded, the ends were shaved with a diamond-blade circular saw, and the cylinder measured for height and tested for uniaxial unconfined compressed strength at 7-, 28-, 91-, and 182- days age. The results of these tests are given in Figures 1 through 5.

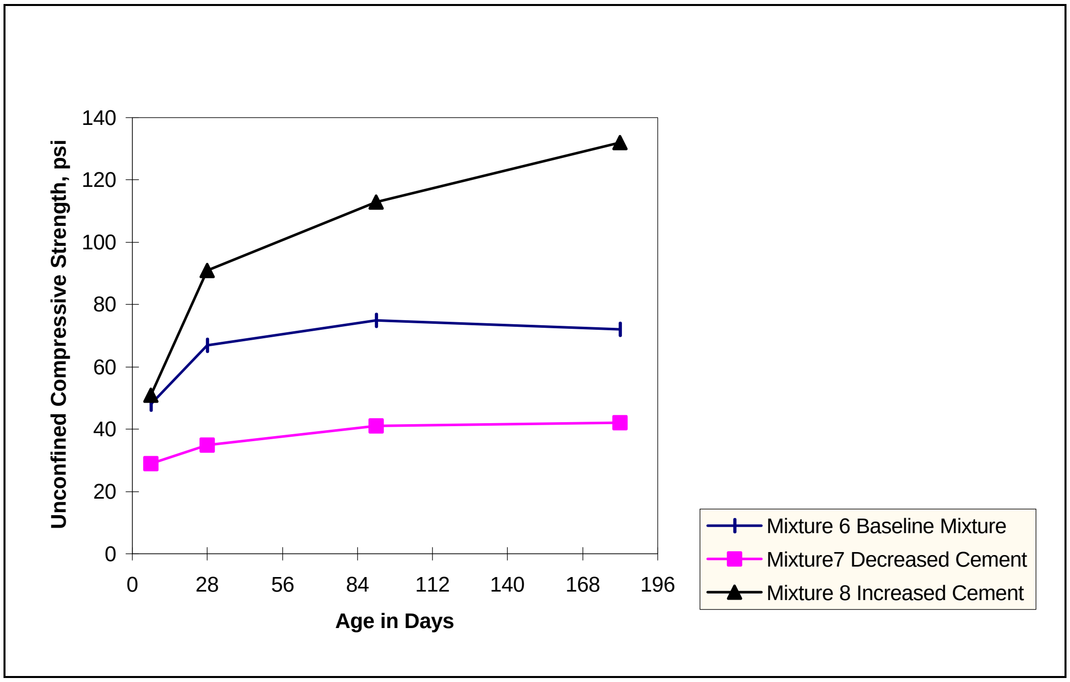

Figure 1
Strength Data for Mixtures 6, 7, 8

Summary and Conclusions

This research investigated the feasibility of developing of soil-based CLSM that could be used to take the place of conventional compacted soil backfill. It was concluded that it is possible to produce CLSM mixtures with a flowable consistency. These mixtures hardened, and achieved an unconfined compressive strengths of 100 psi at 28 days age. Thus the material should be readily excavated as might be required.

A soil-based CLSM could be used to fill large voids at a construction site by using the previously excavated material. This, in turn, will decrease the need to create spoil piles and recycle these materials. A flowable soil-based CLSM mixture will help decrease cost of materials, decrease additional land purchases for spoil piles, and decrease the labor and equipment cost usually associated with compacting conventional backfill.

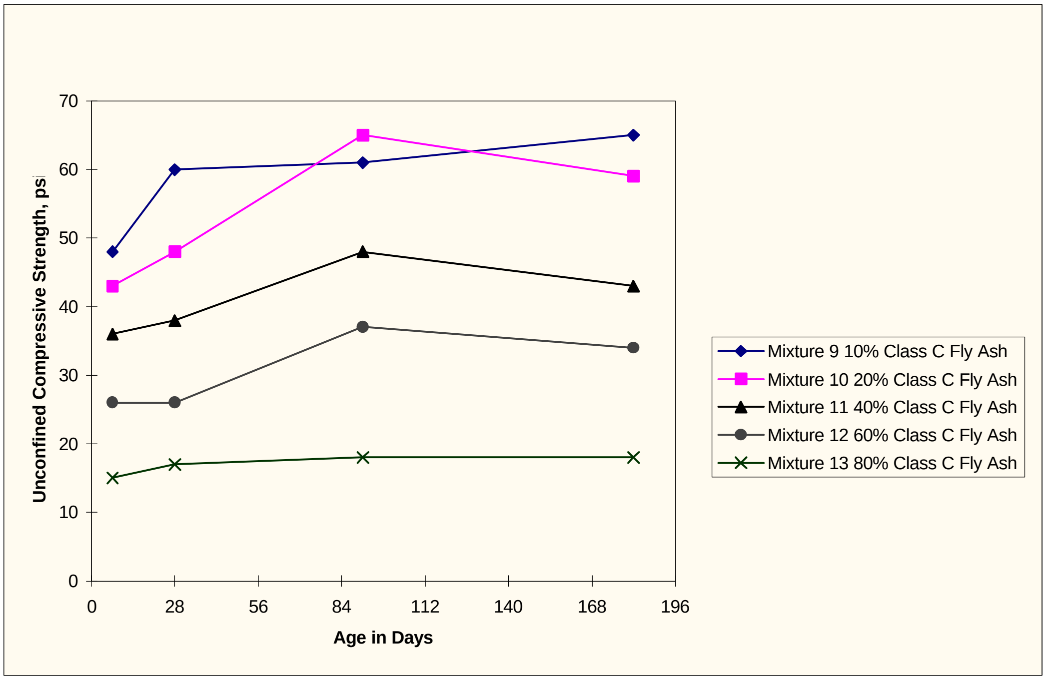

Figure 2
Strength Data for CLSM Mixtures with Class C Fly Ash Replacing Cement

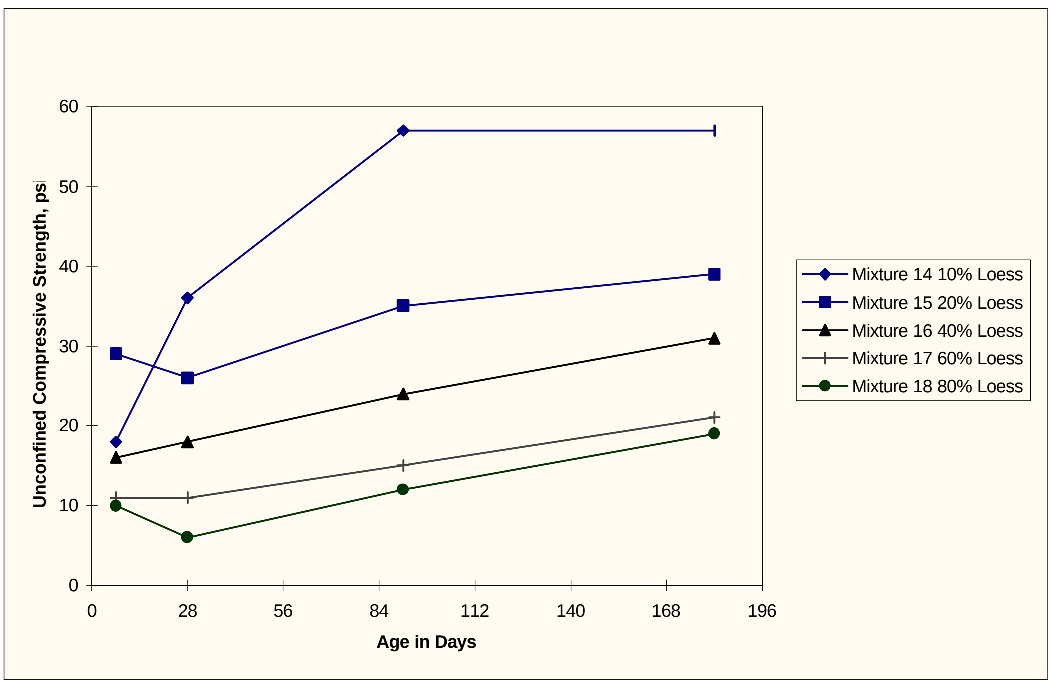

Figure 3
Strength Data for CLSM Mixtures with Soil Replacing Class F Fly Ash

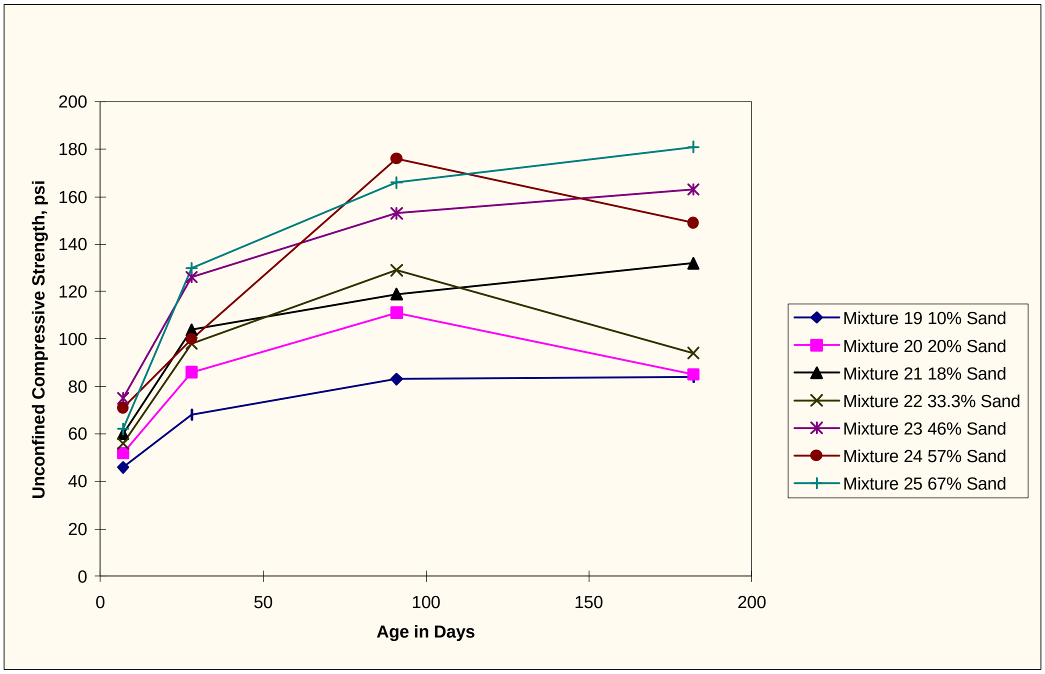

Figure 4
Strength vs. Age Data for CLSM Mixtures Replacing Class F Fly Ash with Sand

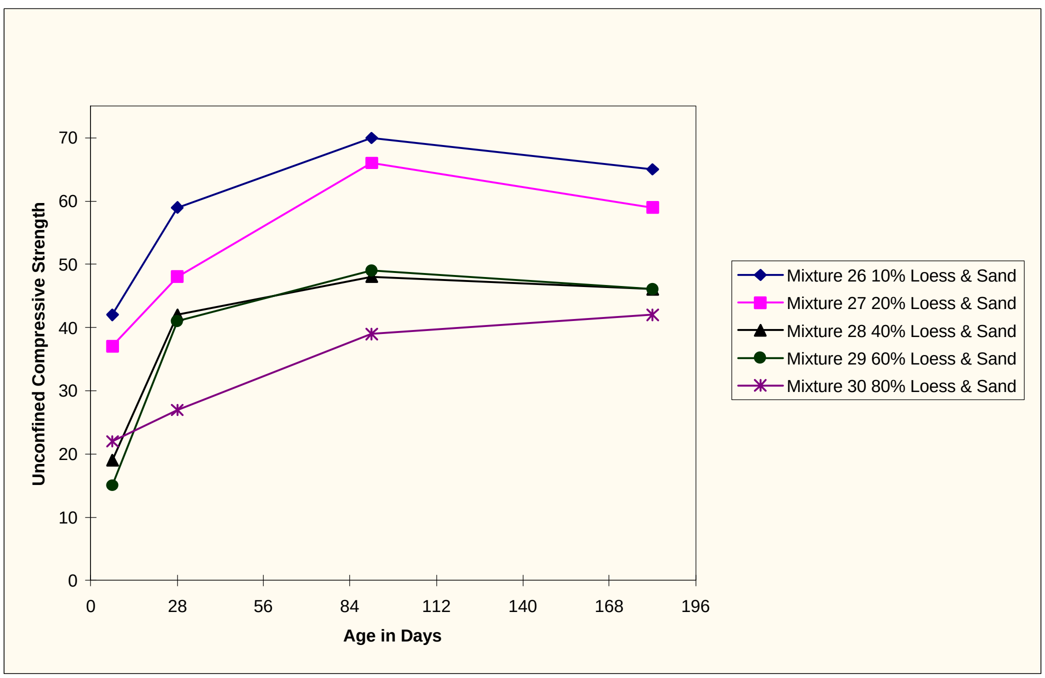

Figure 5
Strength Data for CLSM Mixtures
with Soil and Sand Replacing Class F Fly Ash

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References

1. "Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)." Designation D2487. 1998 Annual Book of ASTM Standards, American Society for Testing and Materials, West Conshohacken, PA., Section 4, Vol. 04.08, 1988.
2. *Cement and Concrete Terminology*. (ACI 116 R-90), American Concrete Institute Farmington Hills, MI, Part 1, 1998. Manual of Concrete Practice,
3. "Controlled Low-Strength Materials (CLSM)." *American Concrete Institute Manual of Concrete Practice*, American Concrete Institute, Farmington Hills, MI. Part 1, No. 229-R 94, 1998.
4. Wayne Adaska, "Controlled Low-Strength Materials," *Concrete International.* Vol. 19, No. 4, p. 41-43 (1997).
5. Amster Howard. "Soil-Cement Slurry Pipe Embedment" *Controlled Low Strength Materials*. American Concrete Institute, Farmington Hills, MI. SP-150 pp. 97-107. 1994.
6. "Standard Practice for Sampling Freshly Mixed Controlled Low-Strength Material."*1998 Annual Book of ASTM Standards*, American Society for Testing and Materials, West Conshohacken, PA. Section 4, Vol. 04.09, Designation D 5971.1998.
7. "Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Controlled Low-Strength Material." *1998 Annual Book of ASTM Standards*, American Society for Testing and Materials, West Conshohacken, PA. Section 4, Vol. 04.09, Designation D 6023.1998.
8. "Standard Test Method for Flow Consistency of Controlled Low-Strength Material." *1998 Annual Book of ASTM Standards*, American Society for Testing and Materials, West Conshohacken, PA. Section 4, Vol. 04.09, Designation D 6103.1998.
9. "Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete." *1998 Annual Book of ASTM Standards*, American Society for Testing and Materials, West Conshohacken, PA. Section 4, Vol. 04.02, Designation C 1064. 1998.