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Investigations of Common Effluent Treatment Plant Sludge based Controlled Low-Strength Material

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The management of industrial waste is a difficult task in the developing country like India. In the study, fresh and in-service properties of controlled low-strength material (CLSM) consisting of cement, class-F flyash, CETP sludge, M-sand and water were determined by laboratory scale tests. The CETP considered when combined with cement and flyash, exhibit self-hardening characteristics similar to cement. The developed CLSM constitute for five classes of mix design (A, B, C, D and E). The results show that the proposed CLSM satisfy for the pavement backfilling for sub-base and sub-grade of flexible pavement requirements.

Keywords: Controlled low-strength material, Unconfined compressive strength, Permeability, Compressibility, California bearing ratio

Introduction

Industrial revolution has increased the requirement of the natural resources and in parallel contributed for large volume of waste generation. The CLSM (controlled low-strength material) is a self-leveling and self-compacting material (compressive strength less than or equal to 8.3 MPa at 28 days). The CLSM has been propagated in utilization of waste/by-products and efficient waste management.[1–3] The CLSM mixes should have a minimum compressive strength of around 0.44 MPa to provide sufficient support for construction and vehicle loads in pavements.[4] Synthetic fibers have also been incorporated successfully in the construction of concrete pavement.[5] The CLSM must be easily flowable, self-compacting and self-leveling; have wearing and freeze-thaw resistance for pavement applications.[6] The study aims at investigation of fresh and in-service properties of CLSM developed.

Methodology

The mix design of CLSM mixes was brought out based on trial and error basis (ACI-229R) and totally 45 mixes were evaluated for fresh and hardened properties. In the study cement used was OPC 53 grade (having specific surface area 3851 cm^2/g and specific gravity 3.15) and the cement content through the mixes varied between 30 kg/m^3 to 120 kg/m^3, at equal intervals of 20 kg/m^3 as shown in Tables 1 and 2. A study on use of flyash and silica fume blended concrete for marine environment has showed promising results comparable with normal concrete.[7] The Class-F fly ash having specific gravity 2.23 obtained from Raichur thermal power plant, Karnataka India; has been another major component in CLSM. The volume of fly ash used was 600 kg/m^3 of sample and the value was constant for all the mixes. The manufactured sand (M-sand) was used in the development of CLSM to improve the bulkiness.

M-sand was used as an alternative for conventional river sand. Successful application of micro silica (upto 8%) and graded coal bottom ash (upto 90%) shown good results on concrete.[8] For the present study, M-sand was confined zone-II as per (IS-2386); having specific gravity of 2.78, density 2.6 g/cm^3 and fineness modulus of 2.51. M-sand content was constant (1500 kg/m^3) for all the mixes. The CETP sludge used was inorganic sludge collected from a CETP Bengaluru, Karnataka, India. The CETP sludge was replaced with 5, 10, 15, 20, 25, 50, 75 and 100 % dry weight of cement contents for each mix (Tables 1 and 2). The chemical composition of the CETP sludge constitutes

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Table 1 — Flowability results of CLSM mixes (in cm)

Mix	Cement Volume (kg/m^3)	0%	5%	10%	15%	20%	25%	50%	75%	100%
		CETP Sludge								
A	30	27	27	26.5	26.5	26	25	24	22	22
B	50	26.5	26	25.5	25.5	25	24	22	20.5	21
C	70	25.5	25.5	25	24	22	21	20.5	20.5	20
D	90	24.5	24.5	24	23.5	22	20.5	19	18	18
E	120	22.5	22.5	22	21.5	19	18.5	17.5	17	15

Flyash : 600 kg/m^3; M-sand: 1500 kg/m^3 Water content: 300 kg/m^3 for all mixes

Table 2 — Unconfined Compressive strength (MPa) of CLSM mix at 28 days

Mix	Cement Volume (kg/m^3)	0%	5%	10%	15%	20%	25%	50 %	75%	100%
		CETP Sludge								
A	30	1.76	1.8	1.7	2.1	1.9	1.6	0.78	0.52	0.41
B	50	1.9	2.3	2.5	3.0	2.3	2.1	1.5	1.45	1.2
C	70	3.2	2.78	3.5	3.7	3.2	2.8	2.1	1.75	0.90
D	90	3.4	3.5	3.5	4.2	3.8	3.5	2.8	2.3	1.8
E	120	4.1	4.3	4.8	5.2	4.3	4.2	3.6	2.85	2.0

maximum amount of SiO_2 (21.6%) in the first, followed by CaO (21.2%), Fe_2O_3 (4.30%), Al_2O_3 (2.0%) and MgO (0.89%). The pH value was 9.56 (with 10% suspension). The water content was constant (300 kg/m^3) for all the mixes. The mixing of the samples was done through Hobart (Model A120) mechanical mixer. During mixing all the entrapped air bubble was removed. The fresh and hardened properties of CLSM in terms of flow (flowability), unconfined compressive strength, permeability, compressibility and California bearing ratio (CBR) were investigated for pavement bases applications.

Results and Discussions

In this section the behavior of the CLSM for different tests has been described. The results for five tests are discussed below:

Flowability

Flowability test for all mixes (A, B, C, D and E) was carried out by flow table test as per ASTM D 6103 standards and flow values for all the mixes was found to be in the range of 20–30 cm except for few mixes of D and E, due to higher cement content as illustrated in Table 1. For all the mixes, flowability was high at 0% sludge and decreases with increase in sludge content (100%). Among all the samples the mix A was found to have high flowability value and conversely mix E showed lower flowability. This variation was due to the finer sludge based mixes require more water to obtain the same flowability because of the increased fineness of sludge particles

Fig. 1 — Cylindrical samples of CLSM

Unconfined Compressive Test (UCS)

UCS strength gain of CLSM mix was ascertained by conducting UCS test at 7 and 28 days (Fig. 1). The samples were prepared through the stainless steel moulds (75 mm diameter and 150 mm length). The CLSM mix was placed into the UCS mould without compaction, and care was taken to remove all air bubbles entrapped. The ends of the mould was covered with plastic sheets to avoid any evaporation loss and the samples were removed from moulds after 24 hours and were kept in desiccators at 100% relative humidity to preserve the moisture (1 day). It was observed that (Table 2), the strength increases with increase in sludge volume (upto 15%). The increase in the strength can be attributed to the reaction between cement/ flyash / cetp sludge. The sludge acts as accelerator for the sludge during the treatment process to increase the pozzolonic reaction. Based on the results it was found that, beyond 15% of sludge replacement, strength reduced gradually. It was evident from the UCS results that, all mixes were within 8.3 MPa representing the behavior of CLSM. The mix E attained higher strength than all the other mixes. The maximum strength achieved through the mix was E4 (E corresponds to the mix and 4 corresponds to the percentage of replacement i.e 15%) having strength of 5.2 MPa after 28 days.

Table 3 — Permeability test of Mix E

Sl.no	Mix	Sludge content	Permeability cm/s
1.	E1	0%	6.7×10^{-5}
2.	E2	5%	7.2×10^{-5}
3.	E3	10%	5.3×10^{-5}
4.	E4	15%	4.7×10^{-5}

Permeability or Hydraulic Conductivity

The permeability is one of the important in-service property used to determine the application of CLSM for pavement bases. It determines the seepage and stability of the structure. It helps in accessing the rate of permeability and range of porosity. The permeability was determined by the flexible wall permeability test. The samples of size 50 mm diameter and 100 mm height were prepared. The confining pressure of 100 kPa was applied and samples were allowed to consolidate after saturation. The Hydraulic gradient of 2 (testing) was used which fall within the specified limits (1 to 5 specified in ASTM standards). The permeability results obtained for mix E (Table 3) shows that, the permeability was reducing with increase in sludge content ranging from 4.7×10^{-5} cm/s to 6.7×10^{-5} cm/s.

California Bearing Ratio (CBR)

The CBR value is used to determine the strength of the subgrades (the piston is allowed to penetrate in mm/ minutes). In order to verify its application for pavement bases the CBR values are essential. The CBR test was conducted as per IS 2720 standards. The test was conducted on both (soaked and unsoaked) conditions. The CBR test results for mix E samples (Fig. 2) varied between 20% to 30% (E1 - E4). It was also noticed that, the soaking effect was not significant for the CLSM. Hence the developed CLSM can be considered for the possible applications in the pavement base. The CBR value keeps on increasing with increase of sludge percentage (Fig. 2).

Compressibility

The compressibility of the CLSM (mix E) was determined after 28 days of curing in desiccators. The CLSM directly was prepared on a consolidation ring (60 mm diameter and 20 mm thick). The prepared CLSM sample was covered with a cling film along with the ring. One-dimensional consolidation test was conducted after 28 days. The results of one-dimensional consolidation test for Mix E samples are represented in Fig. 3. It shows that, the samples with higher cement content were less compressible than samples with lower cement contents.

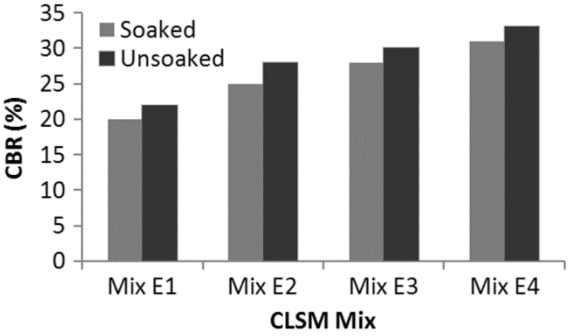

Fig. 2 — Variation of CBR for different CLSM mix

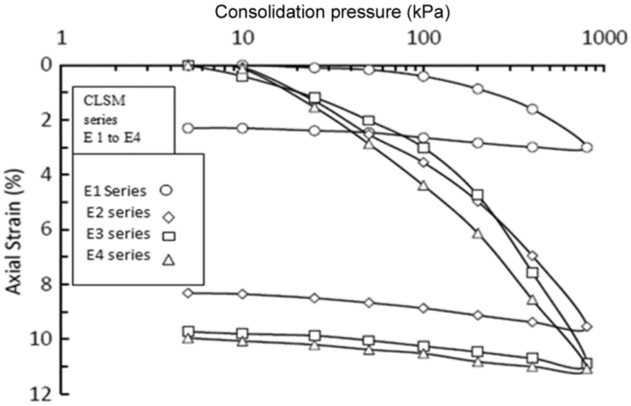

Fig. 3 — Compressibility behavior Mix E CLSM sample

Conclusions

The focus of the present study was to utilize the CETP sludge in development of CLSM while maximizing the by-product utilization and satisfying fresh and in-service properties. It was observed that CLSM composed of waste by-products such as Class F flyash and CETP sludge, can be utilized for pavement base applications. This could be an effective solution for the disposal of waste materials.

The conclusions drawn from the study are:

1. The CLSM developed passes all the preliminary tests adopted in determining its properties
2. The sub-grade and compressive strength increases with CETP up to certain extent (15%) and reduces with further increase.
3. Permeability increases in CLSM with increase in CETP
4. Higher the cement content in the mix the compressibility will be less for CLSM.
5. The CLSM developed can be effectively used as an alternative material for subgrade and subbase/ base in pavement construction.
6. The work carried facilitate in developing eco-friendly CLSM mix without compromising the performances.

Nomenclature

CBR	California bearing ratio
CETP	Common effluent treatment plant
CLSM	Controlled low-strength material
kPa	Kilo Pascal
MPa	Mega Pascal
UCS	Unconfined compressive strength

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