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ABSTRACT

This paper presents a summary of new innovations and the state-of-the-art of Controlled Low Strength Materials (CLSM) in North America. CLSM is defined as a self compacted, cementitious material used primarily as a backfill in lieu of compacted fill which results in a compressive strength of 1200 psi (8 Mpa) or less. CLSM encompasses a whole family of low strength fill materials and has been known by many other names.

The American Concrete Institute Committee 229 published a report in 1994 that has been very helpful in communicating information on material properties, testing, applications, and experience with these materials(10). The American Society of Testing Materials (ASTM) has also issued four provisional standards on testing CLSM (16-19).

Recent innovations include the use of recycled materials such as glass and foundry sand, increased air content, color for rapid identification of buried utilities, blended coal ash, and non-spec./off-spec. aggregates and fly ash. This paper describes the advantages of CLSM use as well as some "lessons learned" in practice.

CLSM is being frequently used as a backfill and void filling material in many locations across the U.S. and Canada. CLSM's predictable engineering properties and labor saving attributes are making it the material of choice for many applications. CLSM provides the engineer and constructor with another tool to help solve the many challenges of constructing and maintaining today's civil infrastructure.

Keywords: Class C Fly Ash, Class F Fly Ash, CLSM, Controlled Low Strength Material, compressive strength, excavatability, flowability, and mix proportions.

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Introduction: Low strength fill mixtures which consist primarily of fly ash, fine and/or coarse aggregates and a small amount of portland cement are being used increasingly in the construction industry and fall under the classification of Controlled Low Strength Materials (CLSM). This paper describes the materials used, mixture proportions, placing techniques, construction experience, quality control and some cautions to be considered on projects.

ACI Committee 229 has prepared a report on Controlled Low Strength Materials and this paper includes comments on recent developments in the industry since it's publication in 1994.

CLSM is being frequently used as a backfill and void filling material in many locations across the U.S. and Canada. CLSM's predictable engineering properties and labor saving attributes are making it the material of choice for many applications. CLSM provides the engineer and constructor with another tool to help solve the many challenges of constructing and maintaining today's civil infrastructure.

The following is a brief summary of some key considerations for the specifier, producer and owner of projects utilizing low strength CLSM fill mixtures. Low strength mixtures are often used for backfill where later excavatability is required. Remember that 100 psi (0.7 Mpa) in concrete compressive strength translates to 14,400 psf (700 kPa) in soil terms. This level of soil strength is comparable to many compacted structural fill materials(1), where typically compacted sand backfill provides bearing capacity of about 3,000 psf (140 kPa).

Literature Review: A comprehensive bibliography on the use of controlled low strength materials was recently (1992) published in ACI Concrete International magazine (2) and therefore will not be repeated here. Two additional papers on medium to high strength CLSM fly ash slurry work at Wisconsin Electric Power Company using ASTM C 618, (Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete) Class C or F fly ash for sub-structural and backfill applications have also been reported (3,4). Several references have also been included on the thermal conductivity, corrosion potential and compatibility with plastics (5-12). A recent paper from Turkey discusses the benefits of lime addition to low calcium fly ash and the production of CLSM without portland cement (13).

Materials: Standard concrete making materials are often used for production of low strength CLSM fill mixtures because they are readily available at ready mixed concrete batch plants. However, many non-standard materials can also be considered that yield the required short term and long term physical and environmental requirements for a project. It is very important that the producer be knowledgeable of the properties of the materials to be used to meet the needs of the project. This includes consideration for maximum ultimate strength if re-excavation is required, compatibility with encased utility lines or other contact materials, set time required, and other project specific requirements. There is no substitute for specific material performance knowledge and experience. Non standard materials such as off-spec fly ash, sand, gravel, used foundry sand, iron slag, bottom ash, glass cullet, and other granular materials have been successfully employed in production of CLSM. Consideration to potential corrosion, thermal conductivity, and any constituents requiring environmental scrutiny is essential to the long term success of a project.

Mixture Proportions: Mixture proportions are normally determined by trial batches to yield the required flowability, strength, and environmental properties required. ACI 229 provides several examples of mixtures that have been used. These examples are not substitutes for having knowledge of the specific component materials to be employed in mixtures but serve as an aid in providing a starting point for your own trial batch recipes. The following two mixtures are being used by Wisconsin Electric for backfill around underground utilities and filling of abandoned underground facilities. Values shown are by percent of total weight as delivered.

Flowable Fly Ash Slurry	Flowable Fly Ash/Sand Slurry
	39% Sand
56% Class F Fly Ash	31% Class F Fly Ash
40% Water	28% Water

4% Portland Cement	2% Portland Cement

Placing Techniques: A wide variety of standard concrete construction equipment can be employed based on the needs of a project. Concrete pumps, ready mixed concrete trucks, portable batch plants, and volumetric mobile mixers are commonly used. Spillage and splashing should be considered on very flowable mixtures during transit and placement. Also, segregation of CLSM with coarse aggregate materials can be a consideration on very wet (high water content) mixtures that are expected to flow long distances.

Construction Experience: Low strength CLSM fill mixtures can provide construction savings by eliminating the need for labor intensive compaction efforts with standard granular materials. It is important to understand that CLSM is placed as a liquid and thus will yield a hydrostatic pressure against basement walls and other structures until it hardens. On deep fills, it may be necessary to place the CLSM in multiple lifts. Another construction caution is that fresh liquid CLSM that has been placed into a deep excavation is essentially a "quick- sand" hazard until the material hardens and must be protected from accidental entry. Probably the most common error of specifiers is to specify low strength CLSM fill mixtures with a minimum compressive strength similar to concrete. Low strength CLSM fill mixtures, where re-excavation will be required at some later date, should be specified with a maximum strength (or a range of strength, i.e. minimum 75 psi (0.5 MPa) to 150 psi (1.0 MPa) at 28 day age) that will allow for easy re-excavation with the equipment to be employed. Re-excavation around underground utilities must be done with extreme care and hand tools thus necessitating a very low strength easily excavatable material.

Other benefits of construction include: easy placement via chute, pump, bucket or conveyor; self compaction, virtually no settlement, flowing into areas with complete compaction that would otherwise be difficult or impossible to reach and compact, placement without sending workers into trenches, reduced equipment needs (i.e., rollers, tampers and loaders), low density mixtures with fly ash and air, and use of by-product materials rather than mining virgin resources.

Quality Control: The American Society for Testing and Materials (ASTM) has introduced four provisional standards to help monitor the consistency and quality of CLSM being produced and delivered. They include:

PS 28 Provisional Standard Test Method for Flow Consistency of Controlled Low Strength Material.

PS 29 Provisional Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Controlled Low Strength Material.

PS 30 Provisional Standard Practice for Sampling Freshly Mixed Controlled Low Strength Material.

PS 31 Provisional Standard Test Method for Ball Drop on Controlled Low Strength Material to determine Suitability for Load Application.

Comments on experience with these provisional standards has been requested by the ASTM Committee responsible for these standards for consideration prior to issuance as regular ASTM standards. Other quality control requirements may be specified depending on the need for source material monitoring and project requirements.

Recent Developments: There are numerous developments in CLSM technology that include:

New methods and products for the introduction of "air" in significant quantities to reduce the material density, extend the raw materials, and improve the thermal insulating properties when dry.

Introduction of colored dyes in CLSM for physical identification of fill over buried facilities and utilities.

Rapid setting CLSM for efficient road cut closures in high traffic areas.

Utilization of various 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.

Corrosion, Thermal Conductivity and Compatibility with Plastics:

The corrosion potential of CLSM has been quantified by a variety of methods specific to the material that is in contact with CLSM. Electrical resistivity tests can be performed on CLSM in the same manner that natural soils are compared for their corrosion potential on corrugated metal culvert pipes, California Test 643. The moisture content of the sample is an important parameter for the resistivity of a sample and the samples should be tested at their expected long term field moisture content.

The Ductile Iron Pipe Research Association has a method for evaluating the corrosion potential of backfill materials. The evaluation procedure is based upon information drawn from five tests and observations: soil resistivity, pH, oxidation-reduction (redox) potential, sulfides and moisture. For a given sample, each parameter is evaluated and assigned points according to its contribution to corrosivity (12, 14, 15). It is important to note that such procedures are intended as guides in determining a soil's potential corrosivity to ductile iron pipe and should be used only by qualified engineers/technicians experienced in soil analysis and evaluation.

One cause of galvanic corrosion is the differences in potential from backfill soils of varying composition. The use of CLSM for new installations provides a uniform backfill material whose composition should only vary by variations in the ingredients used and surrounding materials moisture content.

The corrosion potential of CLSM flowable fly ash slurry produced with fly ash derived from some of Wisconsin Electric's power plants has been shown to be significantly less than that of typical soils used for trench backfill (11). This question often comes up with respect to underground utilities and in particular ductile iron pipe.

CLSM fly ash slurry is not expected to adversely affect polyethylene natural gas lines or polyethylene jacketed power cables due to its high impermeability. Care must be exercised when backfilling polyethylene coated steel natural gas pipelines with all backfill materials to prohibit scratching or damage to the coating (9, 11).

High density very low porosity CLSM should be used where high thermal conductivity is desired such as backfill around underground power cables (5-8). As the moisture content and dry density increases, so does the CLSM's thermal conductivity (11).

Conclusion: CLSM is being frequently used as a backfill and void filling material in many locations across North America. CLSM's predictable engineering properties and labor saving attributes are making it the material of choice for many applications. CLSM's numerous advantages provides the engineer and constructor with another tool to help solve the many challenges of constructing and maintaining today's civil infrastructure.

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