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Review

Utilization of waste materials and by-products in producing controlled low-strength materials

Rafat Siddique*

Department of Civil Engineering, Thapar University, Patiala 147004, Punjab, India

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ABSTRACT

Controlled low-strength material (CLSM) is a self-compacted, cementitious material used primarily as backfill in lieu of compacted fill. It is also known as flowable fill, unshrinkable fill, controlled density fill, and flowable mortar. ACI 229R defines it as materials that result in a compressive strength of 8.3 MPa or less at 28 days. CLSM is generally used in backfills, structural fills, conduit bedding, erosion control, void filling, etc.

Use of several waste materials and by-products such as coal combustion products (fly ash, bottom ash), spent foundry sand, cement kiln dust, wood ash, and scrap tire rubber have been used in making controlled low-strength material. This paper presents an overview of the work published on CLSM made with coal combustion products (fly ash, bottom ash), spent foundry sand, wood ash, cement kiln dust and scrap tire rubber.

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* Fax: +91 175 2393005/2393207.
E-mail address: siddique_66@yahoo.com.

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1. Introduction

American Concrete Institute (ACI) Committee 229 defines controlled low-strength material (CLSM) as a self-compacted, cementitious material used primarily as backfill as an alternative to compacted fill. CLSM is also referred to as flowable fill, unshrinkable fill, controlled density fill, flowable mortar, plastic soil-cement, soil-cement slurry, K-Krete and various other names. By definition, CLSM may have a maximum compressive strength as high as 8.3 MPa (ACI Committee 229R, 1994).

Most current CLSM applications require compressive strengths of 2.0 MPa or less. This lower strength requirement is necessary to allow for future excavation of CLSM. Also, CLSM should not be confused with compacted soil-cement, as defined by ACI Committee 230 on Soil-Cement, requires compaction (consolidation) or curing to achieve the desired strength. Long-term compressive strengths for compacted soil-cement often exceed 8.27 MPa maximum limit established for CLSM. Long-term compressive strengths of 0.35–0.70 MPa are very low when compared to concrete. However in terms of allowable bearing prissier, which is a common criteria for measuring the capacity of a soil to support a load, 0.35–0.70 MPa strength is equivalent to a well compacted fill.

1.1. Advantages of using CLSM

CLSM has the following advantages (i) faster construction; (ii) reduced labor and equipment costs due to self-leveling characteristics; (iii) ability and tendency to place material in confined spaces; (iv) low-strength CLSM allows for future excavation, if required; (v) CLSM is often made with by-product materials, such as fly ash and foundry sand, scrap tire, CKD, etc., there by reducing the demand on landfills.

1.2. Applications of CLSM

The primary application of CLSM is as a structural fill or backfill in lieu of compacted soil. Because CLSM needs no compaction and can be designed to be very fluid, it is ideal for use in tight or restricted-access areas where placing and compacting fill is difficult. If further excavation is anticipated, the maximum long-term compressive strength should generally not exceed 2 MPa.

1.2.1. Backfills

CLSM can be readily placed into a trench, hole or other cavity. Compaction is not required; hence the trench width or size of excavation may be reduced. Granular or site excavated backfill, even if compacted properly in the required layer thickness, may not achieve the uniformity of CLSM.

1.2.2. Structural fills

CLSM may be used for foundation support. Compressive strengths may vary from 0.70 to 8.27 MPa depending upon application. Incase of weak soils, it can distribute the structure's load over a greater area. For uneven or non-uniform sub-grades under foundation footings and slabs, CLSM can provide a uniform and level surface.

1.2.3. Conduit bedding

CLSM provides an excellent bedding material for pipe, electrical, telephone and other types of conduits. The flowable characteristic of the material allows the CLSM to fill voids beneath the conduit and provide a uniform support. CLSM can be designed to provide erosion resistance beneath the conduit. Encasing the entire conduit in CLSM also serves to protect the conduit from future damage. If the area around the conduit is being excavated at a later date, the obvious material change in CLSM versus the surrounding soil or conventional granular backfill could be recognized by the excavating crew, alerting them to the existence of the conduit. Coloring agents have been used in mixtures to help identify the presence of CLSM.

1.2.4. Erosion control

It has been proven through laboratories and field performances that CLSM resists erosion better than many other fill materials. Tests comparing CLSM with various sand and clay fill materials showed that CLSM, when exposed to a water velocity of 0.52 m/s, was superior to the other materials, both in the amount of material loss and suspended material. Rip rap for embankment protection and in stilling basins below dam spillways are often filled with CLSM to hold rock pieces in place and prevent erosion. Flexible fabric mattresses used along embankments for erosion protection are filled with CLSM to provide strength and weight to the fabric revetments. In addition to providing erosion under culverts, CLSM is used to fill voids under pavements, sidewalks, bridges and other structures where natural soil or non-cohesive granular fill has eroded away.

1.2.5. Void filling

In filling old tunnels and sewers, it is very important to use a very flowable mixture. A constant supply of CLSM will help keep the material flowing and make it flow greater distances. Unwanted basements are often filled-in with CLSM by pumping or conveying the mixture through an open window or doorway. CLSM has been used to fill abandoned underground tanks.

1.3. Materials

Conventional CLSM mixtures usually consist of 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. Although materials used in CLSM mixtures may meet ASTM or other standard requirements, the use of standardized materials is not always necessary. Selection of materials should be based on availability, cost, specific application and the necessary characteristics of the mixture including flowability, strength, excavatability, density, etc.

2. Coal combustion products (fly ash and bottom ash)

Fly ash is a by-product of coal combustion and has found uses in a wide range of construction applications, including flowable fill, as shown in Table 1 (American Coal Ash Association, 2007). Fly ash is used mostly in Portland cement concrete, but its use in CLSM has grown considerably in recent years. Though fly ash has established itself as an important construction material, approximately 70–75%

Table 1
Fly ash applications in construction (ACAA, 2007).

Application	Quantity used (million metric tons)	% of total used
Concrete/concrete products/grout	13.70	43.27
Cement/raw feed for clinker	3.63	11.46
Flowable fill	0.11	0.34
Structural fills/embankments	7.72	24.38
Road base/subbase/pavement	0.38	1.20
Soil modification/stabilization	0.86	2.70
Mineral filler in asphalt	0.01	0.03
Aggregate	0.14	0.44
Mining applications	1.36	4.29
Waste stabilization	2.68	8.46
Agriculture	0.05	0.15
Others	1.02	3.22
Total	31.66	100