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Controlled Low Strength Material with Fly Ash and Cinder Aggregates: An Effective Replacement for the Compacted Backfill

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ABSTRACT
Controlled low strength material (CLSM) is a highly flowable material comprised water, cement, and fly ash (FA) but often contain waste by-product material. These are characterized by very high workability and lesser compressive strength. CLSM is used mainly for filling cavities and trenches in civil engineering works where the application of granular fill is either impossible or difficult. CLSM's are engineered materials that have a specified compressive strength of 8.3 MPa or less at 28 days. If future excavation is desired, the compressive strength should be <1.03 MPa. In the present study, fresh and hardened properties of CLSM formed by combining the cinder aggregates along with Class F FA are being investigated. The samples were prepared using different proportions of cinder and FA to study its performance.

Key words: *Controlled low strength material, Fly ash, Portland cement, Cinder, Unconfined compressive strength.*

1. INTRODUCTION

Controlled low strength material (CLSM) is a cementitious material which after hardening allows for future excavation with properties that are similar in characteristics to the stabilized soil. CLSM has other common names such as controlled density fill, K-krete, unshrinkable fill, and flowable fill. After hardening, CLSM provides adequate strength in bearing capacity but can also be easily excavated. To be classified as a CLSM, the material must have a compressive strength between 450 and 8400 kPa. As described by ACI Committee 229 [2], CLSM refers to a self-compacting, cementitious material used primarily as a backfill in place of compacted fill which is in a flowable state at the time of placement and has a specified compressive strength of 8.3 MPa or less at the age of 28 days. CLSMs are defined by "Cement and Concrete Terminology (ACI 116R)" as materials that result in a compressive strength of 8.3 MPa or less.

CLSM can be effectively used as a substitute for compacted soil in backfill applications, especially when possessing the desirable properties of flow (without segregation) under gravity for situations where compaction access is challenging. Other desired characteristics include hardening for early walkability, cover application, and low strength to allow future excavations in case of temporary construction.

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Other benefits gained from using CLSM are improved workers safety because trench exposure is limited, better durability as it is less permeable than compacted granular backfills, and it can be used in hard-to-reach places. Simultaneously, it reduces construction cost because no vibration or tamping is required to compact the material as it limits settlement and eliminates maintenance costs.

2. LITERATURE REVIEW

In 1997, Bruce W. Ramme documented that CLSM provides the engineer and constructor another tool to solve many challenges of construction industry and maintaining civil infrastructure. Tikalsky *et al*. (2000) evaluated the engineering properties of CLSM containing foundry sand (clay bonded and chemically bonded) in the plastic and hardened states and compared these properties with similar CLSM test mixtures of crushed limestone sand.

Brown *et al*. (2003) investigated the use of new and improved capping materials for CLSM cylinders. In this investigation, the soft neoprene caps are compared with other capping materials such as sulfur mortar capping, and gypsum plaster. Naik *et al*. (2006) revealed that the high carbon fly ash (FA) can be used in the manufacture of conducive CLSM and concrete. Moreover, this type of material can be used effectively for conducting electrical charge from lightning to the ground more safely.

The effect of water quality on the strength of flowable fill has been studied by Harthy *et al*. (2005). This paper discusses the potential use of groundwater and oily production water in CLSM. Crumb rubber, obtained from waste and scrap tires can be used to produce a good quality, lightweight flowable fill because of its low specific gravity (Pierce and Blackwell, 2001). Reasonable flowability, improved ductility, and higher thermal insulation were achieved using crumb rubber in flowable fill, when compared to standard flowable fill.

Since most applications require future excavatability, cement kiln dust could be advantageous used in CLSM (Pierce *et al*., 2003). The flowability and setting times within 24 h could be achieved. The successful use of coal combustion products in CLSM has been reported by Naik *et al*. (2001). Practical solution to "disposal problems" for Illinois coal combustion products has been provided through his project.

Various researchers have studied the usage of different industrial by-product materials such as cement by-pass dust, AMD sludge, quarry dust etc., as found in the literature[1, 4, 6-9, 11-15].

3. CLSM MATERIALS

Typical CLSM mix components include FA, cement, water, and sometimes fine aggregates. Recycling of waste material for use in CLSM benefits the environment to a very large extent. However, there is still a need to find new environmentally acceptable uses for increased utilization of waste materials, so that disposal problems are minimized. The use of FA in large volumes in CLSM mixes seems to be a perfect utilization method.

3.1. FA

The purpose of adding FA to the flowable fill is to facilitate flow. The presence of FA helps in retaining the water and simultaneously increases the flow property of the mix. FA used in the present work is Class F FA and was obtained from the Raichur thermal power plant, Karnataka, India. The specific gravity of FA used is 2.1 and it passes completely through 120 μ sieve.

3.2. Cement

The purpose of cement in CLSM mixes is to provide cohesion between the particles, strength gain, and to promote pozzolanic reaction. Ordinary Portland Cement of 43 grade conforming to IS: 8112-1989 [10] was used in the present investigation.

3.3. Water

The amount of water in a flowable fill has a direct effect on the flowability and strength development of the mix. Normal tap water was used for mixing the materials and for conducting the flowability test and water absorption test.

3.4. Cinder Aggregates

Cinder aggregates are also called as clinker aggregates. For usages in concrete, it is important that the clinker be reasonably free from unburnt coal which causes unsoundness. The cinder aggregate used in the present work passes through 10 mm and retains on 4.75 mm IS sieve.

4. SAMPLE PREPARATION AND TEST PROCEDURE

4.1. Flowability

The mould used, the nature and type of flow can be observed in Figures 1 to 3. Flowability is one of the important characteristics of CLSM mixes. The flowability test was conducted using an open-ended cylinder of diameter 75 mm and a height of 150 mm in accordance with ASTM D 6103 [3]. Trial tests were conducted to determine the approximate water demand needed for a target flow of 200-240 mm. In the present study, w/c is maintained between 4.5 and 4.7 to get the required flow. Moreover, proper size and grading are needed for the aggregate or filler material to effectively contribute to the flowability of a CLSM mixture [5]. The CLSM mixes used in the present study are shown in Tables 1 and 2.

4.2. Density

Dry density is defined as the total mass per unit volume of the material in dry condition. The weights and dimensions of the specimens were found, and the average dry density was calculated. The cubes of sizes 50 mm × 50 mm × 50 mm were casted and tested. Densities of the hardened specimen were calculated at 7 and 28 days, and the average value is reported in Table 3.

Table 1: Description of various mixes containing cinder aggregates which were tested for density, unconfined compressive strength, and water absorption (replacement of cinder aggregates by weight of FA).

Mix no	Mix identification	Mix	Proportion
1	CF	Cement: FA	1:10
2	CC1	Cement: Fly ash: Cinder aggregates	1:10-5% Replacement
3	CC2	Cement: Fly ash: Cinder aggregates	1:10-10% Replacement
4	CC3	Cement: Fly ash: Cinder aggregates	1:10-15% Replacement

FA: Fly ash

Table 2: Mix proportions, flow, water-cement ratio, and water-cementitious materials ratio of different CLSM mixes containing cinder aggregates.

Mix identification	CF	CC1	CC2	CC3
Cement (kg/m^3)	118.2	121.1	109.0	122.5
Fly ash (kg/m^3)	1182.7	1150.3	981.0	1041.6
Cinder aggregates(kg/m$^{3)}$	-	60.5	109.0	183.8
Water (kg/m^3)	561.45	575.2	504.1	551.2
W/c	4.75	4.7	4.6	4.5
W/cm	0.43	0.45	0.46	0.47
Flow (mm)	260	215	220	230
Cement (%)	9.08	9.0	9.0	9.0
Fly ash (%)	90.9	86.3	81.8	77.2
Cinder aggregates (%)	-	4.5	9.09	13.6

CLSM: Controlled low strength material

Table 3: Dry density of CLSMs.

Mix no	Mix identification	Dry density (kg/m^3)	
		7 days	28 days
1	CF	1333	1286
2	CC1	1264	1263
3	CC2	1251	1222
4	CC3	1220	1202

CLSM: Controlled low strength material

Table 4: Water absorption for various mixtures at 28 days.

Mix identification	Water absorption after 30 min (%)	Water absorption after 24 h (%)
CF	31.82	36.71
CC1	31.05	33.11
CC2	31.63	33.24
CC3	28.38	32.01

4.3. Water Absorption

Water absorption test for each mix was conducted at the age of 28 days. Three cubical specimens from each CLSM mix were weighed and kept in water. After 30 min and 24 h, percentage water absorption was determined. The results are presented in Table 4.

4.4. Unconfined Compressive Strength

The most important hardened property of CLSM is its strength which is measured as unconfined compressive strength. The axial stress at which the specimen fails is known as the unconfined compressive strength. As CLSM is primarily used as backfill or structural fill, the compressive strength tests serve only as an indicator of the bearing capacity of the material. The compressive strength results at 7 and 28 days for various mixes are presented in Figure 4.

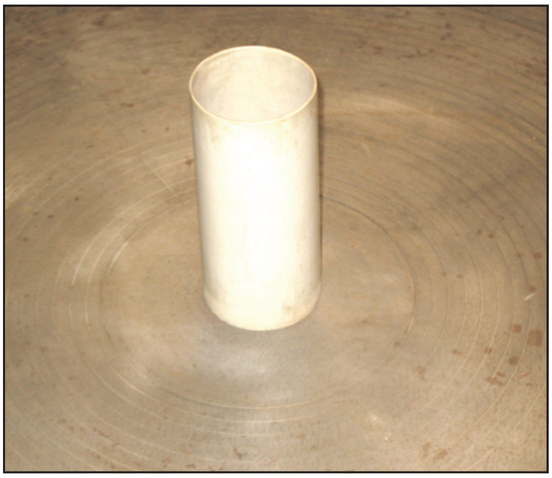

Figure 1: Cylindrical mold 75 mm × 150 mm.

Figure 2: Placing of controlled low strength material mix into the mold.

Figure 3: Measurement of flow diameter.

4.5. Stress-strain Behavior

Stress-strain behavior was recorded for unconfined compression at the age of 7 and 28 days. The stress-strain curves were plotted between the axial stress and the axial strain up to failure. The stress-strain curves

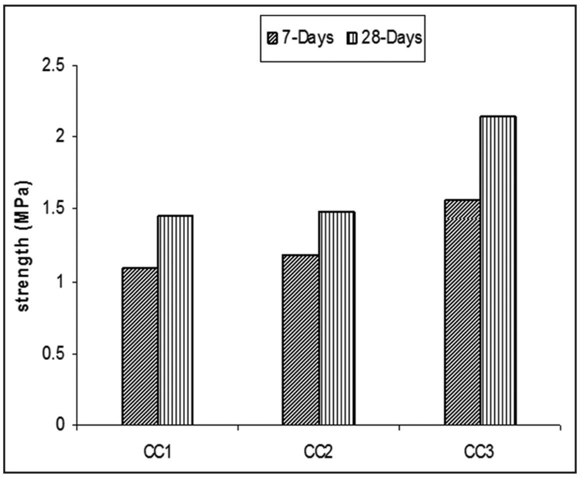

Figure 4: Uniaxial compressive strength of different mixes for cubical specimens.

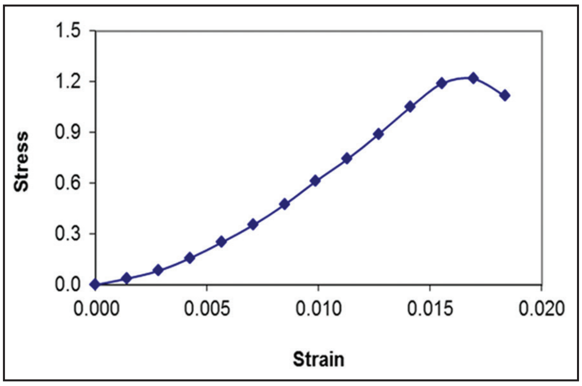

Figure 5: Stress-strain curve for ref. mix CF at 28 days.

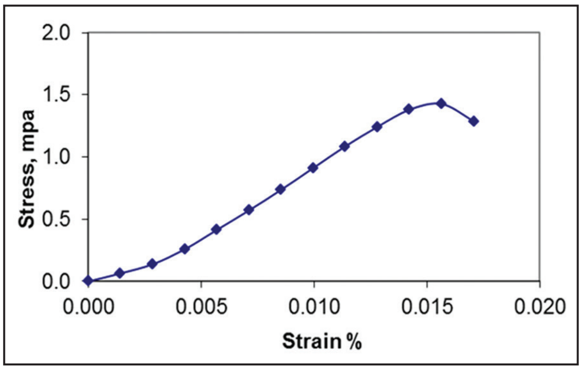

Figure 6: Stress-strain curve for the mix CC1 at 28 days.

for few samples tested can be seen in Figures 5-8.

5. RESULTS AND DISCUSSIONS

Based on the experimental studies in the present investigation, following conclusions can be drawn regarding the performance of CLSM containing the cinder as coarse aggregates.

1. Above 90% water absorption of the flowable fill takes place in the initial 30 min. This indicates that CLSM absorbs maximum water initially.
2. The CLSM mixtures considered in the present study can be classified as regular CLSM based on their density, as the density of all the mixes was more than 800 kg/m^3.
3. The compressive strength of all mixes increases as the age progresses.
4. 7 days unconfined compressive strength for all mixes was greater than the required 440 kPa for walkability.
5. By varying the amount of aggregates, by-product materials, and water, it is possible to create a self-consolidating material with wide range of hardened and fluid state properties for field applications, provided the volume stability meets normal requirements for CLSM.
6. When a soil-like material applications are called for, CLSM mixes containing the coarse aggregates can be effectively utilized at reduced costs as the ingredients are basically by-products, cheaper and readily available.
7. Shrinkage, creep, water absorption, and cracking will be the predominant characters for controlled mix (i.e., mix containing only fly ash). Hence, with the introducing of coarse aggregates, the result will yield a better material of reduced creep, shrinkage, and water absorption along with lesser cracking.
8. Experimental results showed a promising future with respect to the use of coarse aggregates in flowable fill applications. However, to draw comprehensive conclusions, field studies should be conducted to investigate the effects of natural factors such as temperature and humidity.

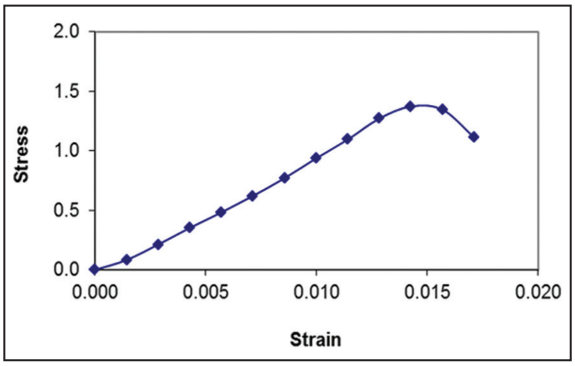

Figure 7: Stress-strain curve for the mix CC2 at 28 days.

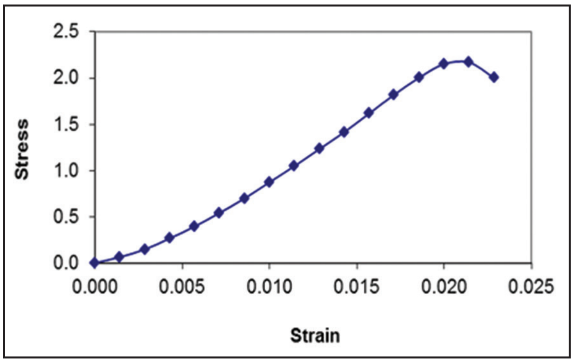

Figure 8: Stress-strain curve for the mix CC3 at 28 days.

6. CONCLUSIONS

From the present study, it can be concluded that for the production of CLSM, the coarse aggregates can be effectively used. The flow behavior and the strength characteristics obtained will satisfy the ASTM requirements for practical applications. The CLSM produced in the present study can be classified as an excavatable type. Further study is required to make concrete conclusions.

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***Bibliographical Sketch**

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