Influence of Addition of Admixtures and Lime on the Properties of Pond Ash Based High Strength Flowable Fills

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Abstract. Flowable fills or Controlled Low Strength Materials (CLSM) are currently considered as better alternative to the conventional fills for various civil engineering applications such as backfill behind retaining walls, bedding layer of pipelines and as subgrade and subbase for pavements, etc. Cement is the primary binding material added along with fine aggregates and water in producing flowable fill mixes. In this paper, the influence of adding lime and admixture along with the regular constituent materials in the production of CLSM mixes is investigated. . Lime contents of 1 and 2% and superplasticizer of 0.2, 0.6 and 1% were added along with regular CLSM mix. The properties of flowable fills, such as flowability and unconfined compressive strength of different mixes of flowable fills, are considered to identify the effect of both lime and admixture addition on the plastic and in-service properties. . Based on the experimental analysis, it was concluded that the addition of lime was found to be more effective than that of superplasticizer addition for high strength flowable fills as the unconfined compressive strength values obtained for lime added mixes were significantly higher.

Keywords: CLSM, Flowable fills, admixtures, lime content.

1 Introduction

Controlled Low Strength Materials (CLSM) of flowable fills are generally considered as a replacement to the natural aggregates for various geotechnical applications such as backfill material behind retaining walls, filling of underground mines, shafts and tunnels, bedding layer of pipelines, etc. (ACI 229R-99, 2005; Bheemasetti et al., 2015; Jadhav et al., 2017). American Concrete Institute (ACI 229R-99, 2005) defines CLSM as a mixture of fly ash, cement, fine aggregates and water which is self-compacting in nature. The performance of CLSM mixes depends to a great extent on the types and quantity of constituent materials considered in the mix. The main materials considered for the production of CLSM mixes are industrial by-products such as fly ash, wood ash, sewage sludge, pond ash, bottom ash, cement kiln dust and mine tailings along with cement and water (Kim et al., 2016; Nataraja & Rao, 2016; Sheen et al., 2013; Yan et al., 2014). In order to achieve certain required properties at the proposed site, admixtures are also added along with the regular CLSM mixes (Du et al., 2012; Hoopes, 1998; Ibrahim et al., 2022). Instead of cement, other binders are also considered by various researchers in the production of CLSM (Lee et al., 2013; Manh Do et al., 2019; Xiao et al., 2021). The main benefits of CLSM include the self- compaction behavior, reduced equipment and labor involved in production of mix, reutilization of industrial waste products in the production of CLSM and increased construction safety.

As CLSM mixes are widely adopted as replacement to granular materials for various applications in civil engineering, vast studies have been conducted by various researchers to identify the utilization of various industrial by-products as constituent material in the CLSM production. The two main properties to be considered for the CLSM mixes for various applications are the flowability and Unconfined Compressive Strength (UCS) of the mix. ASTM D6103-04 (2004) conforms the flowability of CLSM mixes to be between 200 and 300 mm. In applications where the CLSM mixes are to be re-excavated at later ages, low strength CLSM mixes are considered which has a UCS less than 0.7 MPa at 28 days. In situations, where the CLSM mixes are considered as filling material such as structural fills or filling of underground mines, the UCS at 28 days should be in the range of 8.3 MPa (ACI 229R-99, 2005; Ibrahim et al., 2022).

As many of the previous studies considered cement as the binder material for CLSM production, the key interest of the present study is to identify the use of other binding materials in CLSM production along with the regular constituent materials. Pond ash collected from Thermal Power Plants was utilized in this project as the aggregate in the production of CLSM. Lime was considered as the binding material and high range water reducing admixtures (superplasticizer, SP) was also added in the regular CLSM mixes to study the effect of these materials on the properties of CLSM mixes. Different mixes of CLSM were considered in this study by varying the lime content in the mix from 1 and 2% and the 0.2, 0.6 and 1% of SP was also added in some of the mixes. The properties such as flowability and UCS at 28 days for different mixes of flowable fills was evaluated for the study to identify the effect of both lime and SP addition on the different properties of CLSM mixes.

2 Experimental program

2.1 Materials

The aggregates provided in the CLSM mixes constitute the solids in enhancing the strength properties of the mix. The binders added to the mix such as cement, lime, SP and water helps in the hydration process which in turn leads to the production of a cohesive mix. In this project, the aggregates considered for the production of CLSM mix is pond ash, which is a mixture of both fly ash and bottom ash. The pond ash was collected from the Ennore Thermal Power Station in Tamil Nadu, India. The binders considered for the study are Ordinary Portland Cement of 53 grade, lime (Calcium Oxide) and Superplasticizer (SP). DARACEM - 811 was the superplasticizer considered which is a Sulphonated Naphthalene Formaldehyde (SNF) based superplasticizers (SP). Different percentages of SP were added along with water to the flowable fill during mixing stage for analyzing the effect of SP on the flowability and UCS of flowable fills. Tap water was used for all the tested mix formulations of CLSM mixes.

The index properties of the pond ash were determined initially as per ASTM standard specifications which also meets IS standards. As per the grain size distribution and specific gravity studies conducted on pond ash in accordance with IS 2720 procedures, the ash contains 94% of sand sized particles and a specific gravity of 2.21 was obtained. The pH of the ash determined as per ASTM specifications showed a value of 7.5. As per the criteria suggested by Sridharan & Prakash (2007), the considered pond ash was classified as SP – SM.

2.2 Mixture proportions and testing methods

Du et al., (2002) has conducted studies to study the effect of constituent materials on the properties of CLSM mixes and as per the studies it was identified that the mixture compositions considered in the mix has a greater influence on the strength behavior of flowable fills. Thus, to determine it, the present study was done to evaluate the use of lime and admixtures in the production of high strength flowable fills. As per ACI 229R-99 (2005), the CLSM mixes having UCS less than 0.7 MPa at 28 days was considered as low strength flowable fills. Thus, in this study a minimum UCS value of 0.7 MPa at 28 days was considered. Different compositions of CLSM mixes were prepared by varying the cement, lime, SP and water contents in the mix to obtain a high strength flowable fill mix of UCS value greater than 0.7 MPa at 28 days.

The cement contents considered for the study was 5, 7 and 9% of the weight of pond ash. In order to account for a UCS value greater than 0.7 MPa at 28 days, lesser cement contents were not considered in the study. Lime contents of 1 and 2% of weight of pond ash was added along with cement as the binding agent for some of the mixes. 0.2, 0.6 and 1% of SP was added along with cement in some other mixes. The two important characteristics of flowable fills such as flowability and UCS at 28 days were tested for the different mixes prepared as per the mix proportions stated above. The experimental procedures followed for conducting both flowability and UCS tests on CLSM mixes are explained in the coming sections.

2.3 Experimental methodology for flowability and UCS tests

ASTM D6103-04 (2004) specifications were followed to determine the flowability of CLSM mixes. The procedure involves mixing the dry components such as pond ash, cement and lime in required proportions in Hobart mixer for 15 minutes followed by adding the required quantity of water and continuing the mixing for a period of 15 minutes. In SP added mixes, initially the SP was added to water and then it was added to the dry mix for mixing. The designed amount of water for achieving the flowability for all the mixes were obtained by trial-and-error procedure.

The wet mix obtained from the Hobart mixer was poured into a two side open ended cylinder of 75 x 150 mm dimensions and the spread obtained in two perpendicular directions was measured and represented as the flowability of the CLSM mix. The testing of flowability was done immediately after the mixing of the constituent elements in the required proportion in the mixer. The design mixes for preparing the samples for the UCS was decided based on the quantity of water required for obtaining the flowability values of both 200 and 300 mm.

Samples for UCS testing was prepared in accordance with the specifications stated in ASTM D4832-10 (2010). Tests were done on 50 x 100 mm cylindrical samples prepared for both flowability values and cured for different curing periods of 7, 14 and 28 days. Curing was done by keeping the samples in desiccators after covering with cling film. Universal testing machine with a strain rate of 0.5 mm/min was adopted for testing the samples at different curing periods. An average of three samples tested for each design mix was represented as the UCS at the specific period.

3. Test results and discussions

3.1 Flowability for cement based CLSM mixes

The water contents required for achieving the flowability values of 200 and 300 mm for mixes where only cement was considered as the binding agent is given in Fig.1. Both water content and cement content used in the design mixes are expressed as a percentage of the weight of pond ash considered in the mix. As expected, the water contents required for achieving the specified flowability values was found to increase with increase in the cement content.

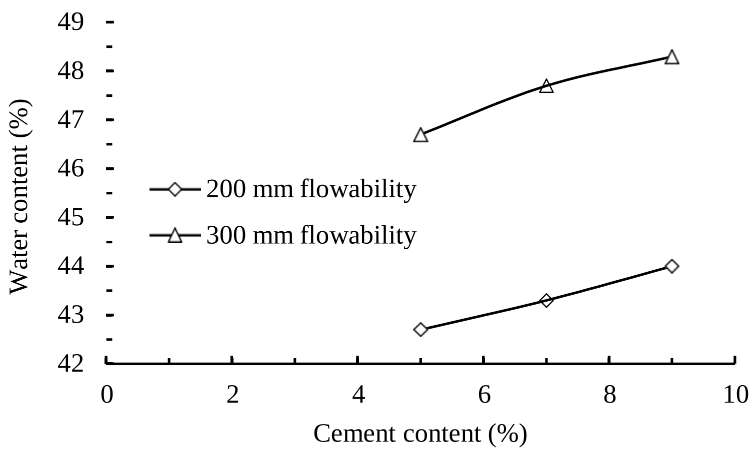


Fig.1. Water content required for both flowability values for higher cement content

3.2 UCS variation for cement based CLSM mixes

The variation of UCS for the different cement content based CLSM mixes for different curing periods of 7, 14 and 28 days are given in Fig. 2. An increment in strength was noted with increase in curing period because of the hydration process of the binding agents considered in the mix. The 28-day compressive strength obtained for 9% cement content was found to be higher than 2 MPa which is the strength required for a structural fill that does not require re-excavation at later ages (ACI 229R-99, 2005).

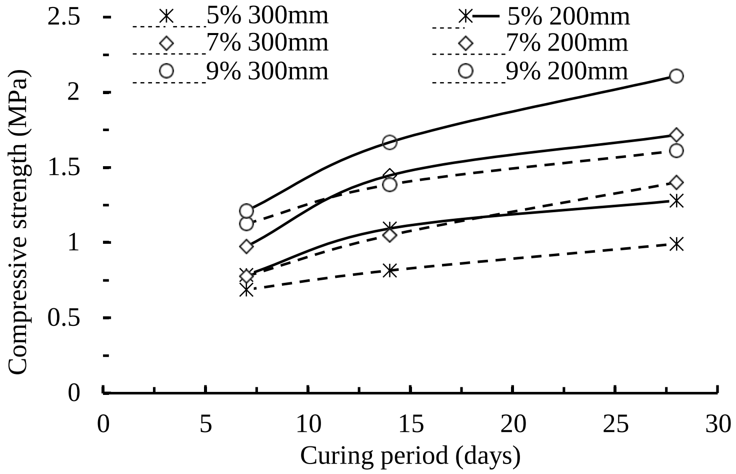


Fig. 2. UCS variation with curing period for higher strength CLSM mixes

3.3 Effect of superplasticizers on high strength CLSM mixes

High range water reducing agents (superplasticizers) are generally added along with cementitious materials in order to reduce the water contents in the mix. Superplasticizers can enhance the strength of CLSM mixes without compromising on the flowability of the mixes. Thus, both flowability and UCS testing were carried out for cement contents of 5, 7 and 9% along with superplasticizers of 0.2, 0.6 and 1% in order to identify the strength enhancement. The reduction in water content for all the cement contents with addition of superplasticizers is given in Fig. 3. It can be noted that with increase in percentage of superplasticizer, the water content required for achieving the flowability was found to reduce. The experiments were carried out for 200 mm flowability samples. The same trend will be shown by the 300 mm flowability samples.

The variation of UCS with curing period for all the cement contents for different superplasticizer content is given in Fig. 4 (a), (b) and (c). The compressive strength increases with increase in the superplasticizer content in the mix. The UCS results obtained for the SP added mixes at 28 days are given in Table 1. It can be noted from the table, that the UCS values improves with SP content for constant cement content. The UCS value obtained at 28 days for 9% cement content with 1% superplasticizer was about 3 MPa which was greater than the value obtained for 9% cement content samples at 28 days.

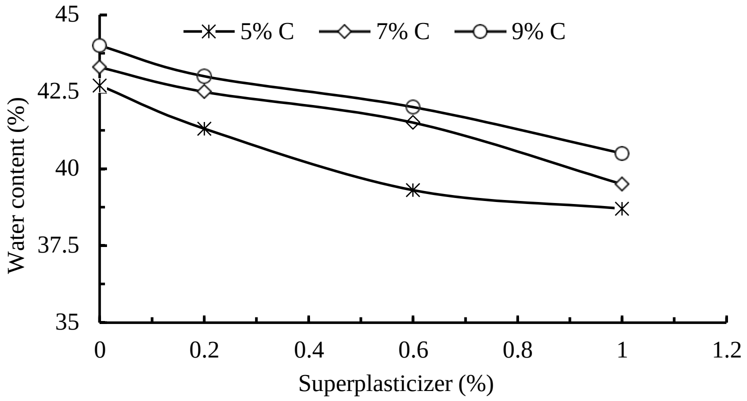
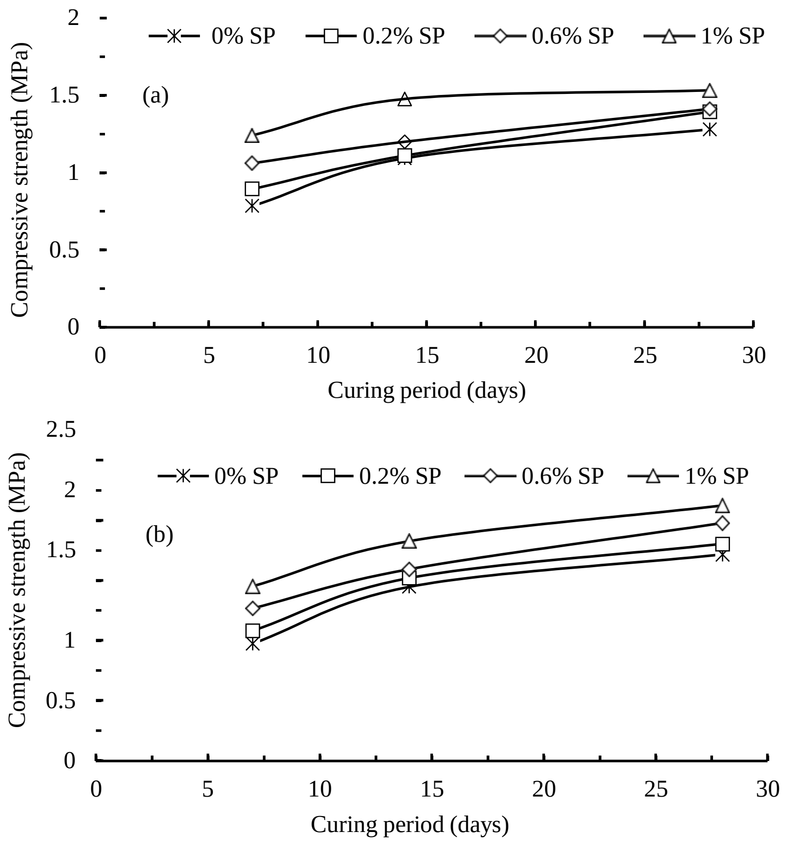


Fig. 3. Water content variation with superplasticizer content for different mixes



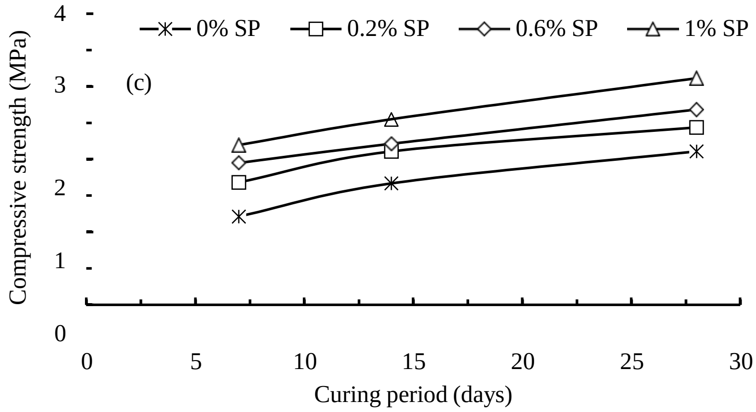


Fig. 4. UCS variation for different percentages of SP for cement contents of (a) 5% (b) 7% and (c) 9%

Table 1. UCS values obtained at 28 days for SP added mixes

Serial No.	Cement (%)	SP (%)	UCS (MPa)
1	5	0	1.28
		0.2	1.4
		0.6	1.42
		1	1.53
2	7	0	1.72
		0.2	1.8
		0.6	1.98
		1	2.13
3	9	0	2.11
		0.2	2.44
		0.6	2.68
		1	3.13

3.4 Effect of lime addition on high strength CLSM mixes

In order to identify the effect of lime on high strength flowable fill samples, experiments were carried out by the addition of 1 and 2% lime along with cement. The cement content in the mix was varied from 5 to 9%. The samples for flowability and UCS were prepared as per the procedures explained before. The water content variation with cement content for both 200 and 300 mm flowability is given in Fig. 5.

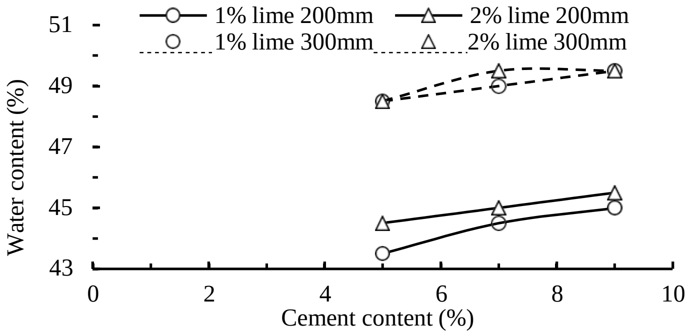
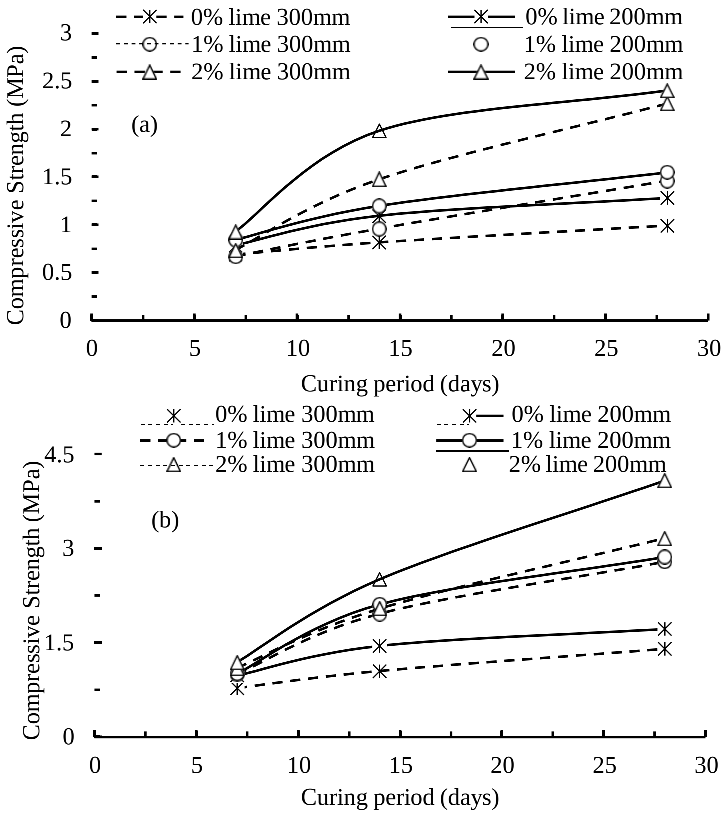


Fig. 5. Water content variation with cement content for different mixes

UCS tests were carried out for all the samples for curing periods of 7, 14 and 28 days. The values showed that the UCS values improve drastically with addition of lime along with cement. The UCS variation with curing period for different lime contents for all the samples are given in Fig. 6 (a), (b) and (c). It can be noted from the figures, that the UCS values increases with increase in lime content for the same cement content. The UCS values obtained for all the mixes for a curing period of 28 day is given in Table 2.



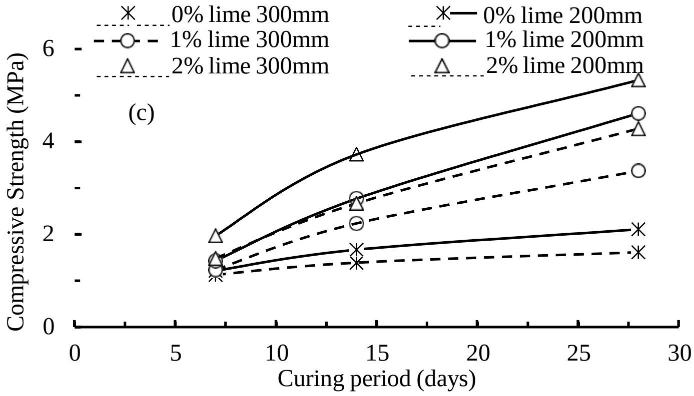


Fig. 6. UCS variation for different percentages of lime for cement contents of (a) 5% (b) 7% and (c) 9%

Table 2. UCS values at 28 days for lime added mixes

Serial No.	Cement (%)	Lime (%)	UCS (MPa)
1	5	0	1.28
		1	1.55
		2	2.4
2	7	0	1.72
		1	2.86
		2	4.08
3	9	0	2.11
		1	4.11
		2	5.33

A comparison of the initial water contents required for 200 mm flowability for 1% superplasticizer and 1% lime added mixes showed that, the initial water content required for superplasticizer added mixes was 38.7% compared to 43.5 % for lime added mixes. The water contents required for lime added mixes were found to be higher compared to superplasticizer added mixes.

The 28-day UCS value obtained for cement content of 9% and lime content of 2% was found to be 5.3 MPa. The value obtained was 152% higher than the values obtained for flowable fill samples prepared with only cement. Thus, from the experimental studies conducted on flowable fill samples of higher strength, it can be noticed that the UCS values increases with addition of either superplasticizers or lime to flowable fill sample during mixing. Thus, in situations where higher strength flowable fills are required, either lime or water reducing admixtures can be added along with cement.

A comparison of the UCS results obtained for flowable fills for the superplasticizer and lime added mixes for the same cement content is given in Fig. 7. The UCS results for 9% cementitious content for all the three cases are given in the figure. It can be noted from the figure, that the UCS obtained for 2% lime content along with 7% cement content was higher than that for the other two cases. Thus, it can be stated that the addition of lime along with cement is the more effective method for obtaining high strength flowable fills. The reason for this strength improvement is the alkaline behavior of lime which helps to improve the cementation bonds in the mix.

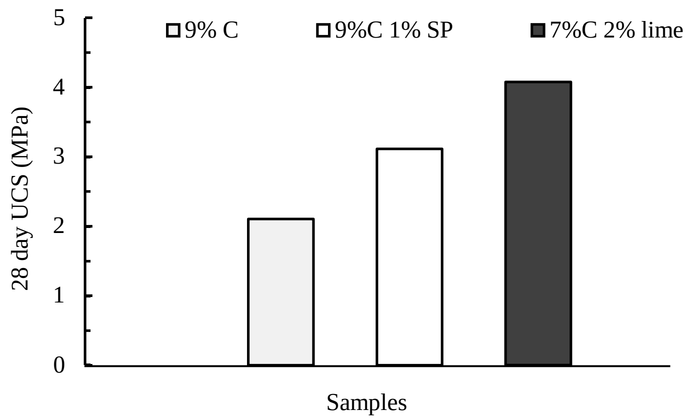


Fig. 7. Comparison of UCS results for high strength flowable fills

4 Conclusions

A comparative study of the high strength controlled low strength materials prepared with different binding agents such as cement, lime and superplasticizers along with pond ash and water were evaluated experimentally. The engineering properties such as flowability and unconfined compressive strength for different mixes were determined as per the standard ASTM specifications. The major conclusions derived from the present study is that both lime and superplasticizers can be added along with cement to improve the UCS values of flowable fill samples. The flowability values of CLSM mixes was found to depend on the binding agents added to the mix. The addition of lime was found to be more effective than that of superplasticizer addition for high strength flowable fills as the UCS values obtained for lime added mixes was higher.

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