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Properties of Controlled Low Strength Materials Containing Quarry Dust

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Introduction

Controlled Low Strength Material (CLSM), as defined by American Concrete Institute (ACI) Committee 229, is a self-compacted, cementitious material used primarily as a backfill in lieu of compacted fill. CLSM, also known as flowable fill, is a self-compacting cementitious material that 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. CLSM consists of fine aggregates, Portland cement, by-product material and water with or without chemical admixtures. After placement, the material sets and hardens within a few hours as the cement and pozzolans hydrate. Once it has set and hardened, flowable fill will not settle under loading. By-product materials such as fly ash, ground granulated blast furnace slag (GGBFS), and waste foundry sand are usually used in flowable fill mixes in order to reduce the cost and to ensure low maximum compressive strengths.

CLSM is a family of artificially made backfill materials, with in-place properties that are between concrete and dense soil. CLSM flows like a liquid, sets like a solid, is self-levelling, and requires no compaction or vibration to achieve maximum density. Non-standard materials may be used to produce CLSM as long as the materials have been tested and found to satisfy the intended application.

CLSM is ideal for use in tight or restricted-access areas where placing and compacting fill is difficult. Applications for flowable fill include backfill in sewer and utility trenches, building excavations, bridge abutments, and conduit trenches as well as miscellaneous uses such as retaining wall backfill and filling abandoned wells, sewers, manholes, and underground storage tanks. Because it does not require compaction or vibration, flowable fill can be a cost-effective fill material. According to the American Concrete Institute 229-99 report, advantages of CLSM include reduced labour and equipment requirements because it is self-levelling, versatility in terms of flowability, strength, and setting times, higher load-carrying capacity than compacted soil or granular fill, reduced excavation costs and improved worker safety because flowable fill can be

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placed without workers entering the trench. Flowable fills are characterized by very high workability and low density and strength, which allow for self-compaction. The material is flowable, allowing perfect filling of any void. High workability is achieved with high amounts of mixing water or by using admixtures (air entraining agents, plasticizers, etc,). They are widely used in backfilling applications, pipe bedding, road-cuts, highway sub base, underground storage tanks, mud slabs and slope stabilization.

Several terms are currently used to describe CLSM, including flowable fill, unshrinkable fill, controlled density fill, lean-mix backfill, flowable mortar, flow-crete, lean concrete slurry, plastic soil–cement slurry, soil–cement slurry and K-Krete. Flowable fill is delivered in a slurry form that resembles very workable concrete and provides for an in-place product that is equivalent to a high-quality compacted soil without the use of compaction equipment and related labour. The mechanical strength of CLSM is generally low (unconfined compressive strength of 0.5 – 2 MPa) permitting re-excavation in the future with conventional excavation equipment. The cohesiveness of highly flowable concrete-like material is generally poor, leading to the risk of segregation, unless a high amount of fines is used in the mix. As the mechanical properties of hardened CLSM are inferior to those of concrete; large amount of fines can be used in its production. With this, the required and much improved properties of the fresh mix can be ensured.

Background and Literature Review

A great deal of research work has been reported in the field of CLSM. Interest in CLSM has increased significantly in recent years, in the area of publications and for use in construction. In western countries, many big and important projects have been completed successfully using CLSM. However, its application in India is very much limited and is in the research stages. Sullivan (1997) reported that the benefits and applications of CLSM were imparted efficiently in the successful completion of the Boston harbour tunnel project. In that project, the underground utility corridors, space between slurry walls and the terrain were filled with CLSM to insure proper filling and to achieve maximum compaction. Goldbaum et al. (1997) documented the use of CLSM by Colorado Department of Transportation (CDOT) for backfilling around pipes or box culverts under existing substandard bridges to convert the bridges to on-grade roadways. For bridge rehabilitation project, the most important property of CLSM was flowability, which was reasonably achieved by the investigators.

Industrial by-products have been used effectively in CLSM production, such as fly ash, ground granulated blast furnace slag (GGBFS) and spent foundry sand. Foundry sand is becoming a more viable product for use in CLSM because of its lower cost, increasing availability, and satisfactory performance. Tikalsky et al. (2000) evaluated the engineering properties of CLSM containing foundry sand. The results they have presented show that by-product foundry sand used in CLSM provide better properties to that of CLSM containing crushed limestone sand. They observed that foundry sand assisted in keeping the strength from exceeding the desired upper limit of 700 kPa. Pierce and Blackwell (2003) examined that crumb rubber from scrap tires can be used to produce a high quality, lightweight flowable fill because of its low specific gravity. They concluded that reasonable flowability, improved ductility and higher thermal insulation were achieved using crumb rubber in flowable fill, when compared to standard flowable fill. Tikalsky et al. (1998) evaluated the use of spent casting sand in CLSM. They conducted tests for strength, water demand, rate of strength development and fluidity. The significance of their research indicates that uniform size of the spent casting sand can provide good flowability and its lower cost enhances its economic advantage as a constituent in CLSM. Research done by Pierce et al. (2003) revealed that low strength property of cement kiln dust (CKD) can be advantageous when used in CLSM because most applications require future excavatability. They observed that flowability and setting times within 24 hours could be achieved with most mixtures and 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 and many other low-strength applications.

Butalia et al. (2000) have evaluated the suitability of using dry FGD (Flue gas desulfurisation) materials in flowable fill applications. A comparison of the characteristics of FGD flowable fill and regular flowable fill in terms of placeability, unconfined compressive strength and digability were made and they observed that FGD flowable fill can be considered as good as regular flowable fill. 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 by Katz and Kovler (2003). Tests were performed for bleeding, water absorption and volume changes of the flowable fill mixes. The results obtained from their research reveal that CLSM with good properties could be made with large proportions of wastes (25 to 50 %), which results in cost savings. Taha et al., (2004) investigated the use of cement by-pass dust in the flowable fill mixtures. The mixtures were tested for compressive strength and they concluded that quantities of materials used in the mix and the difference in the amount of water added to reach the required flow would influence the strength. Folliard et al., (2002) investigated the effects of curing conditions on strength development of CLSM. The effects of curing regime on the compressive and splitting tensile strength of CLSM were studied and it was observed that effects of temperature and humidity were found to largely depend on the constituent materials and mix proportioning.

Ramme (1997) describes that although CLSM generally costs more per cubic meter than most soil or granular backfill materials, its many advantages such as self compacting ability, reduced labour and versatility often result in lower in-place costs. CLSM provides the engineer and constructor with another tool in solving the many challenges of constructing and maintaining today’s civil infrastructure. Landwermeyer et al. (1997) reported the study that was done by city of Tulsa to examine bearing strength, digability, penetration resistance, unconfined compressive strength and subsidence for regular and quick setting CLSM. The results obtained by the study revealed that quick-setting CLSM begins the hydration process more rapidly than regular CLSM. They also observed that quick-setting mixtures begin to harden within minutes of being placed and can be tested for unconfined compressive strength at a test age of six hours or less whereas regular CLSM can only be tested for unconfined compressive strength after a test age of at least one week.

Objectives and Research Significance

After observing the tremendous amount of research going on in abroad and the gaining importance of this material in India, an attempt has been made to study some of the engineering properties of CLSM which contains quarry dust and natural sand. In addition, rice husk ash and fly ash were also used. A total of six different mixtures were considered. The objectives of this research are:

- To evaluate the potential of quarry dust in Controlled Low Strength Materials
- To study the engineering properties of CLSM such as flowability, density, unconfined compressive strength, stress-strain behaviour and water absorption, using quarry dust and comparison of these properties with similar CLSM mixtures containing sand.
- To study the performance of quarry dust when used with and without other by-products such as fly ash and rice husk ash.

Materials

Cement

Cement used for this project work is 43 Grade ordinary Portland cement conforming to the requirements of IS: 8112-1989. The amount of cement in a flowable fill mix, together with the water and the quantity of binder materials added, determines the ultimate strength of the mixture. Table 1 shows the properties of the cement used.

TABLE 1: Properties of Cement Used

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

Fly Ash (FA)

Fly ash is a finely divided residue resulting from the combustion of powdered coal, transported by the flue gases, and collected by electrostatic precipitator. Fly ash is the most widely used pozzolanic material all over the world. The increased use of coal as an energy source has drawn the greater attention of researchers and engineers towards utilisation of fly ash as construction materials, which has enormous potential for its application in buildings, roads and other structures. Fly ash for the present research has been obtained from the Raichur thermal power plant, Karnataka. Specific gravity of fly ash was found to be 2.1. It passes completely through 90 micron sieve

Rice Husk Ash (RHA)

RHA is a very fine pozzolanic material and its particle size and specific surface depend upon the burning conditions under which it is produced. In general, the average particle size ranges from 5 to 10 μm, and the specific surface area ranges from 20 to 50 m^2/g. The rice husk ash used in the present research was obtained from the local brick industry. In brick industry, rice husk was used to burn the bricks. The ash obtained from burning rice husk has been grinded in a flour mill to obtain finer rice husk ash. The specific gravity of rice husk ash was found to be 2.04. The material passes completely through 90 micron sieve

Sand

The sand used for this study was natural river sand. For the present research, the sand passing through 4.75 mm sieve was used. The sand was tested as per IS: 2386-1963 procedure. The sand conforms to grading zone III as per IS: 383-1970. The specific gravity, fineness modulus of sand were 2.68, 2.54 respectively. The bulk unit weight was 14.80 kN/m^3 corresponding to ssd condition. The sand was coarser than the quarry dust used.

Quarry Dust

Quarry dust consists mainly of excess fines generated from crushing, washing, and screening operations at quarries. The material properties of this waste vary with the source, but are relatively constant at a particular site. The quarry dust passing through 4.75 mm sieve was used for the present research. The quarry dust is not conforming to any grading zones as per IS: 383-1970, as the material is deficient in certain fractions. Its specific gravity and fineness modulus were 2.63 and 2.03 respectively. The bulk unit weight of quarry dust was 15.87 kN/m^3 corresponding to ssd condition. The quarry dust was finer than the sand used.

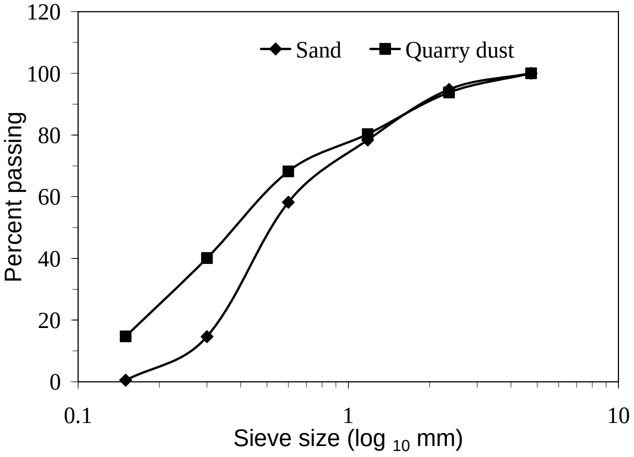

Fig. 1 Sieve Analysis of Sand and Quarry Dust

Water

The amount of water in a flowable fill mix has a direct effect on the flowability and strength development of the mixture. Water requirements for mixture fluidity depend on the surface properties of the solids in the mixture. Potable water was used for mixing of the materials, flowability test and water absorption test.

Experimental Programme

To perform effectively, flowable fill must meet specific criteria regarding physical and mechanical properties such as flowability, density, unconfined compressive strength, stress-strain behaviour, Young's modulus and water absorption. Table 2 shows the different mixes, their identification and proportion which were tested for the above said properties. The various proportions selected for CLSM mixes is based on the range of typical proportions used by the various researchers as found in the literature.

TABLE 2: Mix Identification and their Proportions for Various Mixes

Mix No.	Mix Identification	Mix	Proportion
1	CS	Cement: Sand	1:12.5
2	CFS	Cement: Fly ash: Sand	1:12:50
3	CRS	Cement: Rice husk ash: Sand	1:12:50
4	CQ	Cement: Quarry dust	1:12.5
5	CFQ	Cement: Fly ash: Quarry dust	1:12:50
6	CRQ	Cement: Rice husk ash: Quarry dust	1:12:50

Flowability

The flowability test was conducted according to ASTM specifications. Flowability was measured using an open-ended 75mm x 150 mm cylinder in accordance with ASTM D 6103. First, the dry mix was prepared, and then water was added by gradually increasing the water/cement (w/c) ratio. The cylindrical mould was set upright on flat surface. The mould was filled with sample without tamping and then top was strike off with flat edge to form a flat surface. The residue from around the bottom of the mould was cleared. The mould was lifted straight up for duration of 3 seconds, allowing sample to spread on the flat surface and lifted vertically upwards. The resulting flow diameter in two perpendicular directions was measured. A spread of 175 mm to 225 mm is considered flowable.

Density and Unit Weight

Densities of the mixes were calculated at the time of testing for unconfined compressive strength. The cube and cylinder specimens were weighed and the dimensions of the specimens were found out accurately. The specimens were kept in water for 24 hours and the weights of the specimens were taken in saturated surface dry condition. Unit weights of the mixes in saturated surface dry condition were found.

Unconfined Compressive Strength and stress-strain behaviour

The most important property of flowable fill is its strength, measured as unconfined compressive strength. Strength development in flowable fill mixtures is directly related to the components of the mix. The cubes of size 50mm x 50mm x 50mm and cylinders of 75mm x 150 mm were cast and tested for unconfined compressive strength. Before casting cylinders for testing, the plastic cylindrical moulds were cut lengthwise from top to bottom, exactly into two halves so that casting and demoulding of the specimens will become easy. The two halves were kept against one another and tied throughout with rubber band to take care of any expansion while filling the mix into the moulds. The CLSM was then placed into the moulds and finished smoothly. Then, the moulds were covered with plastic bags. Eighteen cubes (using Mould Three Gang) and ten cylinders were cast for compressive strength tests. The cubes and cylinders were tapped lightly with a metal rod to remove entrapped air.

The specimens were cast taking into consideration that the flow to be approximately 200 mm. Therefore, to achieve 200mm flow, w/c ratio for a particular type of mix was taken from flow test results. The specimens were demoulded after 2 to 3 days, when enough strength has been obtained for proper demoulding, that is, without damaging the specimen. Six cube specimens and three cylinder specimens from each CLSM mix were tested for 7 day, 28 day and 60 day strengths. Loading was applied to the specimens through a loading frame consisting of high sensitivity proving ring of 2 kN capacity at a uniform strain rate until failure. Stress-strain behaviour was also recorded during the testing.

Water Absorption

Water absorption test for each mix was conducted at the age of 28 days. Three cubical specimens from each mix were weighed and kept in water for 30 minutes and were taken out from the water and again weighed. Then, the specimens were kept dried for 48 hours. Again, the specimens were weighed and kept in water for 24 hours. After 24 hours, the specimens were taken out from water and weights of the specimens were taken.

Results and Discussion

Flowability

Table 2 represents the composition of various mixes that were tested for flowability characteristics. The flowability test was conducted according to ASTM specifications. Flowability was measured using an open-ended 75mm x 150 mm cylinder in accordance with ASTM D 6103. For each sample, starting from the flow of about 175mm, flow test was conducted. W/c ratio was gradually increased to get higher flows up to a range of about 275 mm. For this flow range i.e., from 175 mm to 275 mm, w/c ratio for different mixes was tabulated. Graphs of flowability v/s w/c ratio for different mixes were plotted. The effect of w/c ratio on the flowability can be seen from the graph. The variation of flowability with w/c ratio is shown in Figures 2 - 4. All the mixtures attained flowability from a range of about 175 mm to 275 mm with the corresponding increase in the w/c ratio. However, significant bleeding was observed in case of mixes CQ and CS when a flow range of 225 mm to 275 mm was attained. It can be observed from Figures 2 – 4 that, for the mixes containing quarry dust, desired flow can be achieved with less w/c ratio compared to mixes containing sand. This is true even when pozzolanic materials like fly ash or rice husk ash were used with sand or quarry dust.

Density

The density or unit weight of flowable fill mixtures is dependent primarily on the unit weight of the filler or aggregate material. Table 3 shows the mixtures that were tested for density corresponding to about 200 mm flow. The table also contains the actual flow, w/c ratio and w/cm ratio of the mixes at the time of casting the specimens.

TABLE 3: Flowability, Water cement ratio and Water cementitious materials ratio of Various Mixes

Mix No.	Mix identification	Flow (mm)	w/c	w/cm
1	CS	165	4	-
2	CFS	195	16	1.23
3	CRS	210	28	2.15
4	CQ	205	3	-
5	CFQ	208	13	1.00
6	CRQ	203	25	1.92

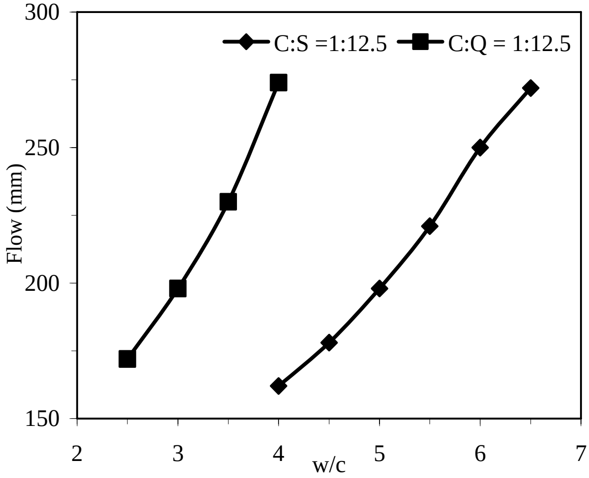

Fig. 2 Flow v/s w/c for Mixes CS and CQ

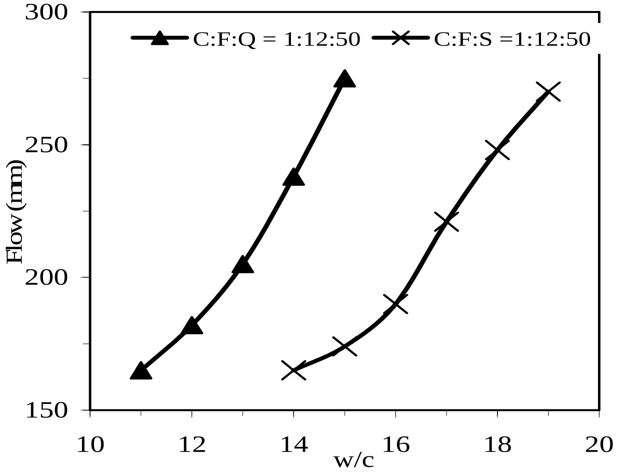

Fig. 3 Flow v/s w/c for Mixes CFS and CFQ

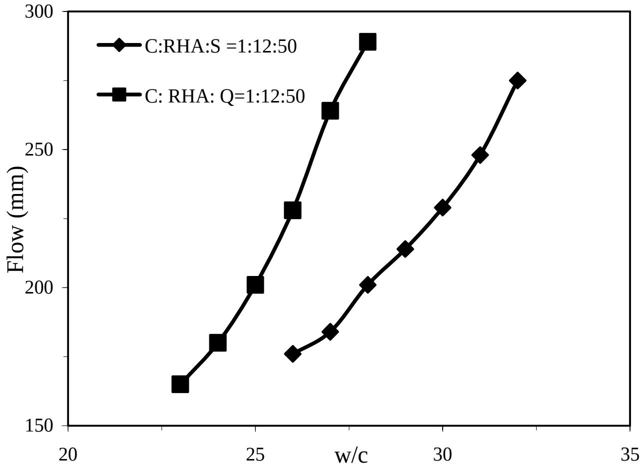

Fig. 4 Flow v/s w/c for Mixes CRS and CRQ

Density of cubes and cylinders were found and the average density considering three cubes and three cylinders was calculated. In addition, densities of the mixes in saturated dry condition were also found. Table 4 shows the density and saturated surface dry density of each mixes. It can be observed from Table 4 that the average dry unit weight of all the mixtures was within 13.3 – 18.32 kN/m^3, whereas the saturated surface dry unit weight was within 15.98 - 20.82 kN/m^3. These values compare well with the normal density of regular CLSM mixtures specified in ACI Committee 229. The dry unit weight of the mixes containing quarry dust was more when compared to mixes containing sand. Because the majority of the material mass comes from sand or quarry dust, the density was reasonably consistent for all mixtures as there is no significant difference in the specific gravity between sand (2.68) and quarry dust (2.63). However, the mixtures containing rice husk ash (CRS and CRQ) has a low density than other mixtures due to its low specific gravity (2.04).

TABLE 4: Dry Density and Saturated Surface Dry Density of Different Mixes

Mix No.	Mix identification	Dry unit weight (kN/m^3)	Saturated surface dry unit weight (kN/m^3)
1	CS	17.91	20.82
2	CFS	17.77	19.88
3	CRS	13.30	16.12
4	CQ	18.32	20.67
5	CFQ	18.12	20.24
6	CRQ	13.40	15.98

Unconfined Compressive Strength

Table 3 shows the different mixes with their properties considered for unconfined compressive strength test. The specimens were tested for 7 day, 28 day and 60 day compressive strengths. These results for cubes and cylinders are presented in Table 5. The results indicate that the quantity of materials used in the mix would influence the strength. In addition, the strength of the mixes varies quite significantly because of the considerable difference in the amount of water added to reach a desired flow of about 200 mm. For this desired flow, the water content required for quarry dust is lower than that of the sand and hence the water-cement ratio is higher. This is probably due to the finer fractions of quarry dust contributing to increased flow. With this the strength of the quarry dust mixes is significantly higher than that of sand mixes.

TABLE 5: Unconfined Compressive Strength of Different Mixes and their Coefficient of Variation

Mix identification	Cube/ Cylinder	7 day compressive strength		28 day compressive strength		60 day compressive strength	
		Mean (kPa)	C.O.V	Mean (kPa)	C.O.V	Mean (kPa)	C.O.V
CS	Cube	206.67	0.25	273.43	0.17	301.84	0.11
	Cylinder	154.10	0.24	269.70	0.12	289.96	0.20
CFS	Cube	47.49	0.20	73.33	0.35	90.00	0.36
	Cylinder	30.40	0.22	48.61	0.28	65.93	0.42
CRS	Cube	50.00	0.22	76.67	0.33	98.40	0.28
	Cylinder	34.37	0.24	55.31	0.39	74.39	0.32
CQ	Cube	986.67	0.12	1210.0	0.07	1231.53	0.05
	Cylinder	867.80	0.08	933.00	0.05	963.33	0.03
CFQ	Cube	361.17	0.12	380.00	0.10	392.84	0.13
	Cylinder	190.90	0.08	213.33	0.07	220.20	0.12
CRQ	Cube	56.67	0.25	69.72	0.12	76.82	0.08
	Cylinder	41.90	0.33	53.12	0.13	56.27	0.14

It can be observed that the strength of CLSM increases as the age increases. However the strength increase is only marginal. The 60-day strength was slightly more than its 28-day strength. This is due to reduced pozzolanic activity of the cementitious materials. The same trend was observed in all the mixes and can be seen in Figures 5 and 6.

The 28-day unconfined compressive strength of all the mixes were below 2 MPa i.e., they fall below the maximum strength criterion for excavatability. From Table 5 it can be observed that the 28-day cube strength of all the mixtures except CFQ and CQ and 28 day cylinder strength of all the mixtures except CQ was less than 300 kPa which would allow for manual excavation. In addition, the 28-day cube strength and cylinder strength of mix CQ was more than 700 kPa but less than 1400 kPa, which allow for excavation with mechanical equipment such as backhoes. The 28 day cube strength of mixtures containing quarry dust i.e., CQ, CFQ and CRQ were 1210 kPa, 380 kPa and 69.72 kPa respectively. These values are representative of medium and very stiff clays as investigated by previous researchers. Also, the 28 day cylinder strength of CLSM containing quarry dust comes under the category of medium and very stiff clays. This suggests that CLSM mixtures containing quarry dust can be used in applications where conventional clay fills is normally used, thus eliminating the compaction requirement. These different mixtures can be specified for different applications with a varying range of required strength.

Cube compressive strength of the specimen was more than its corresponding cylinder compressive strength as expected regardless of the type of the mix. The mean unconfined compressive strength and the co-efficient of variation of the different mixes based on six specimens were calculated and tabulated as shown in Table 5. The relation between the cube compressive strength and cylinder compressive strength has not been derived. This ratio appears to depend on the type of mix and the amount of ingredients. As such no constant ratio exist between these two strengths.

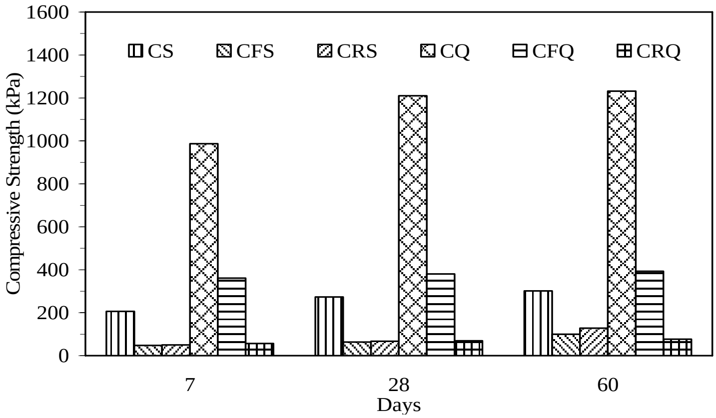

Fig. 5 Compressive Strength of Cubes for Different Mixes

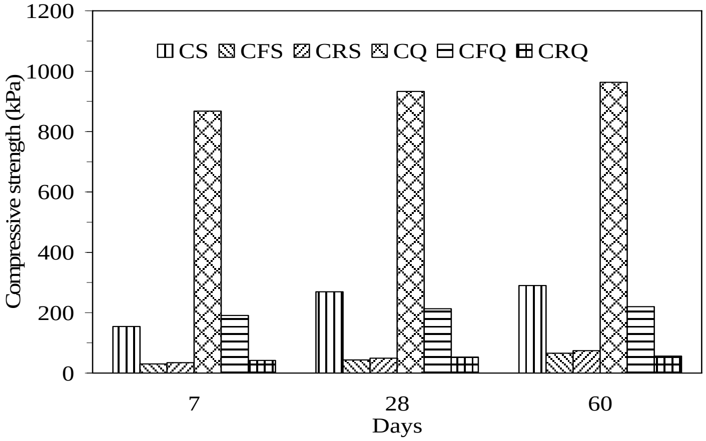

Fig. 6 Compressive Strength of Cylinders for Different Mixes

Stress-Strain behaviour

Axial stress-strain behaviour was recorded during the unconfined compression test at the age of 60 days for both cubes and cylinders. However the stress-strain curves were plotted for cubes only and are shown in Figures 7-9. From these Figures, it can be observed that the strain corresponding to peak stress is about 0.02 to 0.03 and are well within the usual values for soft to medium clay as reported by Pierce and Blackwell (2003). From these Figures, it can be further observed that the stress in case of CLSM can be sustained to nearly 0.035 or 3.5% strain before fracture in case of mixes CFQ and CRQ. However, for mix CQ, this strain is up to 0.045 or 4.5% before fracture. This represents an increase in ductility of the mix compared to other two mixes. These strain values compares well with the values for standard flowable fill, which is about 2.5% strain before fracture as observed by Pierce and Blackwell (2003). Modulus of elasticity, E was calculated as the tangent to the stress-strain curve at 50% of maximum stress. Modulus of elasticity increases as the strength increases. The moduli of elasticity for mixtures CQ, CFQ and CRQ were 48.75 MPa, 25 MPa and 4.23 MPa respectively. For a given mixture the differences in measured E from cube to cube are similar to the differences in measured compressive strength. Average stress-strain values were considered for plotting these curves.

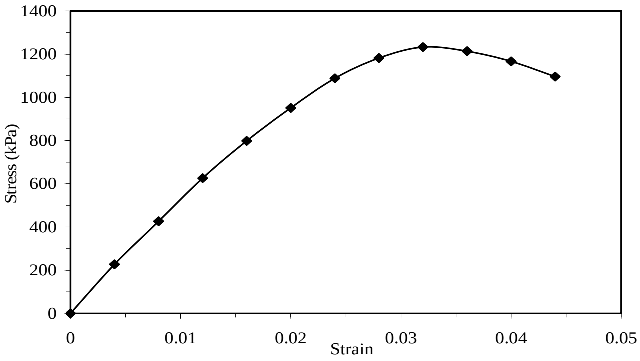

Fig. 7 A 60 day Stress-Strain Curve for Mix CQ

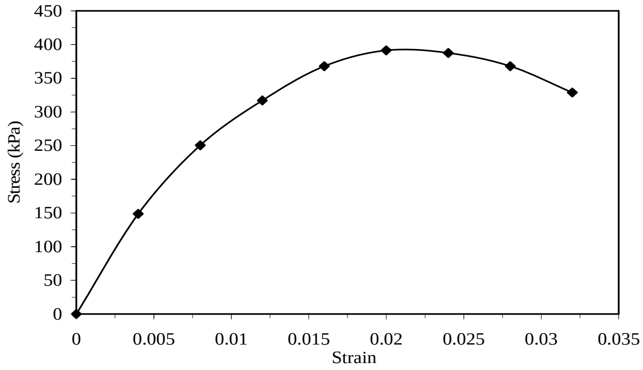

Fig. 8 A 60 day Stress-Strain Curve for Mix CFQ

The ratio of E_{avg}/UCS_{avg} was also calculated for the three mixes and the results are shown in Table 6. The reason for this calculation is to show that the stress-strain behaviour of CLSM containing quarry dust is similar to clay soils in unconfined compression. The ratio, E_{avg}/UCS_{avg} was less than 100 for all the three mixes CQ, CFQ and CRQ. Experimental studies by Duncan and Buchignani (1973) suggest that there are approximate lower and upper bounds for Eavg/UCSavg of clays, where 50 represents very soft clay and 250 represents hard clay. From the results it can be observed that the CLSM containing quarry dust represents a range of soft to medium clay. Thus the range of CLSM mixtures considered in the present study behaves in a similar manner to a wide range of clay soils.

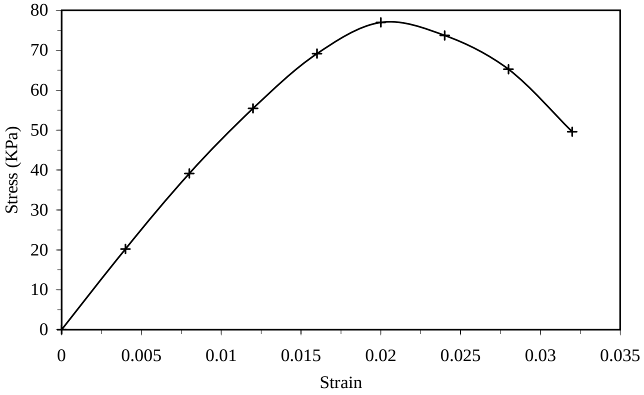

Fig. 9 A 60 day Stress-Strain Curve for Mix CRQ

TABLE 6: Average 60 day Unconfined Compressive Strength and Modulus of Elasticity for Mixtures containing Quarry Dust

Mix	UCS_{avg} (kPa)	E_{avg} (kPa)	E_{avg}/UCS_{avg} (kPa)
CQ	1231.53	48750	39.58
CFQ	392.84	25000	63.64
CRQ	76.82	4230.77	55.07

Water Absorption

Water absorption test for each mix was conducted. Tests were conducted by keeping the specimens in water for 30 minutes and 24 hours. Percentage water absorption of the mixes ranges from minimum of 11% in case of CFQ mix to maximum of about 21% in case of CRS mix. The water absorption in case of mixes containing rice husk ash was more compared to all other mixes. This could be due to low density and high porosity of the mix.

It can be observed from Figure 10 that the water absorption was less in mixes containing quarry dust when compared to the similar mixes containing sand. It can be also observed that the percentage water absorption after 24 hours was marginally more than the percentage water absorption after 30 minutes. This shows that flowable fill materials absorb maximum water with minimum time.

Conclusions

Following are the conclusions based on the results of this investigation.

1. As the water content was increased, the flow increases, regardless of the type of the mix. Bleeding was observed in case of mixes CS and CQ. Less w/c ratio is required to get a particular flow in case of mixes containing quarry dust than that of mixes containing sand.

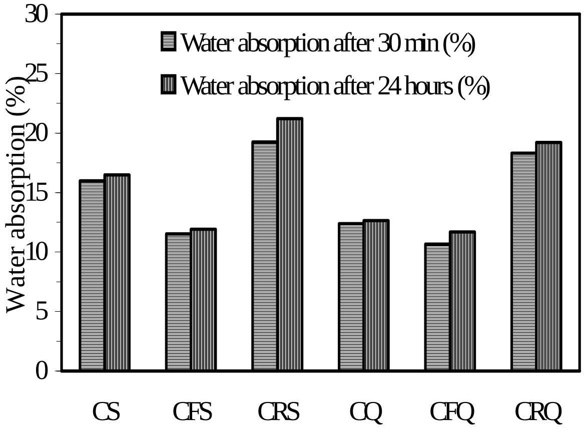

Fig. 10 Water Absorption of Different Mixes

2. All the CLSM mixtures considered in the study can be classified as regular CLSM based on their density. The density varies over a wide range depending on the type of ingredients to suit a particular field application.
3. Cube compressive strength was more compared to cylinder compressive strength regardless of the type of the materials used in the mix. The compressive strength of all mixes increases as the age progresses.
4. The strength obtained in case of mixes containing quarry dust (CQ and CFQ) was more when compared to mixes containing sand (CS and CFS).
5. The percentage water absorption of the flowable fill materials after 30 minutes was approximately same as that after 24 hours. This indicates that CLSM absorbs maximum water with minimum time. Water absorption was less in mixes containing quarry dust when compared to the mixes containing sand which is due to fineness of the material.
6. 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 can be likened to a range of behaviours from soft to medium clay. By varying the amount of quarry dust, cementing materials and water, it is possible to create a self consolidating material with wide range of hardened to fluid state properties for field applications, provided the volume stability meets normal requirements for CLSM. Thus when a soil like material applications are called for, the performance of CLSM mixtures containing quarry dust and sand show a promising future.

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