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Performance evaluation of Controlled Low Strength Materials (CLSM) using sustainable materials

M. C. Nataraja[1] and N.R.VadirajRao[2]

[1]Professor, Civil Engineering Department,Sri Jayachamarajendra College of Engineering, Mysore, India

[2]Research scholar, The National Institute of Engineering, Mysore, India

Abstract

Controlled Low Strength Material (CLSM) also known as flowable fill is a self-compacting and self-levelling cementitious material used primarily as a backfill in place of a compacted fill. CLSM is mainly the slurry consisting of a mixture of cement, sand, water and fine aggregates. Since sand and cement are the major components, replacing the cement and or natural sand with waste materials is an attractive beneficial reuse option.

Fly ash is widely used in flowable fill mixes in order to reduce the cost and to ensure low compressive strengths .Other waste materials used in flowable fills includes the ground granulated blast furnace slag (ggbfs), waste foundry sand, Cement kiln dust, bottom ash, pulverized rubber tires, flue gas desulphurization materials and a wide range of industrial by-products which otherwise pose a problem in their safe disposal.

CLSM’s are basically the engineered materials that have a specified compressive strength of 8.3MPa or less at 28 days. If future excavation is desired the compressive strength should be less than 1.03 MPa. Flowable fills are characterized by very high workability with low density and strength, which allows for self-compaction. Application includes backfilling, road-cuts, road bases, mud slabs and slope stabilizations. Also CLSM is used primarily as a backfill in place of compacted fill and also filling cavities in civil engineering works in which the application of granular fill is either difficult or impossible.

The typical mixture proportions of CLSM are 80 to 85% sand, 10 to 15% fly ash and 5 to 10% cement by mass. The actual mix proportions of these constituents vary depending on the physical properties of the materials and the intended use or requirements of the application. High workability is achieved through the use of high amounts of mixing water or by using admixtures (air entraining agents, plasticizers, etc.)

1. Introduction

The ACI Committee 229 describes Controlled Low STRENGTH Materials (CLSM) as a cementitious material having self-compacting properties in which the material will be in a fluid state at the time of placement.

The “Cement and Concrete Terminology (ACI 116R)” specifies the compressive strength of CLSM as 8.3 MPa or less. A strength range of 0.3 to 1.1 MPa is a good index of sufficient strength and for easy future excavations. The CLSM's predictable engineering properties and labour 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 construction and maintaining the timely deadlines of the project.

The major problem of compacting the soil and allowing it for further consolidation before the application of the loads in the construction of roads or pavements can be avoided by using these materials. Hence the overall construction time will be greatly reduced. Like concrete, CLSM may be mixed in central-mix concrete plants, ready-mixed concrete trucks or pug mills. A truck often can be discharged in less than 5 minutes. A constant supply of CLSM will keep the material flowing and will make it flow horizontal distances of 300 feet (91 m) or more.

Objectives and Research Significance

The objectives of the present research are

1. To study the suitability of crushed paver aggregates as coarse aggregates in CLSM

2. To compare between the different types of fine aggregates such as normal sand, cinder sand and quarry dust
3. To investigate flow characteristics of different CLSM mixes and to study the stress-strain behaviour
4. To study the dry density and saturated surface dry density of various CLSM mixes
5. To study the water absorption of different CLSM mixes

2. Literature review

Tikalsky P., Gaffney M., 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. The results showed that by-product foundry sand used in CLSM provide better properties to that of CLSM containing crushed limestone sand.

Gabr and bowders. (2000) introduced sludge as a replacement for fly ash and studied its fresh and hardened properties. The unconfined compressive strength containing sludge yielded 10 to 70% higher strength as compared to those without sludge. Also all the mixes that were considered has the unconfined compressive strength greater than 440kpa at 28 days which is the walkability limit.

Naik et al. (2006) revealed that the high carbon fly ash can be used in the manufacture of conducive CLSM and concrete. Also this type of material can be used effectively for conducting electrical charge from lightning to the ground more safely.

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.

Tikalsky P., Smith, E. et al. (1998) evaluated the use of spent casting sand (Used foundry sand) in CLSM. Tests for strength, water demand, rate of strength development and fluidity have been conducted. The significance of their research indicates that uniform size of the spent casting sand can provide good flowability and the lower cost of spent casting sand enhances the economic advantage of CLSM.

Since most applications require future excavatability, cement kiln dust (CKD) could be advantageous used in CLSM (**Pierce et al.,** 2003). The flowability and setting times within 24 hours could be achieved with most mixtures and they concluded that CKD can be beneficially added to produce a very low-strength material due to the smaller amount of lime and silica present in CKD, that offers comparable strengths to soils used for conventional fills.

Research done by **Butalia et al.** (2000) revealed that many flue gas desulfurisation (FGD) materials have low unit weight and good shear strength characteristics and thus hold promise for flowable fill applications. It was observed that the FGD flowable fill without any additives was comparable to regular (normal set) flowable fill in terms of placeability, UCS and diggability.

The feasibility of Industrial by-products such as cement kiln dust, asphalt dust, coal fly ash, coal bottom ash and quarry waste were tested for the production of CLSM (**Katz and Kovler.**, 2003). Tests were performed for bleeding, water absorption and volume changes of the flowable fill mixes. CLSM with good properties could be made with significant amounts of dust (25–50% of wastes), especially when the dust has some cementing or pozzolanic potential as do fly ash and cement kiln dust, which results in cost savings.

Taha et al. (2003) investigated the use of cement by-pass dust (CBPD) in the flowable fill mixes. The strength of the mixes varies quite significantly because of the considerable difference in the amount of water added to reach the required slump.

The application of CLSM was imparted efficiently in the successful completion of the Bostonharbor tunnel project (**Sullivan.**, 1997). Sullivan observed that CLSM could be placed at a rate of approximately 60 m^3/hour at least six times faster than the placement of conventional backfill.

The successful use of coal combustion products in CLSM has been reported by **Naik & Kraus**. (2001). Practical solution to “disposal problems” for Illinois coal combustion products has been provided through his project.

Naik, Ramme B.W & Kolbeck H.J., (1990) studied CLSM with low cement content, class F fly ash, and no aggregates. They observed that the mix has excellent flowability and a compressive strength in the range of 345 to 690 kPa

3. Materials And Mix Proportions

The following materials were used for the present experimental study

1. Cement
2. Fly ash
4. Paver Aggregates
6. Natural river sand
7. Quarry dust
8. Cinder sand
9. Water

Cement

The purpose of cement in CLSM mixtures is to provide cohesion and strength gain and is also used to promote pozzolanic reaction. Ordinary Portland cement of 43 Grade conforming to IS: 8112-1989 was used in the present investigation. The properties of cement are shown in Table 3.1.
Specific gravity of Cement: 3.08

Table 3.1 Properties of cement used

Sl No	Properties	Test results	IS 8112 – 1989 requirements
1	**Standard consistency, %**	30	No standard value
2	**Setting time, in minutes** a) Initial setting time b) Final setting time	 138 242	 Not less than 30 Not more than 600
3	**Specific gravity**	3.12	No standard value
4	**Compressive strength, MPa** 3 days 7 days 28 days	 24.41 37.45 44.14	 23 33 43

Fly ash (FA)

The purpose of adding fly ash to the flowable fill is to facilitate flow. Fly ash used in the present research was obtained from the Raichur thermal power plant, Karnataka. The Particle size distribution of FA is shown in Fig. 3.1.
Specific gravity of Fly ash: 2.18

Quarry dust

Quarry dust consists mainly of excess fines generated from crushing, washing and screening operations at quarries. The quarry dust used for the investigation was sieved through 4.75 mm sieve. It conforms to zone III as specified by IS 383–1970. The percentage passing through different IS sieve sizes are shown in Table 3.2 and the gradation curve for sand is shown in Fig 3.1.
Specific gravity of quarry dust: 2.49
Fineness modulus of quarry dust: 1.85'

Sand

The sand used for this study was natural river sand. The sand passing through 4.75 mm sieve was used. The sand conforms to grading zone II as per IS 383 - 1970. The fineness modulus and specific gravity of sand were determined as per IS: 2386-1963.
Specific gravity of sand : 2.52
Fineness modulus of sand: 2.45

Table 3.2 Sieve analysis of sand and quarry dust used

IS Sieve designation (mm)	Percentage passing (sand)	Percentage passing(quarry dust)	Percentage passing as per IS 383–1970 requirements			
			Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10.00	100	100	100	100	100	100
4.75	100	100	90-100	90-100	90-100	95-100
2.36	98.3	99.5	60-95	75-100	85-100	95-100
1.18	86.3	92.1	30-70	55-90	75-100	90-100
0.60	60.7	76.2	15-34	35-59	60-79	80-100
0.30	8.6	35.4	0.5-20	0.8-30	12-40	15-50
0.15	0.6	11.5	0-10	0-10	0-10	0-15

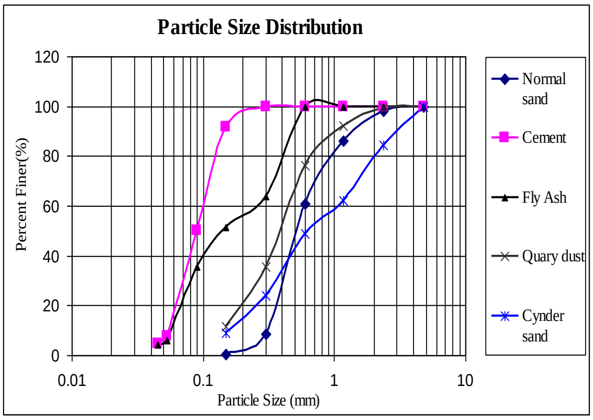

Fig 3.1 Gradation curves for Cement, Fly ash, sand, Quarry dust and Cinder sand

Water

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

Paver Aggregates

The paver aggregates used is the crushed pieces of waste and discarded paver blocks. This represents the construction waste and is very much similar to that of the recycled aggregates. The aggregates used were passing through 10mm and retained on 4.75mm sieve.

Cinder sand

It is the powdered form of cinder aggregates. The properties such as fineness modulus and specific gravity were determined as per IS: 2386-1963.
Specific gravity : 1.76
Fineness modulus: 2.71

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The gradation curve is shown in Fig 3.1.

Mix Proportion

The various CLSM mixes that were casted and tested to study the properties such as flowability, density, unconfined compressive strength and water absorption are presented in Table 3.5.

Table 3.5 Mixes Containing Paver aggregates. (Replacement of paver aggregates by weight of fly ash)

Mix No.	Mix identification	Mix	Proportion
1	C1	Cement: Fly ash	1:5
2	CP1	Cement: Fly ash: Paver aggregates	1:5-10%Rept.
3	CP2	Cement: Fly ash: Paver aggregates	1:5-20%Rept.
4	CP3	Cement: Fly ash: Paver aggregates	1:5-30%Rept.
5	C2	Cement: Fly ash	1:10
6	CP4	Cement: Fly ash: Paver aggregates	1:10-10%Rept.
7	CP5	Cement: Fly ash: Paver aggregates	1:10-20%Rept.
8	CP6	Cement: Fly ash: Paver aggregates	1:10-30%Rept.
9	C3	Cement: Fly ash	1:15
10	CP7	Cement: Fly ash: Paver aggregates	1:15-10%Rept.
11	CP8	Cement: Fly ash: Paver aggregates	1:15-20%Rept.
12	CP9	Cement: Fly ash: Paver aggregates	1:15-30%Rept.
13	C4	Cement: Fly ash	1:20
14	CP10	Cement: Fly ash: Paver aggregates	1:20-10%Rept.
15	CP11	Cement: Fly ash: Paver aggregates	1:20-20%Rept.
16	CP12	Cement: Fly ash: Paver aggregates	1:20-30%Rept.

Table 3.7 Mixes containing fine aggregates

Mix No.	Mix identification	Mix	Proportion
1	CFS	Cement: Fly ash: sand	1:12:25
2	CFQ	Cement: Fly ash: Quarry dust	1:12:25
3	CFC	Cement: Fly ash: cinder sand	1:12:25

Table Mix Proportions, flow, water-cement ratio and water-cementitious materials ratio of different CLSM mixes containing paver aggregates

Mix	C1	CP1	CP2	CP3	C2	CP4	CP5	CP6
Cement (Kg/m^3)	228.6	233.0	243.6	256.6	121.0	125.8	129.5	130.0
Fly ash (Kg/m^3)	1143.3	1048.5	974.7	898.3	1210	1132.3	1036.3	910.0
Paver aggregates (Kg/m^3)	-	116.5	243.6	385	-	125.8	259	390
Water (Kg/m^3)	628.8	566.1	578.5	520	574.7	566.1	540.8	520
w/c	2.75	2.43	2.37	2.03	4.75	4.5	4.175	4.0
w/cm	0.45	0.44	0.47	0.45	0.43	0.44	0.46	0.5
Flow (mm)	240	230	220	220	220	230	225	240
Cement (%)	16.6	16.6	16.6	16.6	9.09	9.09	9.09	9.09
Fly ash (%)	83.3	75.0	66.6	58.3	90.9	81.8	72.7	63.6
Paver aggregates (%)	-	8.4	16.8	25	-	9.0	18.1	27.2

Table 3.9 (b) Mix Proportions, flow, water-cement ratio and water-cementitious materials ratio of different CLSM mixes containing paver aggregates (Contd…..)

Mix	C3	CP7	CP8	CP9	C4	CP10	CP11	CP12
Cement (Kg/m^3)	80.5	82.5	86.9	91.8	60.2	63.1	63.6	69.2
Fly ash (Kg/m^3)	1208.4	1114.5	1043.1	964.6	1205.7	1136.5	1017.9	969.3
Paver aggregates (Kg/m^3)	-	123.8	260.8	413.4	-	126.2	254.4	415.4
Water (Kg/m^3)	576	536.6	530.2	514.4	572.6	561.9	496.1	481.1
w/c	7.15	6.5	6.1	5.6	9.5	8.9	7.8	6.95
w/cm	0.44	0.44	0.46	0.48	0.45	0.46	0.45	0.46
Flow (mm)	220	220	230	230	230	240	220	230
Cement (%)	6.24	6.24	6.24	6.24	4.76	4.76	4.76	4.76
Fly ash (%)	93.7	84.3	74.9	65.6	95.2	85.7	76.1	66.6
Paver aggregates (%)	-	9.3	18.7	28.1	-	9.5	19.0	28.5

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Table 3.10 Mix Proportions, flow, water-cement ratio and water-cementitious materials ratio of different CLSM mixes containing cinder aggregates and fine aggregates

Mix	CFS	CFQ	CFC
Cement (Kg/m^3)	47.6	47.2	35.1
Fly ash (Kg/m^3)	571.0	566.8	422.2
Cinder aggregates (Kg/m^3)	-	-	-
Sand (Kg/m^3)	1190.0	-	-
Quarry dust (Kg/m^3)	-	1180.0	-
Cinder sand (Kg/m^3)	-	-	879.6
Water (Kg/m^3)	357.0	377.6	494.2
w/c	7.5	8.0	14.0
w/cm	0.57	0.61	1.08
Flow (mm)	230	225	220
Cement (%)	2.6	2.6	2.6
Fly ash (%)	31.5	31.5	31.5
Cinder aggregates (%)	-	-	-
Sand (Kg/m^3)	65.7	-	-
Quarry dust (Kg/m^3)	-	65.7	-
Cinder sand (Kg/m^3)	-	-	65.7

In the present work nineteen mixes were studied for flow characteristics and other engineering properties such as density, unconfined compressive strength and water absorption. All the mixes were analysed for stress-strain behaviour.

4. Experimental Procedure

The study was an investigation on the use of coarse aggregates and to evaluate the performance of sustainable materials in CLSM properties such as flowability, unconfined compressive strength, stress-strain behaviour, density and water absorption. All samples were prepared and tested in accordance with the relevant standards.

Sample Preparation and Testing Procedure

Flowability

The flowability test was conducted using an open-ended 75mm x 150 mm cylinder (Fig. 4.1) in accordance with ASTM D 6103. Mixing was performed to determine the approximate water demand needed for a target flow of 220mm to 240mm.

Fig. 4.1 Cylindrical mould of75mm x 150mm used for flow test

Fig. 4.2 Pouring of fresh CLSM mix into the cylindrical mould

Fig. 4.3 Measurement of flow diameter

Density

Densities of the hardened specimen were calculated at 7 and 28 days and the average for each mix has been considered. To find out saturated surface dry density, the specimens were kept in water for 24 hours and the weights of the specimens were taken in saturated surface dry condition. Average densities of the specimens in saturated surface dry condition were found.

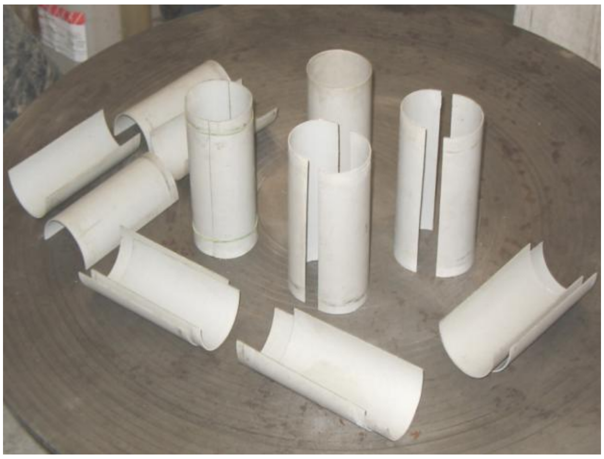

Fig. 4.4 Cut cylindrical moulds used for casting the specimens

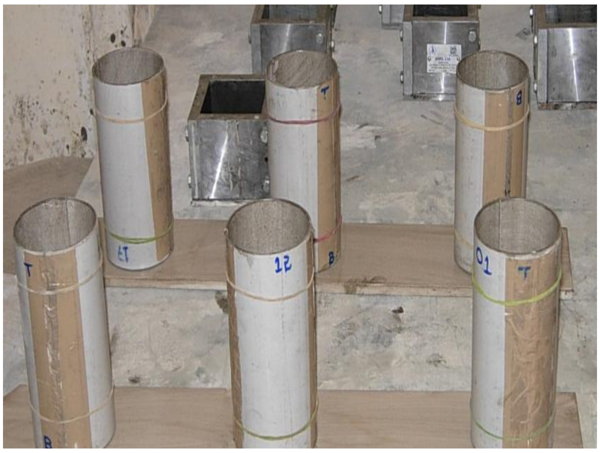

Fig. 4.5 Prepared cylindrical moulds used for casting the specimens

Fig. 4.7 CLSM specimens casted for testing

Unconfined Compressive Strength and Stress-Strain Behaviour

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, compressive strength test only serve as indicators of the bearing capacity of the materials. Unconfined compressive strength testing machine with a proving ring is used to measure the compressive force. The 7-day and 28-day strengths were measured.

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Fig. 4.8 Unconfined compressive strength testing machine

Fig. 4.9 Failure of specimen in unconfined compressive strength

Fig. 4.12 Specimens failed in unconfined compression

Water absorption

Water absorption test for each mix was conducted at the age of 28 days. Three specimens from each CLSM mix were weighed and kept in water. After 30 minutes the specimens were taken out from the water and weighed. Thus, the percentage water absorption after 30 minutes can be determined. Similarly the percentage water absorption after 24 hours was also determined.

5. Results and Discussions

The properties such as flowability, density, unconfined compressive strength, stress-strain behaviour and water absorption were evaluated for different CLSM mixes based on the experimental procedure and test results obtained.

Graphs of flowability versus Percentage replacement for different mixes were plotted. The flowability increases with an increase in water-cement ratio, regardless of the type of the mix.

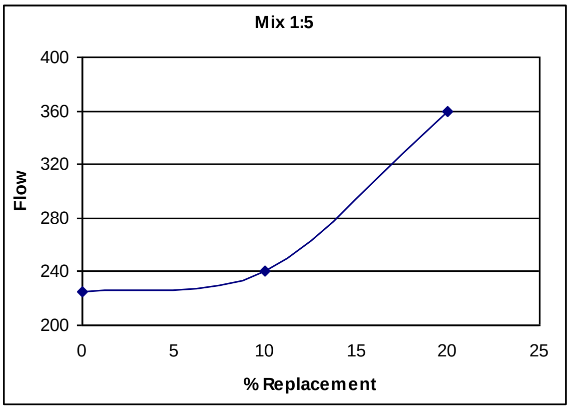

Fig. 5.2 Flow Vs Percentage replacement of fly ash by paver aggregates for the mix 1:5

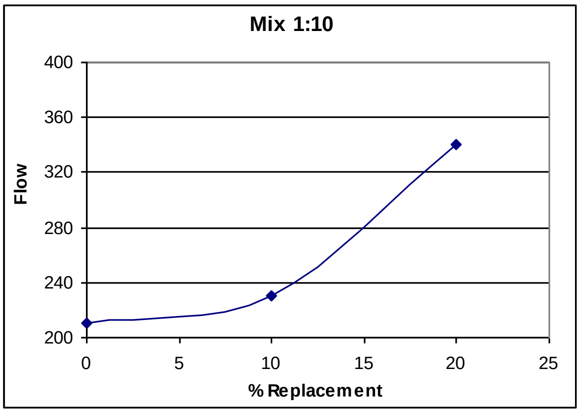

Fig. 5.3 Flow Vs Percentage replacement of fly ash by paver aggregates for the mix 1:10

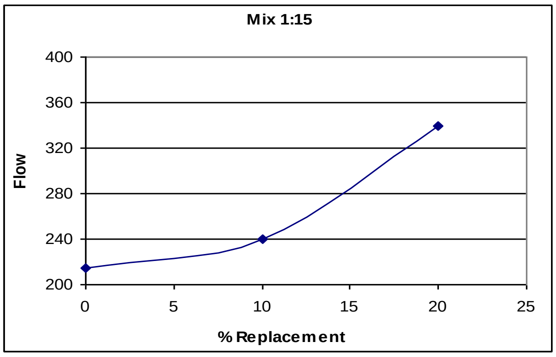

Fig. 5.4 Flow Vs Percentage replacement of fly ash by paver aggregates for the mix 1:15

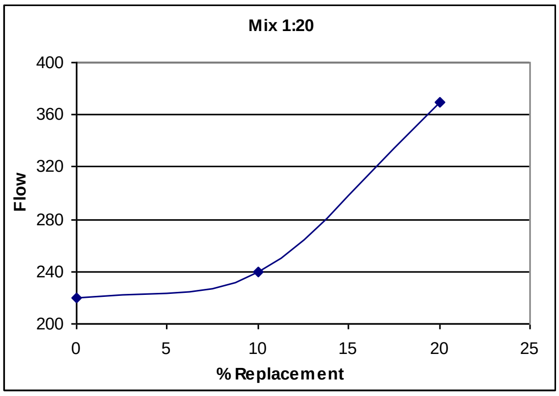

Fig. 5.5 Flow Vs Percentage of fly ash by paver aggregates for the mix 1:20

It can be observed from the Fig 5.2 to 5.5 that, for the mixes containing paver aggregates, the desired flow could be achieved with lesser water-cement ratio compared to the normal mixes (Without replacements).

Density

The density of CLSM mixtures depends mainly on the unit weight of the filler or aggregate material. It can be observed that the average dry density of all the mixes ranges from 1211 kg/m^3 for mix CC3 to 1779 kg/m^3 for mix CFS, whereas the saturated surface dry density ranges from 1502 kg/m^3 for mix CFC to 1981 kg/m^3 for mix CFQ. These values compare well with the normal density of regular CLSM mixtures specified in ACI Committee 229 report. The CLSM mixtures considered in the present study can be classified as regular CLSM as the density of all the mixes was more than 800 kg/m^3.

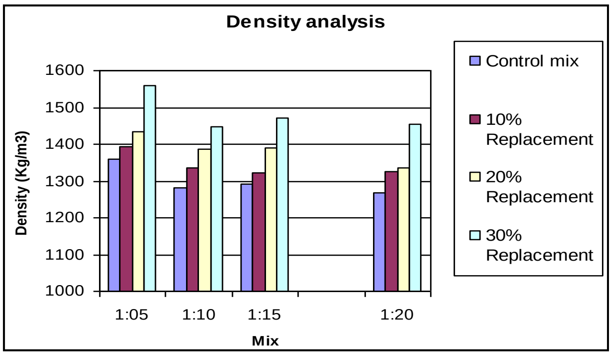

Fig. 5.6 Densities of different CLSM Mixes containing paver aggregates

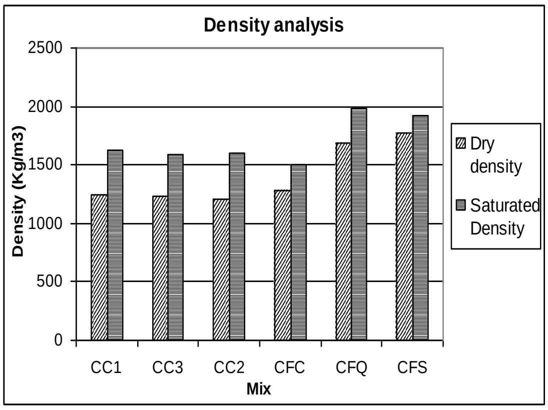

Fig. 5.7 Dry Density and Saturated Surface dry densities of various CLSM mixes

Unconfined Compressive Strength

The 28-day unconfined strength of the mixes C1, CP1, CP2, CP3, CP5 and CP6 were more than 2 MPa (2000 kPa) i.e., they fall above the maximum strength criterion for excavatability.

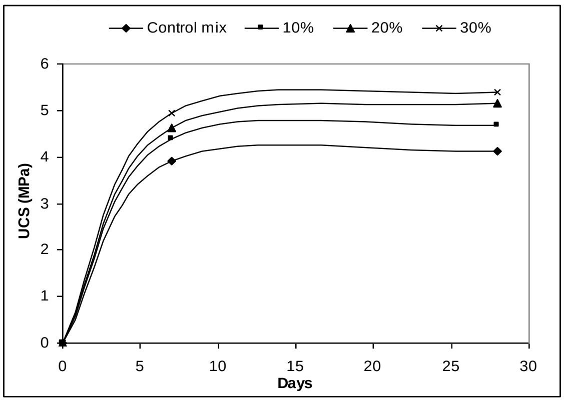

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Fig. 5.8Variation of Unconfined Compressive Strength of 1:5 mix with respect to age for different CLSM mixtures

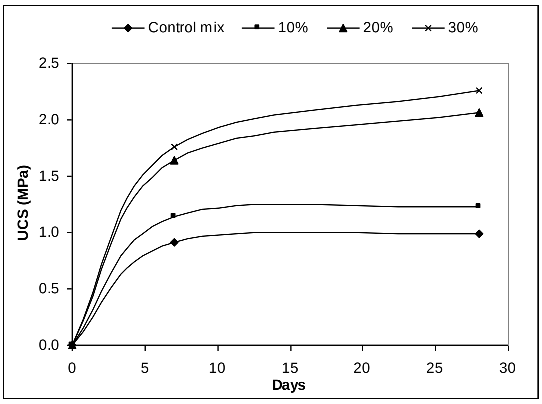

Fig. 5.9Variation of Unconfined Compressive Strength of 1:10 mix with respect to age for different CLSM mixes

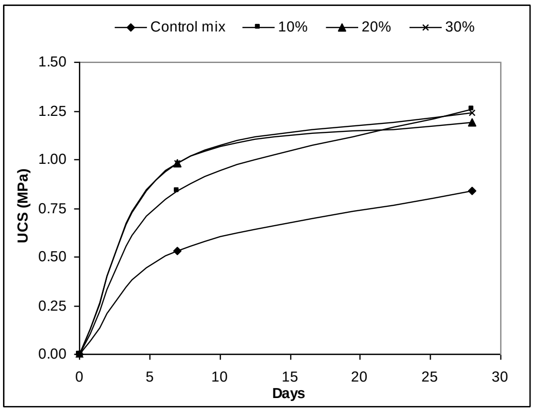

Fig. 5.10Variation of Unconfined Compressive Strength of 1:15 mix with respect to age for different CLSM mixes

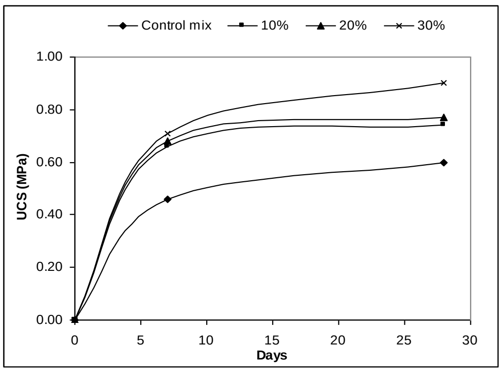

Fig. 5.11Variation of Unconfined Compressive Strength of 1:20 mix with respect to age for different CLSM mixes

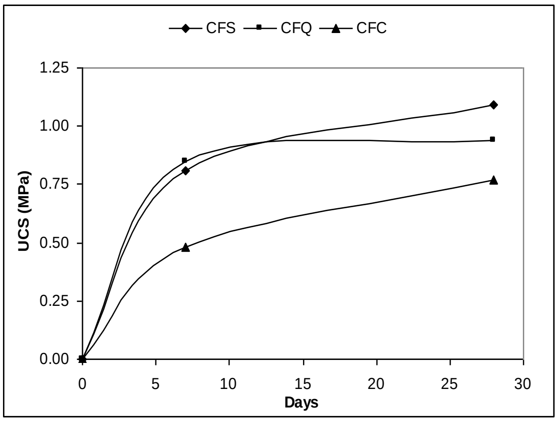

Fig. 5.25 Variation of Unconfined Compressive Strength with respect to age for different CLSM mixes

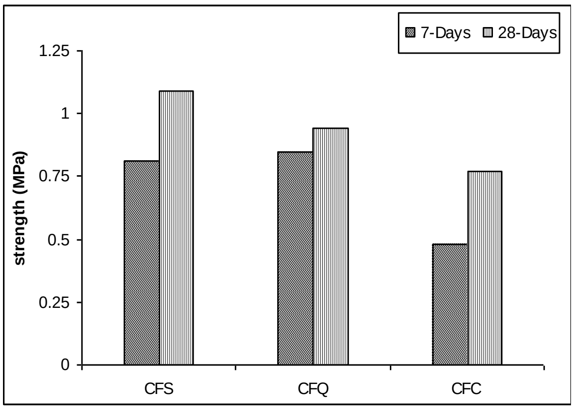

Fig. 5.28 UCS for mixes CFS, CFQ, CFC

Stress-Strain behaviour

Axial stress-strain behaviour was recorded during the unconfined compression test at the age of 7 days and 28 days. The stress-strain data was recorded and the graph was plotted for all the specimens as shown in Figs. 5.38 to 5.44. The stress-strain curve, which fits well, was chosen from the stress-strain curve and that was considered as the stress-strain curve for that particular mix.

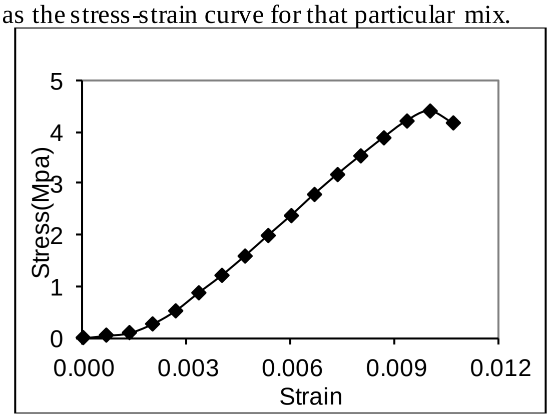

Fig. 5.31 Stress strain curve for the mix C1 at 28-days

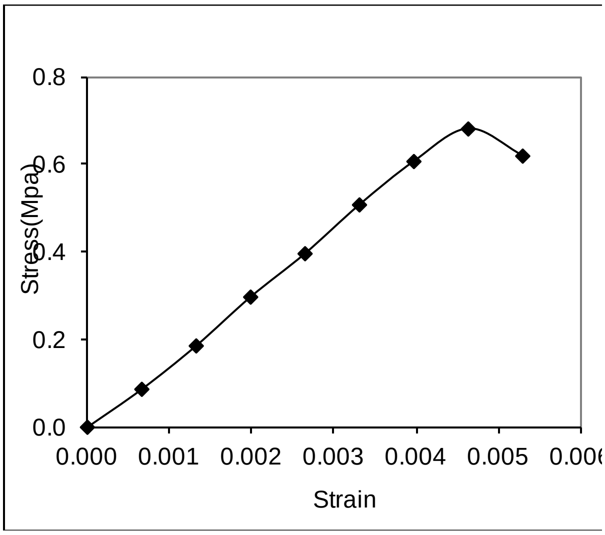

Fig. 5.31 Stress strain curve for the mix C2 at 28-days

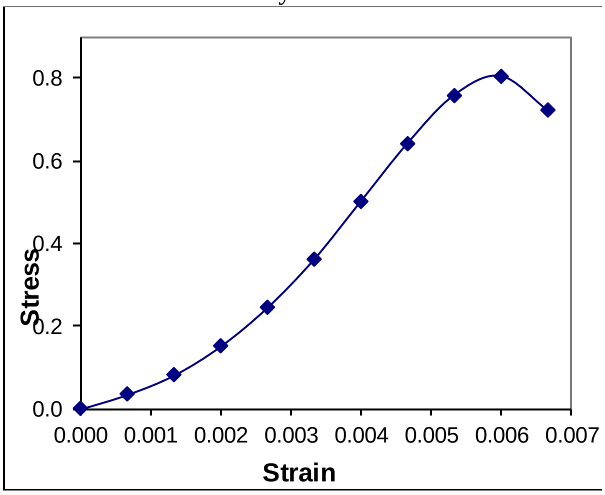

Fig. 5.31 Stress strain curve for the mix C3 at 28-days

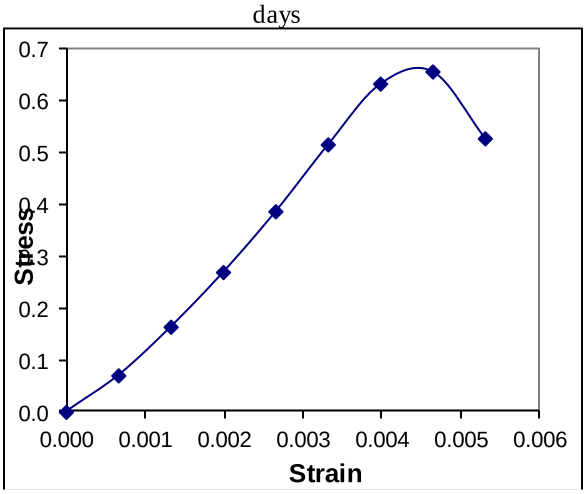

Fig. 5.31 Stress strain curve for the mix C4 at 28-days

Water absorption

Table 5.4 presents the results of water absorption test conducted on different CLSM mixes after 30 minutes and after 24 hours. The Percentage water absorption decreases as the cement content increases. It can be observed from Fig. 5.52 that the percentage water absorption after 30 minutes was approximately the same after 24 hours. This shows that flowable fill absorbs maximum water in minimum time.

Table 5.5 Water absorption of different CLSM mixes

Mix identification	Water absorption after 30 min (%)	Water absorption after 24 hours (%)
C1	25.21	28.07
CP1	22.21	25.49
CP2	23.27	23.98
CP3	20.25	22.69
C2	31.82	36.71
CP4	30.26	32.77
CP5	22.92	23.65
CP6	25.41	26.77
C3	28.91	33.29
CP7	27.13	29.52
CP8	23.80	26.94
CP9	24.85	28.24
C4	40.74	44.59
CP10	32.25	34.59
CP11	28.66	29.83
CP12	23.89	25.33
CC1	31.05	33.11
CC2	31.63	33.24
CC3	28.38	32.01
CFS	12.63	13.87
CFQ	16.01	17.55
CFC	19.36	22.09

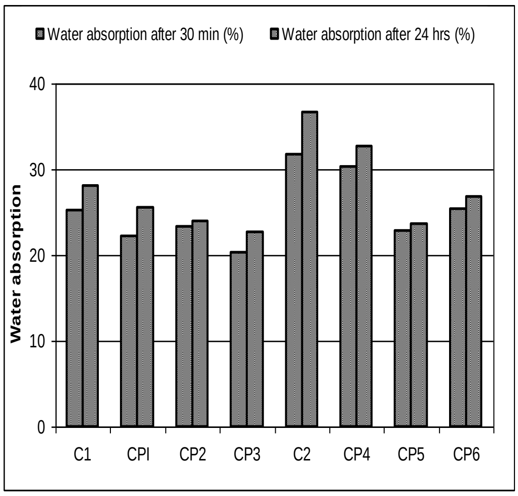

Fig. 5.59(a) Water absorption of different CLSM mixes

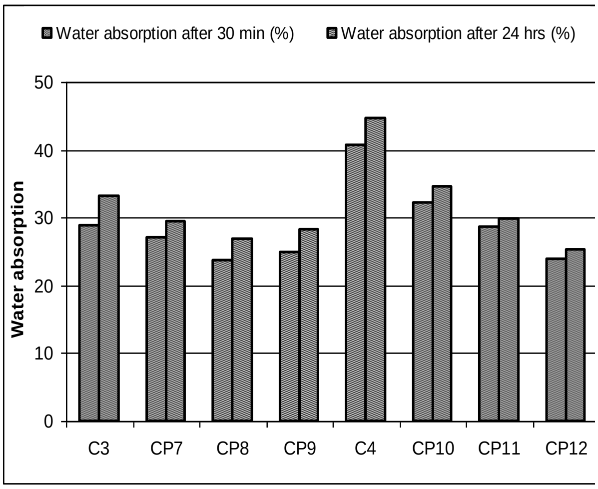

Fig. 5.59(b) Water absorption of different CLSM mixes

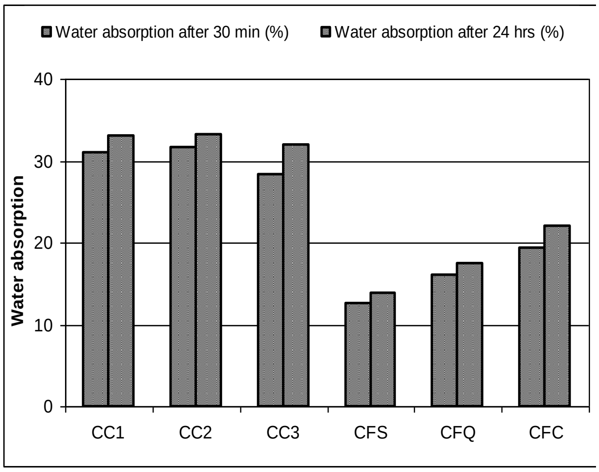

Fig. 5.59(c) Water absorption of different CLSM mixes

6. Conclusions

Based on the experimental studies in the present investigation, the following conclusions can be made regarding the performance of CLSM.

Flowability

• Spread or flow of the mix increases as the fly ash is replaced by coarse aggregates. This is due to the reduction in surface area of the coarse aggregates compared to that of fly ash. Hence water cement ratio is reduced to get the required flow.

• As the water content was increased, the flow increases, regardless of the type of the mix. However, the mixes containing cinder sand requires more water when compared to the mixes containing sand or quarry dust to achieve a particular flow.

• The mix containing quarry dust (CFQ) was homogeneous whereas the mix containing cinder sand (CFC) showed significant amount of bleeding.

Density

• All 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/m3. The density varies over a range depending on the type of ingredients used in the mix to obtain the desired property of the mix.

• The density was less in case of mixes containing cinder sand (CFC) due to low specific gravity (1.83) of the material; hence cinder sand can be added to flowable fill to produce lightweight material.

Unconfined Compressive Strength and Stress - Strain Behaviour

• As the age progresses, the strength of the CLSM mix also gets increased

• The strength of the mix increases as the percentage of coarse aggregate increase

• The initial part of the stress strain curve is non-linear. This may be due to the roughness of the surface on which the load is applied

• The wide range of strength and modulus of elasticity obtained with CLSM mixtures is similar to those of clay soils. The stress-strain behaviour of these mixes in unconfined compression is similar to a range of behaviours from hard to very stiff clay

• 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

• By considering the strain corresponding to fracture, increase in ductility was observed for all the mixes containing coarse aggregates than when compared to standard flowable fill (mixes without coarse aggregates)

• Coarse aggregates such as crushed paver aggregates and cinder sand can be used as a substitute to fly ash in CLSM mixes. The engineering properties of CLSM can be achieved satisfactorily using these materials.

Water absorption

• The percentage water absorption of the flowable fill after 30 minutes was approximately same as that after 24 hours. This indicates that CLSM absorbs maximum water with minimum time.

• Water absorption was lesser in mixes with finer aggregates such as sand, quarry dust and cinder sand than when compared to mixes without aggregates.

• Mixes containing coarse aggregates absorb less water compared to its control mix.

References

IS Codes:

[1] IS 8112:1989; "Specifications for 43 grade ordinary Portland cement", Bureau of Indian standards, New Delhi

[2] IS 2386-1963: (Sep-1982). "Methods of test for aggregates for concrete

[3] IS 2386-1963: (Sep-1982)-part III specific gravity, density, voids, absorption and bulking", Bureau of Indian Standards, New Delhi.

[4] IS 1727:1967, "Specification for methods of test for pozzolanic materials", Bureau of Indian Standards, New Delhi.

[5] IS: 383- 1970, "Specification for Coarse and Fine Aggregate from natural sources for concrete", (Second Version), *BIS, New Delhi*.

ASTM Standards

[1] ASTM D 6103-97 (1997). "Standard Test Method for Flow Consistency of Controlled Low Strength Material (CLSM)", *Annual Book of ASTM Standards: Soil and Rock West Conshohocken*, pp.3.

[2] 2. ASTMD 5971-96 (1996). "Standard Practice for Sampling Freshly Mixed Controlled Low Strength Material".

[3] ASTM D 6024-02 (2002). "Standard Test Method for Ball Drop on Controlled Low Strength Material (CLSM) to Determine the Suitability of Load Application".

[4] ASTM D4832-02 (2002)."Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders".

[5] ASTM D 6023-02 (2002)."Standard Test Method for Unit Weight, Yield, Cement Content and Air Content (Gravimetric) of Controlled Low Strength Material (CLSM)".

Technical Journals:

[1] ACI COMMITTEE 229, (1999). "Controlled Low-strength Materials (CLSM) (ACI 229R-99)", *American Concrete Institute, Farmington Hills, Mich*, pp.15.

[2] BUTALIA, T.S., WOLFE, W.E., LEE J.W., (2001). "Evaluation of a dry FGD material as a Flowable Fill", *Fuel*, 80, pp.845-850.

[3] DU L., FOLLIARD K.J., TREJO D., (2002). "Effects of Constituent Materials and Quantities on Water Demand and Compressive Strength of Controlled Low strength Material", *Journal of Materials in Civil Engineering*, 14(6), pp.485-495.

[4] DU L., FOLLIARD K.J., TREJO D., (2003). "Sustainable development using Controlled Low-Strength Material", *International Workshop on Sustainable Development and Concrete Technology*.

[5] FOLLIARD, K.J., DU, L., TREJO, D., (2002). "Effects of curing conditions on Strength Development of Controlled Low Strength Material", *ACI Materials Journal*, 100 (1), pp.79-86.

[6] GASSMAN, S.L., PIERCE C.E., SCHROEDER, A.J., (2001). "Effects of Prolonged Mixing and Retempering on Properties of Controlled Low Strength Material (CLSM)", *ACI Materials Journal*, 98 (2), pp.194-199.

[7] GOLDBAUM, J.E., HOOK, W., CLEM, D.A., (1997). "Modification of Bridges with CLSM", *Concrete International*, 19(5), pp.44-47.

[8] KATZ, A., KOVLER, K., (2004). "Utilization of industrial by-products for the production of controlled low strength materials (CLSM)", *Waste Management*, 24, pp. 501–512.

[9] LARSEN, R.L., (1990). "Sound Uses of CLSMs in the Environment", *Concrete International*, 12 (7), pp.26-29.

[10] NAGARAJ, T.S., UDAYSHANKAR, B.C., SHASHISHANKAR, A., (2006). "Flow Behaviour of CLSM Slurries – Analysis and Assessment", Bulletin of ACCE (I), 2006 (1), pp.39-44.

[11] NAIK, T. R., KRAUS, R. N., (2001) "Implementation of Technology for Controlled Low-Strength Materials Using Illinois Coal Combustion Products," *Final Technical Report, University of Wisconsin-Milwaukee*.

[12] NAIK, T. R., RAMME, B.W., KOLBECK, H.J., (1990). "Filling Abandoned Underground Facilities with CLSM Fly Ash Slurry", *Concrete International*, 12 (7), pp.19-25.

[13] NMAI, C.K., MCNEAL, F., MARTIN, D., (1997). "New Foaming Agent for CLSM Applications", *Concrete International*, 19(4), pp.44-47.

[14] PIERCE C.E., BLACKWELL, M.C., (2003). "Potential of Scrap Tire Rubber as Lightweight Aggregate in Flowable Fill", *Waste Management*, 23, pp.197–208.

[15] PIERCE C.E., TRIPATHI, H., BROWN, T.W., (2003). "Cement kiln dust in Controlled Low Strength Materials", *A C I Materials Journal*, 100 (6), pp.455-462.

[16] RAMME, B.W., (1997). "Progress in CLSM: Continuing Innovation", *Concrete International*, 19 (5), pp.32-33.
[17] SULLIVAN, R.W., (1997). "Boston Harbour Tunnel Project Utilizes CLSM", *Concrete International*, 19 (5), pp.40-43.
[18] TAHA, R., AL-RAWAS, A., AL-JABRI, K., AL-HARTHY, A., HASSAN, H., AL-ORAIMI S., (2004). "An Overview of Waste Materials Recycling in the Sultanate of Oman", *Resources, Conservation and Recycling*, 41, pp.293–306.
[19] TIKALSKY, P., GAFFNEY, M., REGAN, R., (2000). "Properties of Controlled Low Strength Material Containing Foundry Sand", *ACI Materials Journal*, 97 (6), pp.698–702.
[20] TIKALSKY, P., SMITH, E., REGAN, R., (1998). "Proportioning spent casting sand in Controlled Low Strength Materials", *ACI Materials Journal*, 95(6), pp.740-746.
[21] GABR .M.A, JOHN J. BOWDERS., (2000). "Controlled Low Strength Material using Fly Ash and AMD Sludge", *Journal of Hazardous Materials*, 76, pp.251-263.
[22] NATARAJA .M.C. and NALANDA .Y, (2007, a). "Properties of Controlled Low Strength Materials Containing Quarry Dust", *Indian Geotechnical Journal*, *37(1)*, pp.38-52.
[23] NATARAJA .M.C. and NALANDA .Y, (2007, b) "Performance of industrial by-products in controlled low strength materials (CLSM)", *Waste Management*, article online doi:10.1016/j.wasman.2007.03.030.
[24] PRADEEP. H. R., NAGARAJ. T. S., SHASHISHANKAR. A., (2005). "Analysis and assessment of strength development in controlled low strength materials", *Indian Concrete Journal*, 6(2), pp.27-32.
[25] TURKEL S., (2006). "Long-term compressive strength and some other properties of controlled low strength materials made with pozzolanic cement and class C fly ash", *Journal of Hazardous Materials*, B 137, pp.261-266.
[26] AL-HARTHY. A. S., TAHA. R., ABU-ASHOUR. J., AL-JABRI. K., AL-ORAIMI. S., (2005). "Effect of water quality on the strength of flowable fill mixture", *Cement and concrete composites*, 27, pp.33-39.
[27] HEATHER. J. BROWN., CROUCH .L. K., (2003). "Improved capping methods for CLSM cylinders", *Concrete international*, pp.67-72.
[28] LANDMEYER. S., EDWARD. K. RICE., (1997). "Comparing quick set and regular CLSM", *Concrete International*, pp.34-35.
[29] LIAXIANG. DU., MIGUEL ARELLANO., KEVIN. J. FOLLIARD., SOHEIL NAZARIAN., DAVID TREJO., (2006). "Rapid setting CLSM for bridge approach Repair: A case study", *ACI Materials journal*, pp.312-318.
[30] TARUN. R. NAIK., SHIW. S. SINGH., BRUCE. W. RAMME., (2001). "Performance and leaching assessment of flowable slurry", *Journal of Environmental Engineering*, pp.359-368.
[31] TARUN. R. NAIK., BRUCE. W. RAMME., RUDOLPH. N. CRAUS., (2006) "High Carbon Fly ash in Manufacturing Conducive CLSM and Concrete", *Journal of Materials in Civil Engineering*, pp.743-746.
[32] TARUN. R. NAIK., RUDOLPH. N. CRAUS., RAFAT SIDDIQUE., (2003) "Controlled Low Strength Materials Containing Mixtures of Coal Ash and New pozzolanic Materials", *ACI Materials Journal*, pp.208-215.