A Study of Different Materials Used, Suggested Properties and Progress in CLSM

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Abstract - - *Cement mortar and concrete are not processed only with strength as the governing factor. Workability is the main property required than strength for many applications. With the recognition of the significance of sustainable development, CLSM technology has come forth as a practical means of safely and effectively using by-products and waste materials in infrastructure applications. This paper summarizes the advantages, applications, materials used, and properties, mix proportions, placing techniques, various tests on CLSM and the recent advancements in the field of CLSM.*

***Key Words*: Controlled Low Strength Materials (CLSM), Unconfined Compressive Strength, Portland cement, Fly ash**

1. INTRODUCTION

Soil backfilling is the most usual practice followed after all types of excavation. Generally, material is dumped into the ditch without proper compaction. The U.S. Bureau of Reclamation (1964) documented the first known use of controlled low-strength material (CLSM). The main application of CLSM was as the bedding material for 515 km long pipe line in the Canadian River Aqueduct project by the US Bureau of Reclamation. The Detroit Edison Company along with Guhlman Corporation, a ready mix concrete producer, developed a backfill material called flowable fly ash, made of fly ash with 4% to 5% cement in 1970. Later a company known as K-Krete Inc was started and patented K-Krete as CLSM in 1977. Subsequently, other materials were developed as a replacement for conventional soil backfill and used throughout United States and Canada. To publicize all, ACI Committee was established in 1984 under the title Controlled Low Strength Material (CLSM) and a report was published in the year 1994. Successively, first revision was made in the year 1999 followed by second revision in the year 2005.

Controlled low-strength material (CLSM) is a self-compacted, cementitious material utilized mainly as a backfill in place of compacted fill. Several terms are presently used to label this material like flowable fill, un-shrinkable fill, controlled density fill, flowable mortar, flowable fly ash, fly ash slurry, plastic soil-cement, soil-cement slurry. According to ACI 229R (2005) Controlled low-strength materials are defined as materials that result in a compressive strength of 8.3MPa or less. An unconfined compressive strength of 2.1MPa or less is essential when impending excavation of CLSM is likely while maximum of 8.3 MPa permits the use of this material where future excavation is unlikely.

2. ADVANTAGES

The pros of using CLSM are:

- CLSM can be made by utilizing the locally available means to meet majority of the project specifications.
- CLSM can be easily transported to the job site with the help of truck mixers.
- CLSM can be placed handily by a chute, conveyor, pump, or a bucket. As CLSM is self-leveling, it requires little or no spreading or compacting. This speeds construction and reduces labor requirements.
- CLSM can be adjusted to have higher bearing capacities than that of compacted soils or granular fills. They are less permeable and hence less prone to erosion.
- CLSM mixes can be adjusted to improve flowability, strength, setting time with the help of admixtures etc.
- As is the case in compacted soils, CLSM does not settle under loading.
- CLSM is self-compacting, thus eliminates widening of narrower trenches to provide for compaction equipment. This reduces the excavation costs.
- The worker's safety is improved as CLSM can be placed in a trench without actually entering it.
- CLSM displaces any water existing in a trench or pit due to rains or melting of ice, thereby decreasing the pumping out cost. Also, CLSM can be heated with the methods for heating ready-mixed concrete to place the CLSM in cold weathers. This enables all weather construction using CLSM.
- CLSM with compressive strengths between 0.3MPa to 0.7MPa can be dug effortlessly with conventional digging tools. Yet these are stronger than compacted backfill soil.
- Soil backfill must be checked for proper compaction during its placement. As CLSM is self- compacting

and does not form voids during its placement, it involves less inspection and field testing during its placement.

- CLSM can be placed without the use of loaders, tampers, compactors. Thus, reduces the equipment requirements.
- CLSM can be supplied to the site in truck mixers in required quantities. This eliminates the necessity of storing the materials at the job site.
- Industrial by-products like cement kiln dust, asphalt dust, coal fly ash, coal bottom ash and quarry waste are used in making CLSM there-by helping the environment.

3. APPLICATIONS

The various advantages of CLSM enable it to be used not only for backfilling but also for structural filling, insulation fills, isolation fills, conduit bedding, erosion control, pavement bases, void fillings, nuclear facilities and underground construction.

Following are the main application areas of CLSM:

- *Backfills:* As CLSM is self-compacting, self-leveling, it can be easily placed in a narrow space. CLSM when used as a backfill, can be placed in layers, allowing each layer to harden, to reduce the fluid lateral pressure exerted on the retaining wall.
- *Structural fills:* CLSM can be used as foundation sub-base, sub-footing, floor slab base, pavement bases and conduit bedding for weak soil, uneven or non-uniform sub-grades.
- *Insulating and isolation fills:* Low density CLSM is produced using preformed foam that gives stable air voids within the CLSM paste mix. The air voids present in such CLSM mixes provides thermal insulation, shock resisting properties to the fill materials.
- *Pavement bases:* CLSM can be used for pavement bases, sub-bases and sub-grades. However, in such a case, good drainage should be provided. Also, a wearing surface should be provided as it is relatively less wear- resistant.
- *Conduit bedding:* Owing to its flowable characteristics, CLSM can occupy the space below the conduit providing uniform pipe bedding. Enclosing the entire conduit in CLSM keeps the conduit from future damage. It can also be designed to provide corrosion resistance beneath the conduit.
- *Erosion control:* CLSM is used to seal voids in pavements, sidewalks, bridges and other structures where natural soil or non-cohesive granular fill has eroded away. It can also protect embankment and spillways by holding the rock pieces in-place and resist erosion.
- *Void filling:* CLSM can be filled in abandoned tunnels, sewers, basements, underground structures, mines etc. to eliminate access, cut-off the oxygen supply for fires, reduce acid or other harmful drainage, prevent subsidence, block trespassers entry.
- *Nuclear facilities:* CLSM is used for waste stabilization, sealing of abandoned pipelines and tanks, new landfill construction and a wide variety of chemical and radioactive stabilization requirements.

4. MATERIALS

Normally, CLSM mixtures include water, Portland cement, fly ash or other similar by-products and fine or coarse aggregates or both. Some mixtures consist of water, Portland cement and fly ash only.

Special low density CLSM contain water, Portland cement and preformed foam. Use of air entraining admixtures improves the insulating properties and reduce the density of CLSM. Water content can be reduced and hardening can be hastened by using water reducing admixtures. Chemical or mineral additives can also be added to CLSM to serve specific purposes. For example, bentonite produces low permeable CLSM, magnetite/hematite fines produce radiation shielding CLSM.

The materials used in CLSM mixtures need not always meet the regular requirements. Their selection should be based on availability, cost and precise application. However, pretesting of the materials is required to check their acceptability. Also, in some cases, environmental regulations are required for the qualification of the raw material or CLSM mixture, or both, before use. The nonstandard materials that have been used include bottom ash, kiln dust, coal combustion products, discarded foundry sand, Quarry dust, glass cullet, recycled concrete aggregate, industrial by-products, solid wastes/by-products from paper mills, excavated soil, Cinder Aggregates, Wood Fly Ash.

5. PROPERTIES

- *Flowability:* Flowability of CLSM allows it to flow, fill a void, self-compact and self- level, thus setting it apart from other fill materials. The high flowability of CLSM results in hydrostatic pressure. Where fluid pressure and flotation of pipes is of concern, CLSM can be placed in layers, with each layer being allowed to harden before placement of the next. Also, proper anchorage should be provided.

The flowability of CLSM can be measured using the traditional slump cone test (ASTM C 143) or slump flow test as per ASTM D 6103. CLSM should have a slump flow of at least 200 mm without segregation using the ASTM D 6103 or a slump value of at least 150 mm using ASTM C 143.

- *Segregation:* Separation of components in highly flowable CLSM mixtures can be avoided by adding fines that provide suitable cohesiveness.

- *Subsidence:* Subsidence is the reduction in the volume of CLSM when water and entrapped air are released from the mixture. The water used for flowability, when exceeds than that needed for hydration, is released to the surface as bleed water. Most of the subsidence occurs during placement and the degree of subsidence is dependent upon the quantity of free water released. Mixes of lesser water content experience little or no subsidence.

- *Setting and early strength:* This is important where traffic or construction loads must be carried or where the succeeding construction has to be planned. Hardening time can be as brief as 1 hr, but generally takes 3 to 5 hr under normal conditions. The setting characteristics are judged by scraping off loose accumulations of water and fines on the top and how much force is necessary to cause an indentation in the material. Penetration values by ASTM C 403 between 500 psi and 1500psi are adequate for loading flowable fill.

- *Strength:* The load carrying capacity of CLSM is given in terms of its Unconfined Compressive Strength. For manual excavation, the ultimate strength should be less than 0.3MPa. For excavatability by mechanical equipment, the strength must be kept below 1.4MPa.

  A compressive strength of 0.3 to 0.7 MPa provides a bearing capacity similar to well compacted soils.

- *Density:* A CLSM of fly ash, cement, and water only should have a density between 1440 to 1600 kg/m3 whereas one with ponded ash or basin ash must be in the range in the range of 1360 to 1760 kg/m3. Dry density of CLSM can be less than that of the wet density due to water loss. With the use of lightweight aggregates, air-entraining admixtures and foamed mixtures lower unit weights can be achieved.

- *Settlement:* A CLSM mixture should not show measurable shrinkage or settlement after hardening.

- *Thermal insulation:* CLSM mixtures with lower densities have higher insulating values than the conventional CLSM mixtures. With the use of air-entrained admixtures, lightweight aggregates, foamed or cellular mixtures, the density of CLSM can be reduced and improve the insulating properties.

  In order to increase the thermal conductivity of the CLSM mixture, it should have high density and low porosity.

- *Permeability:* The typical values of permeability of excavatable CLSM should be in the range of 10-4 to 10-5 cm/sec. CLSM mixtures with high strength and higher fines can have permeability as low as 10-7cm/sec.

- *Shear modulus:* The expected shear strength and deformation of CLSM material depends on the shear modulus which is defined as the ratio of shearing stress to shearing strain. The Shearing modulus typically should be in the range of 160 to 380 MPa.

6. MIXTURE PROPORTIONS

CLSM proportioning is largely done by trial and error until mixtures with suitable properties are achieved. The trial mixtures should be evaluated to determine the needs of strength, flowability and density. Adjustments can then be made to achieve the desired properties.

7. MIXING, TRANSPORTING AND PLACING

Mixing: Whatever methods and procedures are used, the primary conditions to be satisfied are that the CLSM mixture is homogeneous, consistent and satisfy the requirements for the intended use.

CLSM can be mixed by several methods which include central-mixed concrete plants, ready-mixed concrete trucks, pugmills, and volumetric mobile concrete mixers. For CLSM mixtures with fly ash, cement, water and no aggregate, filler truck mixers as well as in-plant central mixers can be used. Pugmills are used for both high and low fly ash mixtures and other high fines-content mixture.

Transporting: Usually, CLSM mixtures are transported in truck mixers. During transportation, CLSM must be kept agitated, and the material should be kept in suspension. CLSM is also transported effectively by pumps and other types of conveying equipments.

Placing: CLSM can be placed by chutes, conveyors, buckets or pumps depending on the purpose and its accessibility. CLSM is self-compacting and consolidates under its own weight. The mixture should be protected from freezing until it hardens. For trench backfill, CLSM is usually placed continuously. For pipe bedding, CLSM is placed in layers to prevent floating of the pipe. Each layer should be allowed to harden before placement is continued. CLSM should also be placed in layers when used as a backfill to avoid overstressing of the retaining wall. CLSM has been effectively placed under water without significant segregation. CLSM can fill voids and cavities in in-accessible places. The voids need not be cleaned as CLSM fills the irregularities and can trap any loose material.

8. QUALITY CONTROL

The American Society for Testing and Materials (ASTM) has introduced the following tests to help monitor the consistency and quality of CLSM produced. They are:

A. Tests for consistency

For Fluid mixtures

ASTM D 6103 "Standard Test Method for Flow Consistency of Controlled Low Strength Material." procedure consists of placing 75 mm diameter x 150 mm long (3 in. diameter x 6 in. long) open ended cylinder vertically on flat surface and filling cylinder to top with CLSM. Cylinder is then lifted vertically to let the material to flow out onto level surface. Good flowability is attained when there is no noticeable segregation and material spread is at least 200 mm in diameter. The flow data is synthesized to arrive at relative flow area (RFA) which is calculated from the relation:

$$RFA= (D^2-75^2)/(75^2)=(D/75)^2-1$$

where D is the average diameter of the mix spread in mm.

RFA should be in the range of 5-15 for the CLSM to be self-flowing and self-leveling.

ASTM C 939 "Flow of Grout for Preplaced-Aggregate Concrete." Florida Department of Transportation and Indiana Department of Transportation specifications require efflux time of 30 sec ±5 sec. this procedure is not recommended for CLSM mixtures containing aggregates greater than 6 mm.

For Plastic mixtures

ASTM C 143 "Slump of Portland Cement Concrete."

B. Tests for unit weight

ASTM D 6023 "Standard Test Method for Unit Weight, Yield and Air Content (Gravimetric) of Controlled Low Strength Material."

ASTM C 1152 "Acid Soluble Chloride in Mortar and Concrete."

ASTM D 4380 "Density of Bentonitic Slurries." Not recommended for CLSM containing aggregate greater than 1/4 in.

ASTM D 1556 "Density of Soil In-Place by Sand-Cone Method."

ASTM D 2922 "Density of Soil and Soil Aggregate In-Place by Nuclear Method (Shallow Depth)."

C. Tests for in-place density and strength of clsm mixture

ASTM D 6024 "Standard Test Method for Ball Drop on Controlled Low Strength Material to Determine Suitability for Load Application." This specification involves determination of capability of CLSM to withstand loading by repeatedly dropping metal weight onto in-place material.

ASTM C 403 "Time of Setting of Concrete Mixtures by Penetration Resistance." This test measures degree of hardness of CLSM. California Department of Transportation requires penetration number of 650 before allowing pavement surface to be placed.

ASTM D 4832 "Preparation and Testing of Soil-Cement Slurry Test Cylinders." This test is used for molding cylinders and determining compressive strength of hardened CLSM.

ASTM D 1196 "Non-repetitive Static Plate Load Tests of Soils and Flexible Pavement Components for Use in Evaluation and Design of Airport and Highway Pavements." This test is used to establish the Modulus of Subgrade Reaction (K values).

ASTM D 4429 "Bearing Ratio of Soils in Place." This test is used to determine relative strength of CLSM in place.

9. LATEST ADVANCEMENTS

Some of the advancements in CLSM technology include:

- Use of a variety of industrial by-products and recycled materials in mixtures such as recycled concrete aggregate, recycled glass, fly ash, bottom ash, pond/basin ash, used foundry sand and slag.
- Use of colored dyes in CLSM for identification of fill over buried facilities and utilities.
- Quick setting CLSM for road cut closures in high traffic areas.
- Low-density CLSM is produced with introduction of "air" to reduce the unit weight of the mixture. This improves the properties of thermal insulation and shock mitigation for the fill material. This is also advantageous where weak soil conditions are encountered and the weight of the fill must be minimized.

10. CONCLUSIONS

The use of CLSM as a backfill and void filling material is widespread throughout the world. The engineering properties and economical attributes of CLSM are making it the most preferred alternative for many applications. Advantages of CLSM offer the engineer and constructor to answer the numerous challenges faced during construction and maintenance of today's civil infrastructure.

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