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Flowability and Density Characteristics of Controlled Low Strength Material (CLSM) Using Native High Plasticity Clay

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Abstract

In pipeline construction projects when high plastic clayey soils are encountered in the excavated trench material, they are typically landfilled and better quality materials are imported from outside quarry sources for use as bedding and haunch zone materials. This practice has detrimental environmental and cost impacts; therefore, an efficient reutilization of this high plastic excavated material to produce controlled low strength materials (CLSMs) to use as bedding and haunch zone materials will have major sustainability benefits. As a part of an on-going research study, novel CLSM mix designs were developed by utilizing native high plastic clayey soils from the excavated trench material. Due to the high plasticity nature of the soils, it is essential to address both flowability and density property requirements prior to validating them against other engineering properties. Hence, several CLSM mixtures with the native clayey soils as ingredients were initially designed as per flowability criterion to establish the optimum quantities of chemical binders and water quantities. Later, these mixes were verified for satisfying density property criterion. This technical note presents the step by step procedure followed in preparing these mixes along with test results obtained from various mixes designed as a part of the testing program. Based on these results it was evident that CLSM mixes with high plastic clays can be developed that meet both flowability and density criteria. The success of this research has enhanced the sustainability efforts in pipeline construction projects as this study showed excavated clayey soils canbe successfully reused in CLSM applications than landfilling them.

CE Database subject headings: Flowable fill, Controlled Low Strength Material, CLSM, high plasticity clay, unshrinkable fill, soil-cement slurry.

Introduction and Background

A typical pipeline section can be divided in to three zones bedding, haunch, and backfill. In these three zones, the haunch zone is the most important one where majority of the stress transfer from the pipe material to the underlying layers will take place. It is also difficult to compact this zone due to its location in narrow trenches under the pipe (Brewer and Hurd, 1993). Hence, haunch material for pipeline construction should be strong and stay intact with the pipe section in order to facilitate transfer of stresses to the bedding material (Brewer and Hurd, 1993; Howard, 1996).

Any failure of this material in this role may result in significant stressing between pipe and bedding zone, which may eventually result in tension cracks in the inner section of the pipe (Brewer and Hurd, 1993; Howard, 1990). A chemically treated subgrade material may meet the strength requirements for the haunch material, but it cannot fill the voids effectively around the pipeline due to poor flowability and needs to be compacted. Also, excessive compaction to achieve proper contacts between pipe and haunch material may result in the damage of pipe itself. Other materials including aggregates for bedding support are still practiced, but regions where high quality aggregates are not locally available will lead to use of alternate materials in CLSMs.

Controlled Low Strength Material (CLSM) is a self-compacting cementitious material and is often used in lieu of compacted fill due to its ability to flow and fill the voids without the need of mechanical compaction. CLSM's most typical applications are in bedding and backfilling for pipelines, void filling for underground tanks and basements, and in repair of bridge approaches for road construction projects (Foliard et al., 2008). CLSMs are also known as unshrinkable fill, or controlled density fill, or flowable mortar, or soil-cement slurry in the technical literature (Folliard et al., 2008).

Essentially, the CLSM mix design requires various ingredients including fine aggregates, cement and fly ash and other admixtures. Cement foundry sand or foundry sand, and concrete sand are the most commonly used aggregates for CLSMs and these are standardized by ASTM C 33 (Folliard et al., 2008). Few researchers have attempted to reuse fine cohesive materials available at a construction site in the place of conventional aggregates to produce CLSMs.

Howard and Bowles (2008) have successfully utilized native soil, predominantly silty sand as a fine aggregate in CLSM mix designs for potential utilization as bedding and backfilling materials to support corrugated metal pipes. This pipeline has experienced a deflection of 1% after five years of service, under a 12.2 m (40 ft) cover embedment. Similar studies using local granular materials were also performed by Green and Schmitz (2004), Wu (2005), and Finney et al. (2008) with some success.

Successful implementation of native soil based CLSMs will enhance sustainability aspects of major construction projects by reutilization of large amounts of excavated fine clayey soils especially in the case of long pipeline construction projects, where thousands of cubic meters of excavated local native soils are produced on a daily basis.

A new pipeline construction project in north Texas has been aimed at bringing an additional 350 Million gallons of water per day to serve the future water needs of Dallas-Fort Worth (DFW) metroplex. This pipeline construction project is expected to produce massive amounts of excavated trench material containing highly expansive clayey soil, as the pipeline alignment is primarily located on highly expansive clays in the region. These excavated materials especially when they are expansive in nature, will be utilized in landfills. This research has been focused on the reutilization of these excavated clayey soils in the CLSM mix designs, which has been the major objective of the present research.

Producing CLSMs with native fine clayey soils is a challenging task as fine soils tend to exhibit high moisture affinity properties, low flowability values and low self-compaction properties. Due to these reasons it is important that the flowability and density criteria be first satisfied before testing the material for other properties such as strength and stiffness. Hence, several CLSM mixes with the native clays were initially designed as per flowability criterion to establish the optimum quantities of chemical binders and water quantities and later verified for density.

A target value ranging from 20.3 cm to 30.5 cm was selected for flowability test values while the target density ranged from 14.9 to 18.1 kN/m^3 (95 to 115 pcf) for fresh CLSMs. These target values are typical for CLSM flowability and density for pipeline applications. This paper describes the CLSM mix designs with clayey soils focusing on flowability and density properties. Engineering test results of CLSM mixes and their major findings show that the materials can meet these property specifications (Raavi, 2012). These results are presented in other manuscripts as seen by Chittoori et al. (2014).

Materials and Test Methods

Among the soils located along the proposed pipeline alignment in north Texas, two test soils, Soil-1 and Soil-2 were selected and used in the mix designs. Both soils have been collected from depths between 3.1 to 4.6 m (10 and 15 ft). Soil-1 was classified as high plasticity clay (CH) while Soil-2 was classified as low plasticity clay (CL) as per Unified Soil Classification System (USCS). Using these two soils, two types of fine aggregates were prepared in the CLSM mixes. Type-A CLSM consisted of lone soil-1 material while type-B CLSM consisted of a combination of soil-1 and soil-2 in 1:1 ratio. Type-B fine aggregate was prepared mainly in order to study the effects of reducing the plastic nature of high plastic soil-1 by mixing it with low plastic soil-2.

Lime, fly ash, and cement were primarily used as binder materials; their proportions vary for each mixture designed in the present research. Some mixtures used cement or lime binders, while others used a combination of cement and lime additives, or cement and fly ash additives and these details are given in later sections. Type I Portland cement (ASTM C150 / C150M – 12) was selected due to its common availability and its role in enhancing the strength of the mix. CLSMs produced with Class C fly ash achieve a higher compressive strength than Class F fly ash (Trejo et al., 2002). Hence, Class C fly ash was used in varying proportions to reduce the amounts of cement quantity needed in the CLSM mixes, and as a result, this mix design may lower the overall CLSM's production costs due to utilization of cheaper fly ash materials. In the case of lime products, quicklime (calcium oxide, CaO) was used as it comes in a dry powder form and is easily transportable.

Set accelerators are chemical admixtures that improve the hardening rate of a cementitious material. A cementitious mix treated with such admixtures has improved strength values at early stages of maturation, and this lowers the setting time of a mixture. A non-chloride set accelerator Calcium Formate ($C_2H_2CaO_4$), was used as this type of admixture does not corrode metals, and hence can be used in a pipeline construction project. Visually, this admixture appears as a white crystalline powder, and it is easily soluble in water medium.

Due to a large number of soil and binder variables used in the present mixes, the following notation system is adapted to identify each CLSM prepared in this study. For example, in the notation of A_C5L10_S1 mixture, the first letter "A" indicates the type of fine aggregate (CH only) used; and the second part (C5L10), indicates the binders used and their approximate proportions by percent of dry weight of soil (fine aggregate). In this case a combination of 5% of cement ("C" and "5") and 10% of lime ("L" and "10") are used as binders. The third part of the notation begins with the letter "S" indicating that a set accelerator additive was used in the mix; the symbol "S1" indicates that eight percent of set accelerator additive by dry weight of binder is used. Table 1 lists various notations used in the CLSMs prepared in this research while Tables 2 and 3 present all the mix designs attempted in this research using type-A and type-B materials, respectively.

Specimen Preparation Procedure

The preparation of CLSMs is based on the methodology proposed by Folliard et al. (2008). In order to obtain a uniform soil-binder mixture, soil samples collected from the field were first oven dried at 60°C and then pulverized to obtain soil fraction passing through the U.S. standard sieve No. 40 (0.425 mm). The necessary amounts of dry soil and chemical binder for the mix design were weighed and mixed. If the binder is a combination of more than one component (lime, cement or fly ash), they were mixed in dry conditions separately and then mixed with the soil.

The water content, which was approximately 30% by dry weight of soil, was added separately to the soil at the time of mixing, along with the water content needed for the mix design. It should be noted here that the field procedures for the same CLSM preparation process might be slightly different from the laboratory practice as it is hard to maintain the same level of control on particle size and water contents in the field studies and this should be investigated in future studies.

Flowability and Density Test Procedures

The flow test was performed as per ASTM D 6103-97 and Figure 1 presents pictorial representation of the variations in flow diameter with water content for A_C6 CLSM mix. Several preliminary CLSM mixes for both type-A and type-B materials were prepared and these mixes were subjected to flowability tests to determine whether these mixes have the necessary water content to achieve a targeted flowability value of 203 to 305 mm (8 to 12 in.). Trials were initiated with the water content that was equal to the liquid limit of soil-1 for type-A material with fixed cement amount (6%). Thus the initial water content of the mixes containing type-A material was 64%, and the same for mixes with type-B material was 50% since this material contained partial amount of high plasticity soil-1.

Flowability tests were conducted on these initial mixes and if the flowability values of the mixes did not meet the targeted values, new mixes were prepared using higher moisture contents by raising the moisture content levels by increments of 1%. Tests were repeated until desired flowability value was met. For the preliminary mix using type-A material as fine aggregate, a water content of 72% resulted in a flowability value of 211 mm (8.3 in.) and for the mix using type-B material, a water content of 50% provided a flowability value of 206 mm (8.1 in.).

The density testing apparatus used included a sensitive balance, a filling apparatus, a sampling and mixing receptacle, measuring vessel, and a straight edge. A mixing receptacle and a pail of sufficient capacity facilitated filling of the measuring vessel. The container was a water-tight and sufficiently rigid to retain its form when filled with CLSM. ASTM D 6023-94 method specifies that the ratio of height and diameter of the measuring vessel should be between 0.80 and 1.50; and for this research, the ratio of height to diameter of the measuring vessel is approximately equal to one, and the capacity of the measuring vessel is calibrated as per ASTM C 29 procedure. The density test was performed when the CLSM samples were in wet state. During testing, it was ensured that the surface holding the measure was leveled, and the sample was free from vibrations and disturbances. For each mix, both flowability and density tests were repeated twice and the average values were calculated and reported.

Test Results and Discussion

Flowability Tests

Tables 5 and 6 present the results of the flow tests for all CLSM mixes using type-A and type-B materials respectively. These tables also include statistical variations for each soil tested in this research and it can be observed from the tables that the standard deviation is less than 7.6 mm (0.3 in.) indicating that the flow values did not deviate much from each test result; this indicates that the tests performed are repeatable.

Figure 2a presents the variation of flowability values with cement binder dosage for both type-A and type-B materials. It can be observed from the figure that as the binder content increased the flowability values also increased for the same moisture content. This is expected as the increase in binder content reduces the amount of fine aggregate (clayey soil) and there by improves the flowability.

In order to study the effects of binder type on flowability, test results from both lime-cement and cement-fly ash combination mixes are compared for both type-A and type-B fine aggregates in Figure 2b. It can be observed from the figure that binder type did not have any influence on type-A fine aggregate but for type-B the flowability increased with fly ash when compared to lime additive. This can be attributed to the finer particle sizes of fly ash when compared to lime additive which resulted in the cement-fly ash CLSM to flow better during testing. However, for the high plastic soils, the binder particle size is not affecting flow as the plasticity of the soil is controlling the flow for all tests. Further studies using soils with wide range of plasticity index values are required to understand this phenomenon.

Figure 3a and Figure 3b present the effect of set-accelerator treatment on the flowability of both CLSM mixes. It can be observed from these figures that, irrespective of the fine aggregate type, when set accelerator is added, the flow test provided lower or equal result when compared to the same mixes without set accelerator. This can be attributed to the hardening effects of the set accelerator used. However, as shown in the figures, the differences are minimal as the measurements of the flowability were taken before the set accelerator could alter and influence the mix properties.

Density Tests

The density tests were conducted on fresh CLSMs as well as after 7 day and 28 day curing conditions. These results are presented in Table 7 and Table 8 for CLSM mixes with type-A and type-B fine aggregates, respectively. All these mixes met the target density values of 14.9 to 18.1 kN/m^3 (95 to 115 pcf) for fresh CLSMs. These target density values are typical CLSM densities required for pipeline trench application.

For all the tested mixes used in this research, it was observed that density values decreased as the specimens' maturation progressed. The chemical reactions that caused water absorption could be responsible for this behavior. Due to the presence of high amounts of silt in the CLSM mixes with type-A material, these mixes appear to be less dense when compared to those with type-B material. Density measurements were also made for the mixes that utilized set accelerator and it was observed that set accelerator had no influence on the density measurement.

Sustainability Assessments

One main reason for undertaking this research study to producing CLSMs with native clays is that if successful in producing high plastic clay based CLSMs that meet all property requirements, then major material landfilling can be avoided by reusing the excavated clayey material for mass CLSM productions. This will also result in major environmental and economic savings in a construction project. Other benefits including societal benefits by reducing air pollution issues from the use of crushed aggregate materials to lesser impacts to local roads near the pipeline construction projects can be accomplished.

Summary and Conclusions

The present research developed a total of twenty four (24) CLSM mixes, using both high plasticity clay soil, and mixture of high and low plasticity clays along with different types and dosages of chemical binders comprising of cement, lime, and fly ash binders. A few of these mix designs used a set accelerator to improve the setting time periods. All these mixes were subjected to flowability and density tests and these test results are summarized in this paper. The following are the conclusions made from this research investigation:

- This research study showed that the CLSMs can be designed with both native high plasticity clays and with the combinations of high to low plasticity clay mixtures to satisfy flowability and density considerations.
- Flowability test results indicated low standard deviation values, which are less than 7.6 mm (0.3 in.), showing that the flow values did not deviate much from each individual test results.
- For the preliminary mixes using type-A fine aggregate, a water content of 72% resulted in a flowability value of 211 mm (8.3 in.) and for the mixes using type-B fine aggregate, a water content of 50% provided a flowability value of 206 mm (8.1 in.).
- The effect of set-accelerator treatment on the flowability of the present CLSM mixes appears to be either low or similar results as the mixes without set accelerator. This can be attributed to the hardening effects of the set accelerator used.
- Density values of all tested mixtures meet the property requirements needed for pipe backfill or haunch zone material specifications.
- Pipeline construction projects can see major sustainability benefits as the preparation of CLSMs with native soils will be cost effective and environmentally sound solution than dumping the excavated material in the landfills. Further engineering assessments of the mixtures will enhance the use of the CLSMs in real field applications.

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Table 1 Symbols Adopted for the CLSM Mixes Notations

Symbol	Material and Quantity	Ingredient Role
A	Type-A fine aggregate (Soil-1 alone)	Aggregate
B	Type-B fine aggregate (Soil-1:Soil-2 = 1:1)	
C	% Cement by dry weight of soil	Binder
L	% Lime by dry weight of soil	
F	% Fly Ash by dry weight of soil	
S1	8% Set accelerator by dry weight of binder	Additive

Table 2 CLSM Mix Designs Attempted Using Type-A Fine Aggregate

Mix	Aggregate (kg/m^3)		Water		Binder			Admixture
	CH	CL	% by dry weight of mix	Mass (kg/m^3)	Cement (kg/m^3)	Fly Ash (kg/m^3)	Lime (kg/m^3)	Set accelerator (kg/m^3)
A_C6	1,056	0	72	810	69	0	0	0
A_C10			72	836	105	0	0	0
A_C15			72	872	155	0	0	0
A_L20			74	937	0	0	210	0
A_C5L10			74	898	52	0	105	0
A_C5L15			74	936	52	0	157	0
A_C5L20			76	1,002	52	0	210	0
A_C5F20			72	949	52	210	0	0
A_C10_S1	1,056	0	72	842	105	0	0	8
A_C15_S1			72	883	158	0	0	13
A_C5L10_S1			74	950	70	0	141	17
A_C5L15_S1			74	964	70	0	158	18

Table 3 CLSM Mix Designs Attempted Using Type-B Fine Aggregate

Mix	Aggregate (kg/m^3)		Water		Binder			Admixture
	CH	CL	% by dry weight of mix	Mass (kg/m^3)	Cement (kg/m^3)	Fly Ash (kg/m^3)	Lime (kg/m^3)	Set accelerator (kg/m^3)
B_C6	528	528	54	608	69	0	0	0
B_C10			54	627	105	0	0	0
B_C15			54	654	155	0	0	0
B_L20			62	779	0	0	201	0
B_C5L10			58	721	52	0	135	0
B_C5L15			59	765	52	0	189	0
B_C5L20			60	810	52	0	242	0
B_C5F20			59	778	52	210	0	0
B_C10_S1	528	528	54	627	105	0	0	8
B_C15_S1			54	654	155	0	0	12
B_C5L10_S1			58	721	52	0	135	13
B_C5L15_S1			59	765	52	0	189	17

Table 4 Flow Test Results for CLSM Mixes with Type-A Fine Aggregate

Mix	Flowability, (mm)	Standard Deviation (mm)	Coefficient of Variation (%)
A C6	210.8	3.6	1.69
A_C10	241.3	3.6	1.47
A_C15	247.6	5.3	2.15
A_L20	222.2	1.8	0.8
A_C5L10	231.1	3.6	1.53
A_C5L15	229.9	1.8	0.77
A_C5L20	227.3	1.8	0.78
A_C5F20	228.6	0.0	0.00
A C10 S1	241.3	0.0	0.00
A_C15_S1	229.9	1.8	0.77
A_C5L10_S1	220.9	3.6	1.61
A_C5L15_S1	222.2	5.3	2.4

Table 5 Flow Test Results for CLSM Mixes with Type-B Fine Aggregate

Mix	Flowability, (mm)	Standard Deviation (mm)	Coefficient of variation (%)
B C6	238.8	7.1	2.98
B_C10	251.5	3.6	1.41
B_C15	262.9	1.8	0.67
B_L20	229.9	5.3	2.32
B_C5L10	233.7	0.0	0.00
B_C5L15	229.9	5.3	2.32
B_C5L20	219.7	1.8	0.81
B_C5F20	238.8	7.1	2.98
B C10 S1	246.4	0.0	0.00
B_C15_S1	254.0	3.6	1.40
B_C5L10_S1	229.9	5.3	2.32
B_C5L15_S1	223.5	3.6	1.59

Table 6 Density Measurements for CLSM Mixes with Type-A Fine Aggregate

Mix Designation	Fresh Density (kN/m^3)	7-day Density (kN/m^3)	28-day Density (kN/m^3)
A_C10	14.9	14.3	14.0
A_C15	15.4	14.8	14.6
A_L20	15.1	14.4	14.6
A_C5L10	15.2	14.6	14.8
A_C5L15	15.2	14.6	14.8
A_C5L20	15.2	14.6	14.6
A_C5F20	15.5	14.9	14.9
A_C10_S1	14.9	14.1	14.0
A_C15C_S1	15.4	14.4	14.1
A_C5L10_S1	15.2	14.4	14.4
A_C5L15_S1	15.2	14.4	14.4

Table 7 Density Measurements for CLSM Mixes with Type-B Fine Aggregate

Mix	Fresh Density (kN/m^3)	7-day Density (kN/m^3)	28-day Density (kN/m^3)
B_C10	16.3	16.0	15.7
B_C15	16.3	15.9	15.7
B_L20	15.9	15.2	15.2
B_C5L10	16.3	15.9	15.9
B_C5L15	16.0	15.7	15.7
B_C5L20	15.9	15.2	15.5
B_C5F20	16.3	15.9	15.9
B_C10_S1	16.3	15.9	15.7
B_C15_S1	16.2	15.7	15.5
B_C5L10_S1	16.3	15.9	15.7
B_C5L15_S1	16.2	16.0	16.0

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