International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

Application of Controlled Low Strength Materials as a Backfill

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ABSTRACT - Controlled low strength material (CLSM) is a highly flowable material comprised water, cement, and fly ash (FA) but often contain waste by-product material. These are characterized by very high workability and lesser compressive strength. CLSM is used mainly for filling cavities and trenches in civil engineering works where the application of granular fill is either impossible or difficult. CLSM's are engineered materials that have a specified compressive strength of 8.3 MPa or less at 28 days. If future excavation is desired, the compressive strength should be <1.03 MPa. In the present study, the engineering behavior of proposed fly ash based material prepared by blending fly ash with Onion Peel Ash and a binder such as ordinary portland cement through the laboratory experimental study. The experiments were conducted by adding OPA and fly ash with different mix ratios and percentages. The mix ratios 80%, 70% and 50% were used in the study. The cement to fly ash C/FA ratios were considered as 20%, 30% and 40% and the Onion Peel Ash was added in different percentages as 8%, 10% and 20%.

Key words: Controlled low strength material, Fly ash, Onion Peel Ash, Portland cement, Unconfined compressive strength.

I. INTRODUCTION

Controlled low strength material (CLSM) is a cementitious material which after hardening allows for future excavation with properties that are similar in characteristics to the stabilized soil. CLSM has other common names such as controlled density fill, K-krete, unshrinkable fill, and flowable fill. After hardening, CLSM provides adequate strength in bearing capacity but can also be easily excavated. To be classified as a CLSM, the material must have a compressive strength between 450 and 8400 KPa. As described by ACI Committee 229, CLSM refers to a self-compacting, cementitious material used primarily as a backfill in place of compacted fill which 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. CLSMs are defined by "Cement and Concrete Terminology (ACI 116R)" as materials that result in a compressive strength of 8.3 MPa or less.

CLSM can be effectively used as a substitute for compacted soil in backfill applications, especially when possessing the desirable properties of flow (without segregation) under gravity for situations where compaction access is challenging. Other desired characteristics include hardening for early walkability, cover application, and low strength to allow future excavations in case of temporary construction.

This research attempts to assess the long-term performance of CLSM through durability studies. Durability of the CLSMs refers to its ability to maintain its desired engineering properties during the design life period.

Other benefits gained from using CLSM are improved workers safety because trench exposure is limited, better durability as it is less permeable than compacted granular backfills, and it can be used in hard-to-reach places. Simultaneously, it reduces construction cost because no vibration or tamping is required to compact the material as it limits settlement and eliminates maintenance costs.

II. LITERATURE REVIEW

In 1997, Bruce W. Ramme documented that CLSM provides the engineer and constructor another tool to solve many challenges of construction industry and maintaining civil infrastructure. Tikalsky 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.

This chapter provides a comprehensive literature review of Controlled Low Strength Material (CLSM) including its historical background, range of applications and advantages over conventional compacted fill. Discussions are presented on CLSMs, prepared using native soils as fine aggregates. Previous research studies conducted by various researchers to establish CLSM mix design using native soils classified as Lean Clay (CL), Silty Sand (SM), Poorly Graded Sand (SP) are presented. Also, details of the recent research study at UTA that focused on developing CLSM design mixes using high plasticity clay (CH) soil from Eagle Ford formation is presented (Raavi et al., 2012). Discussions are presented on leach ability and durability related issues in soil stabilization, durability of CLSM along with various

 DOI : 10.35291/2454-9150.2022.0205

methods to perform durability testing. Background and literature review presented in this chapter is based on the reports from the American Concrete Institute (ACI), National Cooperative Highway Research Program (NCHRP), Materials journals, ASTM special publication and Transportation Research Record (TRB) as well as conventional library resources.

Various researchers have studied the usage of different industrial by-product materials such as cement bypass dust, AMD sludge, quarry dust etc., as found in the literature.

III. CLSM MATERIALS

Typical CLSM mix components include FA, cement, water, and sometimes fine aggregates. Recycling of waste material for use in CLSM benefits the environment to a very large extent. However, there is still a need to find new environmentally acceptable uses for increased utilization of waste materials, so that disposal problems are minimized. The use of FA in large volumes in CLSM mixes seems to be a perfect utilization method.

3.1. Fly Ash (FA)

The purpose of adding FA to the flowable fill is to facilitate flow. The presence of FA helps in retaining the water and simultaneously increases the flow property of the mix. FA used in the present work is Class F FA and was obtained from the Mauda Thermal Power Plant Ramtek, Maharashtra, India. The specific gravity of FA used is 1.36% and it passes completely through 120 μ sieve.

3.2. Cement

The purpose of cement in CLSM mixes is to provide cohesion between the particles, strength gain, and to promote pozzolanic reaction. Ordinary Portland cement of 53 grades conforming to ISO: 9002 was used in the present investigation.

3.3. Onion Peel Ash (OPA)

Onion peels were purchased from Friday Market of Kamptee, Nagpur (Dist.), Maharashtra, India. The peels were sorted and the waste present in it were manually removed, dried in room temperature and fried it lightly till its colour becomes brown. And then make it in a powder form with the help of mixture machine. It was then packaged, labeled, sealed and stored at room temperature for further analyses. All the chemicals used were of analytical grade.

3.3. Water

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

IV. EXPERIMENTAL PROGRAM

In this Study effect of addition of OPA and FA on compressive strength of specimen was investigated through a series of compressive strength test has been carried out for three different percentages of cement content. Cylindrical specimen of size 75 mm x 150 mm respectively was used and compressive strength was calculated for 14 and 28 days.

4.1 Mix Ratios and Preparation of Specimens

In this study the mix ratio is defined as ratio between weights of onion peel ash to fly ash. The dry weight of the fly ash W_{FA} required to make specimen was calculated using formula $W_{FA}= \gamma_{dmax}$ x V_{FA}, where γ_{dmax} is maximum dry unit weight of fly ash and V_{FA} is volume of dry fly ash. Volume of dry fly ash V_{FA} was calculated by using the formula $V_{FA}=V-V_{PA}-V_{A}$, where V is total volume of specimen, V_{OPA} is volume of onion peel ash and V_{A} is volume of fly ash. Weight of peel ash was calculated by using formula $W_{OPA}=\rho_{OPA}$ x V_{PA}, where ρ_{PA} is density of onion peel ash. The weight of fly ash was calculated as volume of fly ash with respect to the density of fly ash and fly ash percentages considered in the experimental program was 80%, 70% and 50%. Weight of cement to fly ash ratio(C/FA) was considered as 20%, 30% and 40%. Volume of water to be added was calculated as the 45% of the total weight of all the mix ratios. Similarly, the remaining mix ratios and weight of materials were calculated. These ratios were selected based on specimen. The different mix ratios used in the experimental program are given in Table 4.1.

Electronic weighing balance was used for accurate measurements of all materials. Uniform mass was made by blending fly ash, peel ash and cement thoroughly. Then water was added slowly for compound mixture and fly ash, peel ash and cement mixture was mixed into compound mixture. Then mixture was casted into steel moulds with the help of trowel and compaction was done thoroughly.

C/FA (%)	Fly Ash (%)	Cement (%)	Peel Ash (C/OPA) (%)
20	80	16.282	8.141
30	70	20	10
40	50	30	20

Table.4.1: Mix Ratios Used In the Experimental Program

After setting period all the specimens were removed from the mould and kept for curing in a room temperature. Fig.4.1 shows mixing of material to prepare the specimen. The curing period in the experimental

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program were 14 and 28 days. Fig.4.2 shows photograph of curing of specimens in a room temperature.

C/FA (%)	Fly Ash (Kg)	Cement (Kg)	Peel Ash (C/OPA)(Kg)
20	6.641	1	0.5
30	5.6	1.6	0.8
40	4.891	2.44	0.81

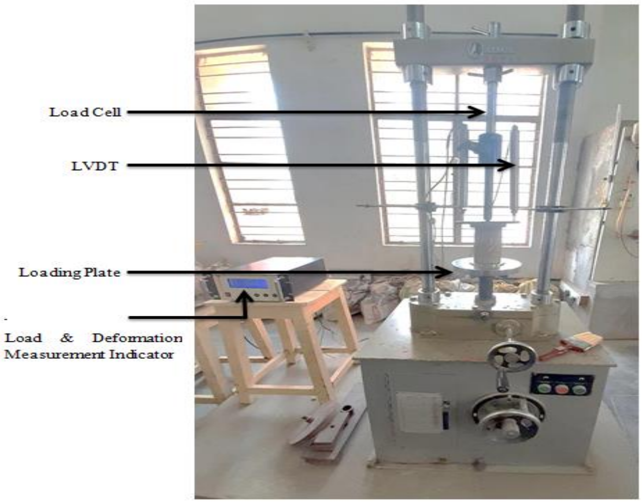

Fig.4.1: Mixing of Different Materials

Fig.4.2: Photograph of Dry Curing Of Specimens

4.2 Test Procedure

The specimens were taken out after curing for air dry and the weight of each specimen is measured using an electronic weighing balance. The compressive strength was calculated by performing compression test on specimens. Compressive strength test were conducted on compression testing machine accommodating the specimen size of 75 mm x 150 mm.

Fig.4.3: Experimental Setup of Compression Testing Machine

A load cell and linear variable differential transducer (LVDT) were used to measure the compressive load and vertical displacement respectively. Load cell and LVDT were connected to a data logger and both were calibrated before use. The maximum load at failure of specimen with corresponding deformation was noted and compressive stress was calculated. The whole setup of compression testing machine is shown in Fig.4.3. Compressive strength of specimen was carried out for 3 mix ratios for 14 and 28 days respectively of dry curing period. For each mix ratio and C/FA with different C/OPA ratios and dry curing periods, total 36 specimens were prepared and tested.

V. RESULTS AND DISCUSSIONS

5.1 Flowability Test

Flowability tests had to be conducted to assure the ability of CLSM to fill the whole abutment in one lift and to prevent blockage of pumping equipment. Flow ability of mixtures was measured by flow cylinder test as shown in Fig.5.1, according to the “Standard Test Method for Flow Consistency of CLSM” (ASTM D 6103) and the target flow value was set to be 300 mm. The measured flowability of mixtures is shown in the Table 5.1.

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Fig.5.1: Flow Cylinder Test

Mix Ratio	Flowability (mm)
Mix 01	270
Mix 02	250
Mix 03	230

Table 5.1: Flow Consistency

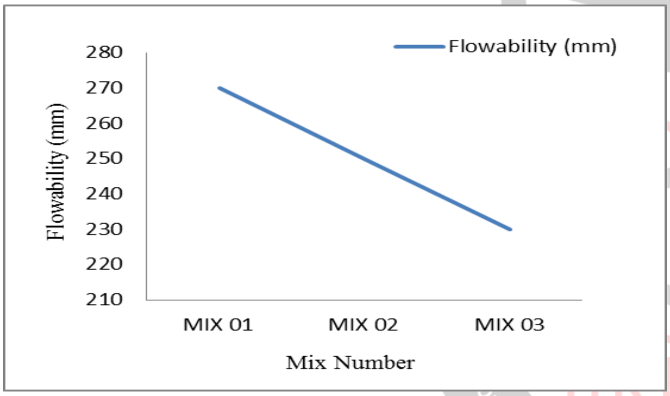
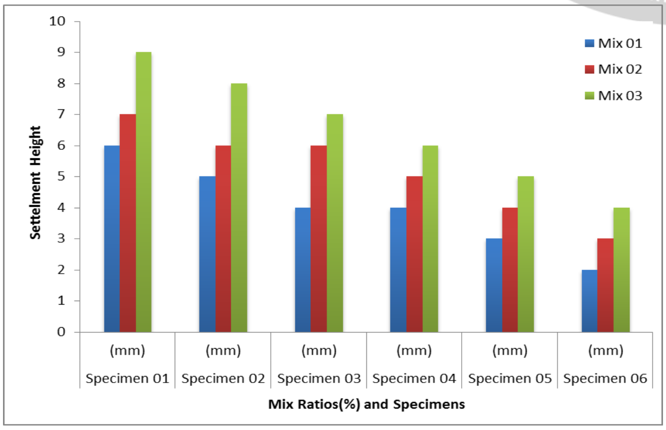


Fig.5.2: Flow Consistency

5.2 Settlement



The original size of the cylindrical specimen is 75 mm x 150 mm. when we fill the specimen the mix of the CLSM gets slowly settled by the removal of water from it by trial and error. Then we kept it in a normal room temperature for curing. After some days, we take out the fill-up from the specimen and kept it for dry curing according to the norms of ACI-229-R. After the completion of dry curing we measured the height of all the samples. And the results of its settlement are shown in the table 5.2 and Fig. 5.3 given below. From graph we found that if we increasing the amount of water in all the mix. The settlement get also increases.

Fig.5.3: Effect of mix ratios on settlement of prepared mix of CLSM

Specimens→ Mix ratio↓	Specimen 01 (mm)	Specimen 02 (mm)	Specimen 03 (mm)	Specimen 04 (mm)	Specimen 05 (mm)	Specimen 06 (mm)
Mix 01	6	5	4	4	3	2
Mix 02	7	6	6	5	4	3
Mix 03	9	8	7	6	5	4

Table 5.2: Settlement of prepared mix of CLSM

5.3 Failure Pattern

Under the axial compressive load the failure patterns of specimens was observed. All the specimens were shown vertical cracks starting from top of the specimen before failure. The failure pattern of the specimen is shown in Fig.5.4.

Fig.5.4: Failure pattern of fly ash based material specimen

5.4 Density

Density was one of the important parameter for newly developed specimens and this was significantly influenced by the mix ratios values as well as cement content. For each C/FA ratio and C/PA ratio, the relationship between density and mix ratio values were found to be linear. The density specimen decreased linearly with increasing mix ratio values for different C/FA and C/PA ratios. Fig.5.5 shows the variation of density of specimens with respect to mix ratio values.

The specimen prepared with 80% of FA and with the addition of Onion Peel Ash (C/PA ratio) in the range of 8% and C/FA ratio 20% , the density of specimen decreased from 174.6 to 167.9 Kg/m³.

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Table.5.3: Mix ratio on density of CLSM with FA=80%, C/FA=20% and C/PA=8%

Specimens→ Mix Ratio↓	Specimen 01 (Kg/m³)	Specimen 02 (Kg/m³)	Specimen 03 (Kg/m³)	Specimen 04 (Kg/m³)	Specimen 05 (Kg/m³)	Specimen 06 (Kg/m³)
Mix 01	174.6	173.7	173.4	172	171.4	167.9

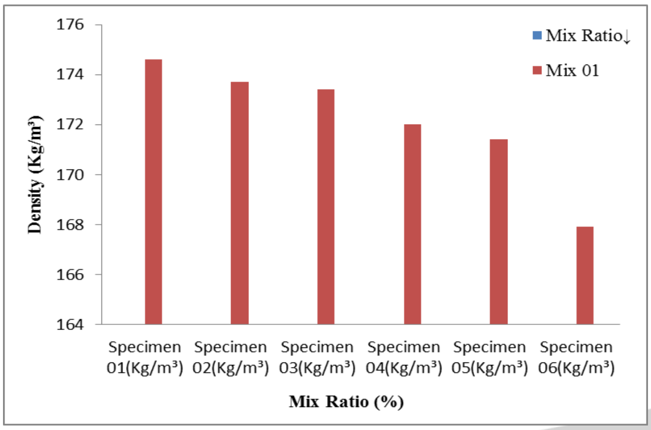

Fig.5.5: Effect of mix ratio on density of CLSM with FA=80%, C/FA=20% and C/PA=8%

Similar trend were observed even for specimen prepared with 70% of FA. With the addition of Onion Peel Ash (C/PA ratio) in the range of 10% and C/FA ratio 30% , the density of specimen decreased from 156.2 to 149.1Kg/m³. Fig.5.6 shows the variation of density of specimen with respect to mix ratio values with 30% of C/FA and 10% of C/PA ratios.

Specimens→ Mix Ratio↓	Specimen 01 (Kg/m³)	Specimen 02 (Kg/m³)	Specimen 03 (Kg/m³)	Specimen 04 (Kg/m³)	Specimen 05 (Kg/m³)	Specimen 06 (Kg/m³)
Mix 02	156.2	154.8	153.3	151.8	151	149.1

Table.5.4: Mix ratio on density of CLSM with FA=70%, C/FA=30% and C/PA=10%

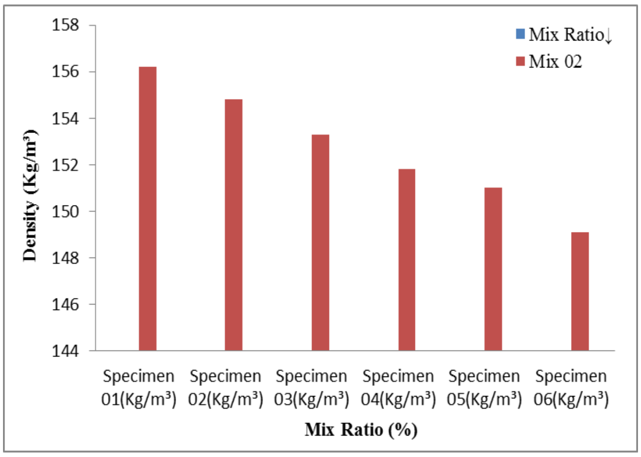

Fig.5.6: Effect of mix ratio on density of CLSM with FA=70%, C/FA=30% and C/PA=10%

Similar trend were observed even for specimen prepared with 50% of FA. With the addition of Onion Peel Ash (C/PA ratio) in the range of 20% and C/FA ratio 40% , the density of specimen decreased from 154.5 to 147.3 Kg/m³. Fig.5.7 shows the variation of density of specimen with respect to mix ratio values with 40% of C/FA and 20% of C/PA ratios.

The effect of mix ratios on density of specimen is shown in Fig. For each mix and C/FA ratio values, the specimen prepared using FA of 80% has shown higher values of density compared to the FA of 50%. It was observed that the density of specimen was decreased with decreasing the percentage of FA.

Specimens→ Mix Ratio↓	Specimen 01 (Kg/m³)	Specimen 02 (Kg/m³)	Specimen 03 (Kg/m³)	Specimen 04 (Kg/m³)	Specimen 05 (Kg/m³)	Specimen 06 (Kg/m³)
Mix 03	154.5	153.2	153.1	151.7	150.7	147.3

Table.5.5: Mix ratio on density of CLSM with FA=50%, C/FA=40% and C/PA=20%

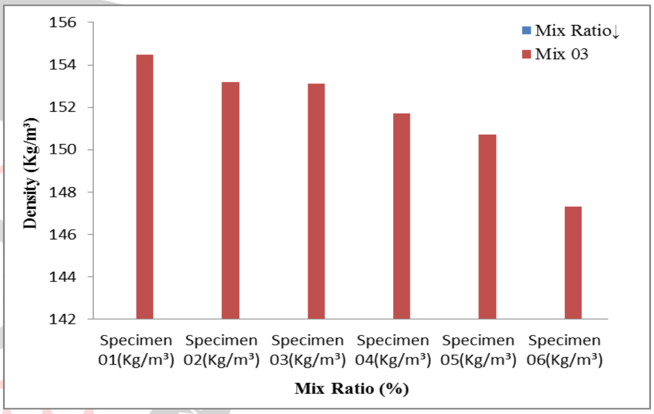

Fig.5.7: Effect of mix ratio on density of CLSM with FA=50%, C/FA=40% and C/PA=20%

5.5 Stress-Strain Pattern

The stress strain characteristics and stiffness of the specimen was determined from the compressive strength test data. The effect of mix ratio values on compressive stress and axial strain curves for all the different percentages of FA and different mix ratios of C/FA and C/PA are shown in the figures given below. The 1st specimen of FA of 80% with the mix ratio of C/FA of 20% and the mix ratio of C/PA of 8% for 14 days of curing are shown in the Fig.5.8.

Similar trend were observed for 28 days of curing periods and are shown in Figures and the effect of mix ratio values on compressive stress and axial strain curves for all the C/FA ratios and C/PA ratios being observed.

The 2nd specimen of FA of 80% with the mix ratio of C/FA of 20% and the mix ratio of C/PA of 8% for 28 days of curing are shown in the Fig.5.9. For particular mix ratio and C/FA ratio, the stiffness of the specimen was increased with

 DOI : 10.35291/2454-9150.2022.0205

International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

increasing curing periods as shown in the Fig.5.8 and Fig.5.9.

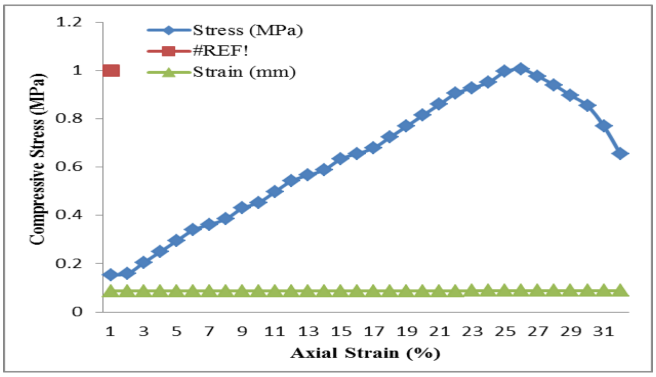

Fig.5.8: Compressive stress and axial strain curves for 14 days curing period with FA=80%, C/FA=20% and C/PA=8% mix ratios

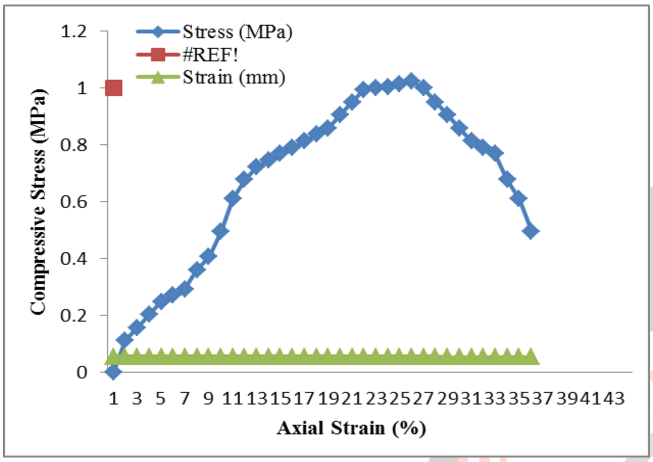

Fig.5.9: Compressive stress and axial strain curves for 28 days curing period with FA=80%, C/FA=20% and C/PA=8% mix ratios

The 3rd specimen of FA of 80% with the mix ratio of C/FA of 20% and the mix ratio of C/PA of 8% for 28 days of curing are shown in the Fig.5.10.

The 4th specimen of FA of 80% with the mix ratio of C/FA of 20% and the mix ratio of C/PA of 8% for 28 days of curing are shown in the Fig.5.11. For mix of 80% FA and C/FA ratio of 3rd and 4th specimen has shown higher stiffness as shown in Fig.5.10 and Fig.5.11.

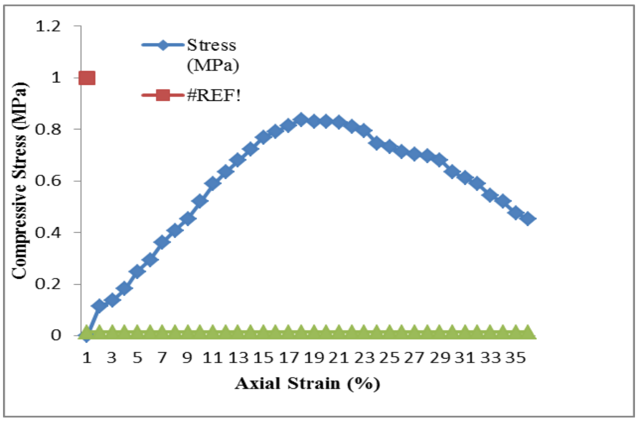

Fig.5.10: Compressive stress and axial strain curves for 28 days curing period with FA=80%, C/FA=20% and C/PA=8% mix ratios

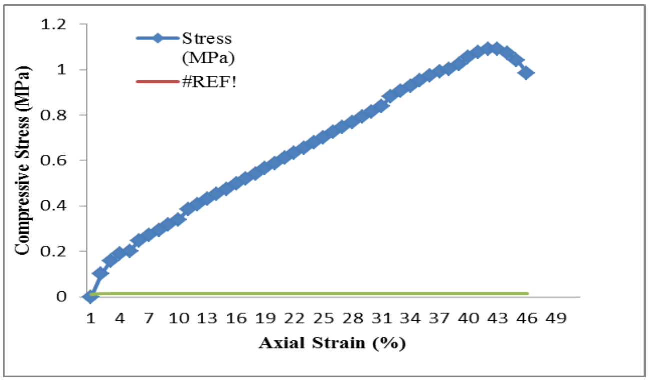

Fig.5.11: Compressive stress and axial strain curves for 28 days curing period with FA=80%, C/FA=20% and C/PA=8% mix ratios

The 5th specimen of FA of 70% with the mix ratio of C/FA of 30% and the mix ratio of C/PA of 10% for 28 days of curing are shown in the Fig.5.12. For each curing period, stiffness of the specimen was decreased with increasing mix ratios as shown in Fig.5.11 and Fig.5.12.

The 6th specimen of FA of 50% with the mix ratio of C/FA of 40% and the mix ratio of C/PA of 20% for 14 days of curing are shown in the Fig.5.13.

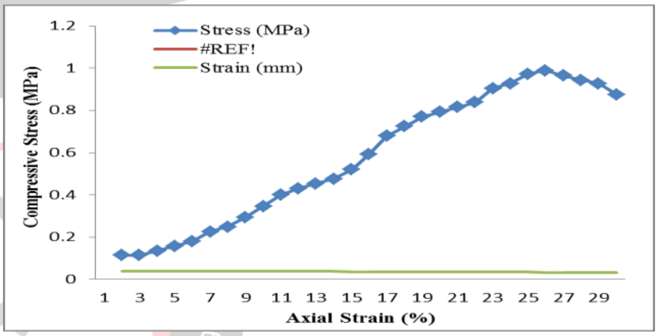

Fig.5.12: Compressive stress and axial strain curves for 28 days curing period with FA=70%, C/FA=30% and C/PA=10% mix ratios

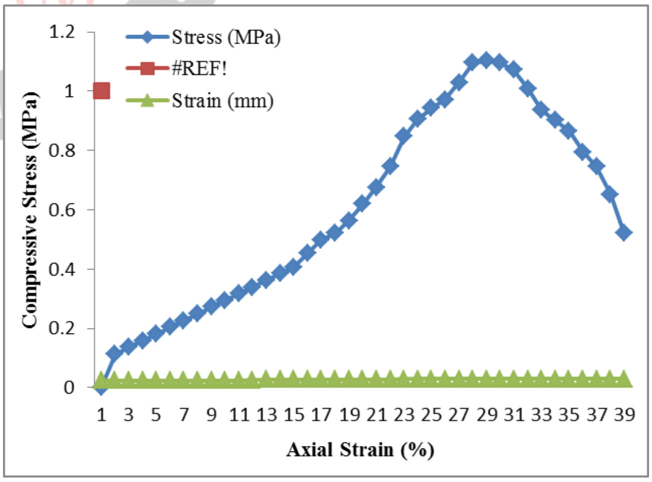

Fig.5.13: Compressive stress and axial strain curves for 14 days curing period with FA=50%, C/FA=40% and C/PA=20% mix ratios

The 7th specimen of FA of 50% with the mix ratio of C/FA of 40% and the mix ratio of C/PA of 20% for 14 days of curing are shown in the Fig.5.14.

The 8th specimen of FA of 80% with the mix ratio of C/FA of 40% and the mix ratio of C/PA of 20% for 28 days of

 DOI : 10.35291/2454-9150.2022.0205

dry curing are shown in the Fig.5.15. The stiffness of the specimen was decreased with increasing mix ratios and as shown in Fig.5.13, Fig.5.14, and Fig.5.15 respectively.

The compressive strength and stress-strain behaviour of specimen was highly influenced by the C/FA ratio values. The behaviour of specimen is ductile with increasing C/FA ratio values. For all the mix ratios and C/PA ratios, non-linear relationship was observed between compressive stress and axial strain.

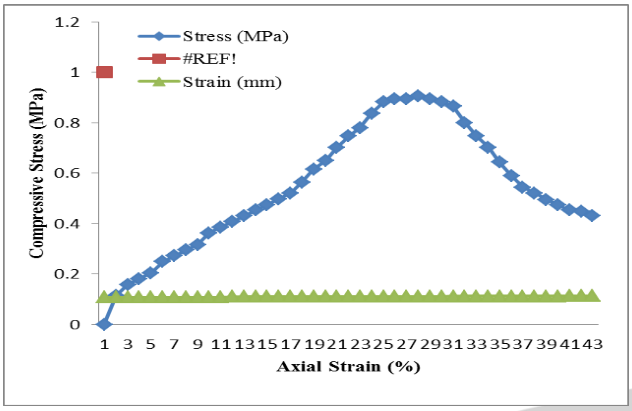

Fig.5.14: Compressive stress and axial strain curves for 14 days curing period with FA=50%, C/FA=40% and C/PA=20% mix ratios

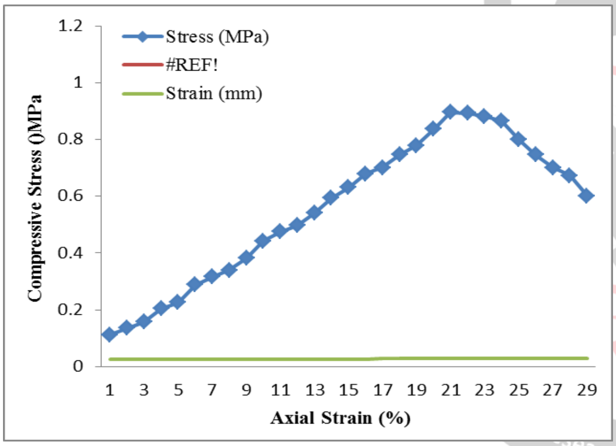

Fig.5.15: Compressive stress and axial strain curves for 28 days curing period with FA=50%, C/FA=40% and C/PA=20% mix ratios

5.6 Major Findings

An experimental study was carried out to know the behavior of CLSM specimen prepared by using Onion Peel Ash, Fly Ash, and Cement. From the study following are the major findings are drawn.

- As the Mix Ratios of C/FA 20% to 40% and C/PA 8% to 20% gets increases, the flowability of CLSM gets decreases.
- As the amount of water increase for the increasing percentage of the mix ratio, the settlement of the CLSM's specimen will also get increases.
- For each C/FA ratio and C/PA ratio, the relationship between density and mix ratio values were found to be linear. The density specimen decreased linearly with increasing mix ratio values for different C/FA and C/PA ratios.
- The density of specimen decreased from 174.6 to 167.9 Kg/m³ when C/PA ratio in the range of 8% and C/FA ratio is 20%.
- The density of specimen decreased from 156.2 to 149.1Kg/m³. when mix ratio values are in the rangr of 10% of C/PA and 30% of C/FA ratios.
- With the addition of Onion Peel Ash (C/PA ratio) in the range of 20% and C/FA ratio 40% , the density of specimen decreased from 154.5 to 147.3 Kg/m³.
- For each mix and C/FA ratio values, the specimen prepared using FA of 80% has shown higher values of density compared to the FA of 50%. It was observed that the density of specimen was decreased with decreasing the percentage of FA.
- Compressive strength values were significantly influenced by the mix ratios, C/FA ratios, C/PA ratios and curing periods. Curing period of 28 days specimen have higher compressive strenght with respect to curing period of 14 days.
- The compressive strength values of the Specimens were in the range of
  0.8375 to 1.092 MPa for 14 days.
  0.9054 to 1.102 MPa for 28 days.
- Stress-Strain behavior was also significantly affected by all the mix ratios used for preparation of specimen.
- Non-linear compressive stress-strain relation was observed.
- The stiffness of the CLSM specimen was decreased with decreasing compressive strength.

The compressive strenght values of CLSM specimens of Onion Peel Ash are in higher range than that of

- Fly Ash and Cinder Aggregates values reported by M. C. Nataraja, N. R. Vadiraj Rao as it was 0.44MPa ().
- Polypropylene (PP) fiber-reinforced cemented paste backfill (CPB) values reported by Xin Chen, Xiuzhi Shi, Shu Zhang, Hui Chen, Jian Zhou, Zhi Yu, Peisheng Huang as it was 0.4MPa ().
- Waste precipitates from Mineral Processing values reported by S. Bouzalakos, A.W.L. Dudeney, C.R. Cheeseman as it was 0.17MPa (2008).
- Scrap Tire Rubber values reported by Tammie Cheung, Daniel C. Jansen, A.M. ASCE, James L. Hanson, M. ASCE, P.E. as it was 0.25MPa ().
- Wood Fly Ash values reported by Tarun R. Naik, Rudolph N. Kraus, Rafat Siddique, Yoon-Moon Chun as it was 0.3, 0.8 and 0.6MPa ().
- Spent Foundry Sand values reported by Rafat Siddiquea, Albert Noumoweb as it was 0.94MPa (2008).
- Controlled Low-strength Rubber light weight aggregate concrete (CLSRLC) values reported by Her-Yung Wang, Bo- Tsun Chen, Yu-Wu Wu as it was 0.7MPa ().
- Fly Ash values reported by S. Turkel as it was 0.85MPa ().

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- Stone Dust and EPS Beads values reported by V. R. Marjive, V. N. Badwaik, B. Ram Rathan Lal as it was 0.31to 0.52MPa and 0.52 to 0.7MPa (2015).
- Residual Soil and Class F Fly Ash values reported by Yeong-Nain Sheen, Duc-Hien Le as it was 0.21 to 0.47MPa (2014).
- Industrial by-products values reported by Amnon Katz, Konstantin Kovler as it was 0.5MPa (2004).
- Circulating Fluidized Bed Combustion Ash and Recycled Aggregates values reported by Wei-Ting Lin , Tsai-Lung Weng, An Cheng , Sao-Jeng Chao, Hui-Mi Hsu as it was 0.21 to 0.41MPa (2006).
- Marine Dredged Soil as a Thermal Grout values reported by Tan Manh Do, Anh Ngoc Do, Gyeong-O Kang,Young-Sang Kim. As it was 0.16 to 0.57MPa and 0.31 to 0.95MPa ().
- Novel Grout values reported by Tan Manh Do, Hyeong-Ki Kim, Min-Jun Kim, Young-Sang Kim. As it was 0.15 to 0.49MPa and 0.28 to 0.83MPa (2020)
- Pond Ash values reported by Tan- manh Do, Young-sang Kim, Byung-cheol Ryu as it was 0.2 to 0.51MPa ().
- Granulated compacting soil, river sand and eco-friendly materials values reported by Duc-Hien Lea, Khanh-Hung Nguyenb 0.3 to 0.47MPa and 0.59 to 0.81MPa (2016).

VI. CONCLUSION

Laboratory experimental study was performed on CLSM containing fly ash, onion peel ash, and ordinary Portland cement. Different mix proportions of VFA/γFA C/FA and C/PA were used to prepare the CLSM. From the study following conclusions are drawn.

The compressive stress strain behavior of CLSMs specimens was significantly affected by all the mix ratios, V_{FA}/γ_{FA}, C/FA ratios and C/PA ratios used for its preparation. Higher compressive strength and stiffness was observed with increasing C/FA ratio and C/PA ratio.

The nature of compressive stress and axial strain curves were found to be nonlinear and it was similar for all curing period days. The density values of CLSM specimens was lesser than lightweight fill material and higher than geomaterial and have shown higher compressive strength values than both lightweight fill material and geomaterial values reported in literatures. The Onion Peel Ash is light in weight compared with conventional fill materials, so it can be used effectively as an alternative fill material over weak and sensitive areas where conventional fill material causes excessive over burden pressures thus settlements.

6.1. Limitations of the study

Proper care should be taken during preparation of Specimen mix. Because Onion Peel Ash is very lightweight, they can disperse at the time of mixing, which can change the mix ratio and change the quality of CLSM. If the fly ash and cement are not available in the area of the construction site, the cost of transportation of these materials may lead to increased project cost.

6.2. Future Scope of Work

This work can be extended further by preparing a specimen of larger size and also with cubical specimens. The compressive strenght can be checked by increasing fly ash percentages and by increasing the values of Onion Peel Ash and it can be used in the backfilling of the building structure and in the backfilling of the pipelines.

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