ANALYSIS OF EXCAVATABLE FLOWABLE COMPOSITES

C P Ramesh[1], Sphoorthy S M[2], Mohiyuddin C S[3], Shashishankar A[4]

[1]*Associate Professor and Head, Department of Civil Engineering, SETJU*
[2]*Master of Technology student in Building Science and Technology, SETJU*
[3]*Assistant Professor, Department of Civil Engineering, AMCEC, Bengaluru*
[4]*Professor and Head, Department of Civil Engineering, AMCEC, Bengaluru*

Abstract

A flowable fill composite termed as Controlled Low Strength Material (CLSM) is a good alternative to compacted soils. CLSM is unique in achieving compressive strength without compacting effort and is superior to compacted earth. However, future digability can be allowed through a proper method of proportioning. The study uses combinations of CLSM composite mixtures constituting Processed Slag Sand (PSS) and Ground Granulated Blast Furnace Slag (GGBFS). The characteristics of CLSM composites mixtures viz., uniaxial compressive strength, absorption of water and lixiviate limits were determined by conducting various laboratory tests. Low GGBFS flowable fills with higher percentage of PSS are obtained with desirable flowability and lower uniaxial compressive strengths between the ranges of 1.20-2.70 MPa for easy future excavation process. The study is promising for a new area of applications for carbon footprint (CFP) mitigation. Thus, the objective of the study is to examine bulk utilization of low energy materials for CFP mitigation and to evaluate the use of PSS as fine aggregates in excavatable flowable fill composites. The uniaxial compressive strength properties in the range of 1.2-2.7 MPa and RFA of CLSM composite mixtures between 5 and 15 would be studied for different combinations and a comparative analysis would be made.

***Keywords**: Controlled low strength material; GGBS; PSS; Uniaxial compressive strength; Capillarity; Toxicity; CFP mitigation; RFA.*

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1. INTRODUCTION

Several researchers during last one decade have developed many engineering applications for CLSM as an alternative to compacted fill. CLSM is a class of cementitious matrix composites known by different terminologies viz., controlled density filling (CDF) material, flowable mortar (FM), flowable fill (FF). CLSM needs no compactive effort being a proportioned non newtonian fluid and suitable for placing and compacting in constricted inaccessible areas. For digability, uniaxial compressive strength is fixed at a lower level of 1.2-2.7 MPa. Most fills exhibit a 7 days compressive strength of 0.7 M Pa. For excavation of trench fills, maximum strength shall not exceed 2.7 M Pa. ACI 229R-99 report suggests a higher limit of 2.1 MPa [1].

Mixtures consisting of conventional materials such as OPC, river sand have been widely used. Also industrial waste like acid mine drainage [4], spent foundry sand [2, 3] and recycled glass [5] have been tried.

A reduced in-place cost, placement and compressive strength properties make CLSM mixes are more economical and suitable for backfilling applications because of less labour requirement and ruggedness to moisture content variation [6]. Easy production and on-site delivery by a RMC producer, increases its suitability for placement application under old bridges, box or pipe culverts, open trenches, mine fills and specialised fills for telecom and gas pipe line applications.

Generally uniaxial compressive strengths in the range of 0.35 N/mm^2 - 2.00 N/mm^2 have been reported for most of the CLSM fill applications. Higher values of compressive strengths for non-digability can also be obtained by proper proportioning. Of CLSM and is a better alternative for natural soils due to higher strength than surrounding in-situ materials. However, CLSM provides easy excavation using regular methods whenever it is required. Higher range of strength becomes problematic for future excavation in case of cable trenches and hence merits should be considered [7].

2. MATERIALS OF PRODUCTION

Ground granulated blast-furnace slag (GGBS), a by-product of iron and steel making can be used in CLSM in combination with cementitious materials such as Portland cement. Silicate (glass) is the raw material for GGBFS cementing material. Molten slag is cooled and finely ground to form GGBS cementing material. It is a recycled product and has no identical chemical constituents as Portland cement.

GGBS is used by comparing the strength versus time graph for mixes of Portland cement which gains strength much more slowly when compared with that of Portland cement mix. CLSM are desirable for their lower strength, however the ultimate compressive strength are found to be higher due to higher content of Calcium Silicate Hydrate (C-S-H) gel and less Calcium Hydroxide (lime) in the resulting concrete.

C-S-H gel acts as binder that holds the aggregates and provide strength, whereas lime provides a small amount of strength to the concrete. The GGBS consumes this weaker C-H over period of time and replaces it with more stable C-S-H gel.

The sphericity of GGBS particles with very high fluid binder ratios enormously increases the fluidity for easy placement with no tamping or compaction effort. This is responsible to achieve saving in operational time. No hand usage for filling inaccessible areas is an added advantage. In constricted locations, sometimes hand application makes the operation time longer and hence less economical.

The investigation on CLSM composite mixtures shows the use of several combinations of proportions of processed slag sand from Oblapuram Andrapradesh and GGBFS procured from JSW Bellary. Basic physical characterisations of these materials were carried out and possible environmental hazards were investigated by subjecting to EP toxicity test for heavy metals like chromium, cadmium, barium and lead.

3. EXPERIMENTAL STUDY

Testing program, the materials used and the results are presented below:

3.1 Materials

CLSM mixtures in the present study used: Ground granulated blast furnace slag (GGBFS) as binders, processed slag sand (PSS) as fine aggregate and potable water.
Cementitious Materials

3.2 GGBFS

Cohesion and strength properties are gained due to hydration reactions in CLSM. Present literature reports Portland cement ASTM C150, Ordinary Portland cement (OPC) as binder (Table 1), due to cost effectiveness. GGBFS from JSW Thorangal with physical and chemical properties are shown in Table 2.

3.3 Fine Aggregate

Processed Slag Sand (PSS) obtained from Obalapuram in Andrapradesh, is used in the present study. The gradation and physical properties of the PSS fine aggregates are shown in Table 3. PSS fine aggregate passing 74µm (#200 sieve) was 5%.

3.4 Preparation of Specimen and Testing Procedure

The flowable mixtures used in the present study is shown in the Table-4. These are selected using trial and error method [15].Required number of cylindrical test specimens of 50mm x100mm were cast. In this type of CLSM mixture, GGBFS was kept at constant. The PSS fine aggregates was proportion by weight. The ratio of OPC/GGBS was chosen as 0.05 in all the CLSM mixtures. Krell [16] recommended 5-6 per cent of ordinary Portland cement, which is to be added to the dry mass FA with required quantity of water for maintaining the required consistency for pumping of CLSM composite for various applications. Fluid per total solid material ratio is selected as 0.2 required least value as per the available literature [17].

The open-ended cylinder has been used for measuring the flowability of CLSM mixtures, which is described in ASTM D6103 [18]. No compacting effort or vibration was used during filling of the mixture into moulds.

The CLSM in combination with higher amount of GGBS content could not be de-moulded after 24 hours of open air curing, due to low value of compressive strength gaining. The cylindrical test specimens were kept in a tray after de-moulding for seven days in room temperature. The CLSM mixture density was determined between 1.90 and 2.10 g/cm^3, according to the ASTM D854-92 [19].

The tests were conducted for determining unconfined compressive strength on 50mm×150mm cylindrical specimens, as described in ASTM D4832 at different ages such as 7, 14, 28 days. Unconfined compression testing machine was used in the test.

The required prisms were casted for determining the absorption of water in CLSM mixtures by the action of capillarity according to the TS 4045 [20]. At the end of 28 days casting the prism is once again dried by placing the specimen in the oven at 105◦C. The prism specimen is placed in a cylindrical container in vertical position in contact with water.

A few CLSM mixtures were selected for subjecting to the extraction procedure for EP toxicity test as per unite states Environmental Protection Agency [21].

Table 1: Physical and chemical properties of OPC

Physical properties

Specific gravity	3.1
Blaine's (cm^2/g)	4708
% retained on 90mm sieve	0.8
% retained on 90mm sieve	2%
Compressive strength (MPa)	
2 days	18.1
7 days	29.5
28 days	56
Setting time	
Initial (min)	55mm
Final (min)	350mm

Chemical properties

Element	**%**
CaO	49.20
SiO_2	3.9
Fe_2O_3	3.4
Al_2O_3	9.5
MgO	0.90
Na_2O	0.9

SO_3	3.1
K_2O	2.5
Loss on ignition	3.50
Insouble residue	28.10
Free lime	1.60

Table 2: Physical and chemical properties of GGBFS

Physical properties

Specific gravity	2.9
pH	9.9
Moisture content (%)	0.7

Chemical properties

Index (%)	80
SiO_2	35.8
Al_2O_3	17.7
CaO	36.3
Fe_2O_3	1.4
SiO_2+Al_2O_3+Fe_2O_3	54.9
MgO	7.0

SO_3	0.63
Loss on ignition	1.6

Table 3: Physical properties and grading of fine aggregate PSS

Physical properties

Unit weight (kg/m^3)	
Loose	1680
Compacted	1840
Specific gravity	2.60

Grading of aggregate

Sieve size (mm)	**% passing**
6.3	100
4.75	100
2.36	98.6
1.18	78.2
0.6	27.5
0.3	6.0
0.15	1.6

Table 4: Mix proportions of CLSM mixtures

Mixture	**Materials weight (kg/m3)**				**PSS/(OPC+GGBS)**	**W/(POC+GGBS)**	**Mix design**	**Workability Test**
	OPC	GGBS	PSS	Water				
M1	19	396	1169	396	3:1	1.00	1980	215
M2	20	404	1233	363	3.5:1	1.00	2020	212
M3	20	412	1258	370	4:1	1.10	2060	205

4. RESULTS AND DISCUSSIONS

Compressive Strength: Unconfined compressive strength test results are shown in Fig. 1

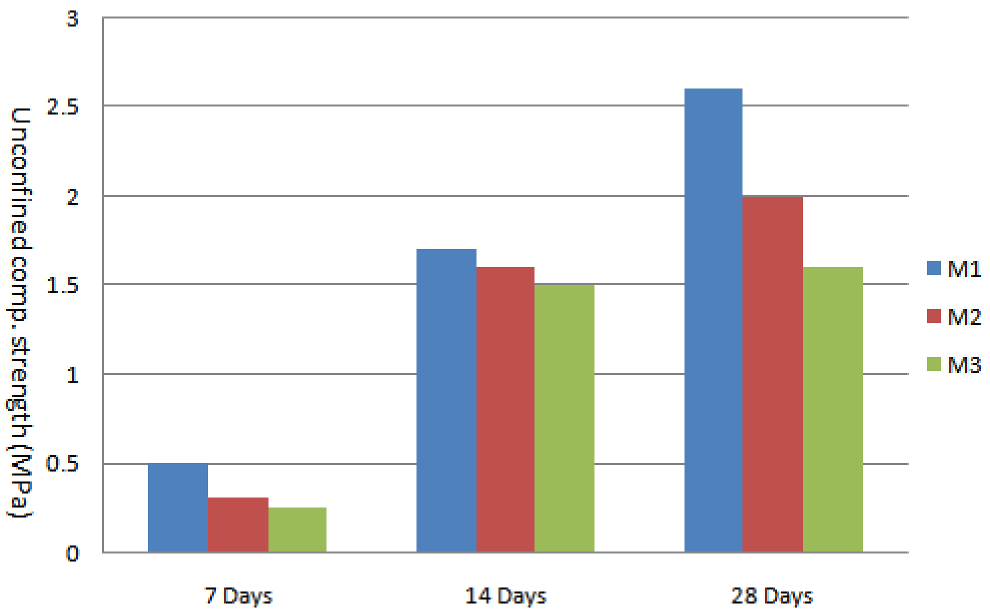

Fig.1: Uniaxial compressive strength of different types of CLSM mixtures

Following observations were made regarding the strength behaviour of the mixtures.

Higher strength is achieved with lower ratio of W/ (OPC+GGBFS) of M1 is 1.0 and its 28 days strength is 2.60MPa. In other words, W/ (OPC+GGBS) ratio of M3 is 1.15 and its 28 day strength is 1.60MPa.

Considering fig. 2, the strengths of mixtures with higher ratios of W/ (OPC+GGBS) is found to be less. Considering the test results, the ratios lies between 1.25 to 2.80 for M1 to M3 respectively.

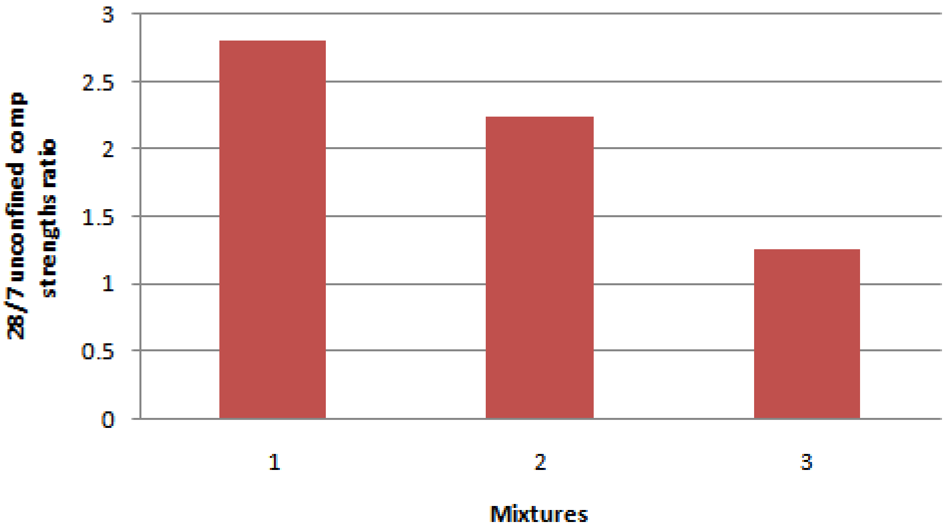

Fig 2: 90/28 days uniaxial compressive strength ratios

With respect to the fig.3, CLSM mixtures compressive strengths v/s time relationships is established in logarithmic equation in the form of f_c =a ln (t)−b. The coefficient correlation is computed between 0.90 and 0.95 for the equation. These coefficients showed that the logarithmic equation is more reliable than the others. The logarithmic coefficients ‘a’ and ‘b’ of the equations also the regression ‘R’ for CLSM mixtures is given in fig. 3.

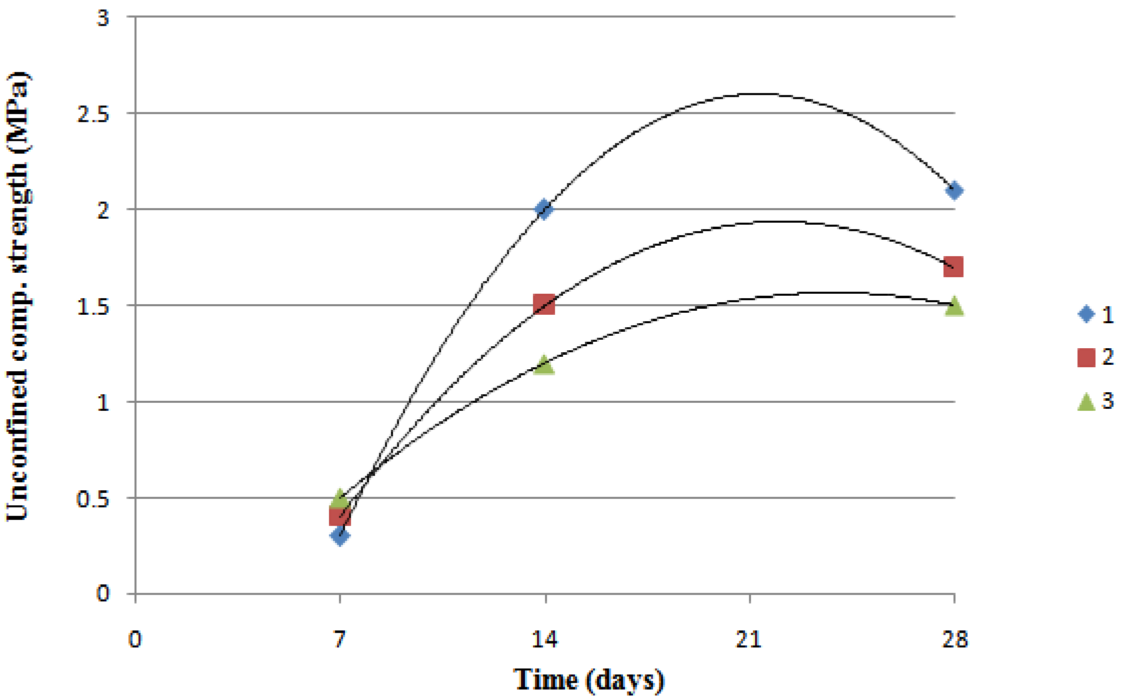

Fig.3: Uniaxial compressive strength-time relationship

The quantity of GGBS and aggregates have higher impact on strength at lower W/(OPC+GGBS) ratio. As per the test results obtained, the ratio between fine aggregate to cementitious material of 6.0 could be used for W/(OPC+GGBS) ratio of 1.42 for condition, where low value of compressive strength is needed. The fine aggregate to cementitious materials ratio of 3 and W/binder material ratio of 1.0 provides good results for higher strength.

4.1 Water Absorption by Capillarity Action

Capillary coefficient of absorption is calculated using the equation $(Q/A)^2 = kt$ [23]. Where 'Q' is the water absorption at 24h (cm^3), 'A' is the cross sectional area (cm^2), 't' is the time in seconds and 'k' is the coefficient of capillary absorption (cm^2/s). Capillarity action test is shown in fig. 4. The water absorption value ranges between 1.43×10^{-3} and 1.79×10^{-3} cm^2/s at 28 days. The least amount of water absorption for M1 of 1.43×10^{-3} cm^2/s and the highest amount of water absorption is found to be at M3 mixture. As per the investigation, an increase in fine aggregate content and also W/ (OPC+GGBS) ratio indicate increases the capillarity coefficient.

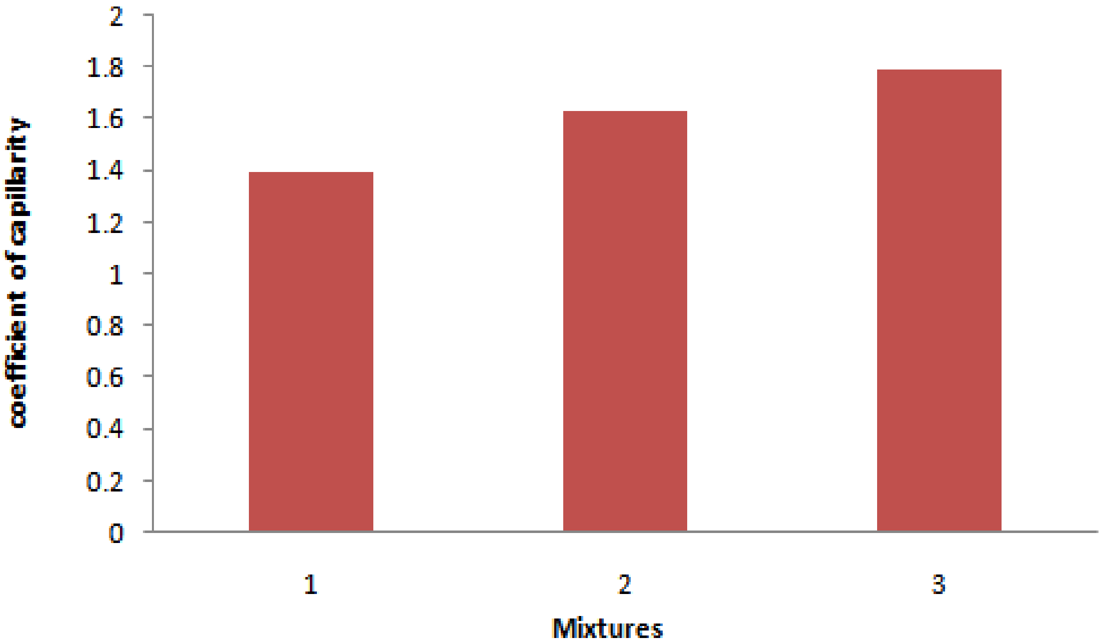

Fig.4: Test results for 28 days mixtures of CLSM for capillary water absorption

4.2 EP Toxicity Test

CLSM mixtures are primarily used in various applications such as trench fillings or as liner materials in land fill. The possible effects of EP toxicity on environment is also studied.

Leaching of certain components into ground water is an important aspect, which causes number of hazardous problems on human health. Barium, cadmium, chromium and lead concentrations are also measured, after conducting the EP toxicity test and the results are shown in table 5.

From the investigation, the concentrations of heavy metals were found to be lower than that stated in EPA limits, hence the CLSM mixtures are not hazardous to groundwater.

The results indicate that CLSM mixtures are environment friendly and acceptable filling material.

Table 5: Test results of EP toxicity for selected CLSM mixtures

Element	**Concentration (ppm)**			
	M1	**M2**	**M3**	**EPA limits**
Barium	16.6	17.11	16.89	100.0
Cadmium	0.10	0.10	0.05	1.0
Chromium	0.07	0.04	0.02	5.0
Lead	0.30	0.30	0.21	5.0

5. CONCLUSION

The results obtained from the experiments are recapitulated as follows:
The study evaluated the flowable mixtures such as Ground Granulated Blast Furnace Slag, low Ordinary Portland cement and Processed Slag Sand as fine aggregate. Good flowability and a compressive strength in the range of 1.15–2.70MPa at 90 days is achieved. The achieved compressive strength is suitable for future excavations.

By increasing Ordinary Portland Cement content or by minimizing water, higher strength can be achieved. Ratios of GGBS, OPC and PSS need to be selected carefully to fulfil the requirements.

Over and above, the CLSM mixtures are environmentally acceptable, according to EPA standards.

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