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Evaluating the properties of controlled low-strength material (CLSM) using class c fly ash, GGBFS, PS sand, and quarry dust

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ABSTRACT

A Controlled Low Strength Material (CLSM) is a highly flowable self-compacting material which is primarily composed of sand, cement, water and other filler materials. It is principally used as a replacement for soil backfill. The purpose of this project was to optimize the mixture proportions for performance using various fillers such as Quarry Dust and PS Sand, and cementitious materials such as Ground Granulated Blast Furnace Slag (GGBFS), Fly Ash (FA) and cement. The recycling of these waste materials contributes to construction sustainability. The mixes must possess the consistency, flowability and strength which is required for CLSM. This was achieved through trial mixing, where derivation of new mixes was based on the performance of previous pours. To investigate the performance of the mixes derived, tests for flowability, and compressive strength were carried out.

Keywords*: CLSM, GGBFS, FLYASH, Flowability, Consistency*

1. INTRODUCTION

Sustainability is important for the well-being of the planet, continued growth of a society, and human development. Concrete is the most widely used construction materials in the world. However, the production of Portland cement, an essential constituent of concrete, leads to the release of significant amounts of CO2, a greenhouse gas (GHG); production of one ton of Portland cement produces about 850kg of CO2 and other GHGs. The environmental issues associated with GHGs, in addition to natural resources issues, will play a leading role in the sustainable development of the cement and concrete industry in the future.

To build infrastructure that are cost-efficient, environment friendly, and durable, the impact of the building materials on local and worldwide air conditions must be examined. At the current rate of increase of cement production (USGS 2006, 2007), worldwide cement production is expected to rise from about 2.5 billion tones in 2006 to about 5 billion tones by 2020. Thus, CO2 emissions caused by Portland cement production are expected to rise by 100% from the current level by 2020. For each metric ton of Portland cement clinker, 1.5 to 10 kg of NOx is also released into the atmosphere. If the challenges associated with reducing CO2, NOx, and other GHGs are to be met, then the concrete industry must develop other materials to replace Portland cement.

Therefore, supplementary cementing materials, which are waste/co-products from other industries such as fly ash, limestone dust and ground granulated blast - furnace slag should replace larger amounts of Portland cement in concrete. However, before any construction occurs, all aspects of the building materials to be used should be evaluated. The use of blended cements and organic chemical admixtures must be significantly increased for sustainability of the cement and concrete industries.

A controlled low-strength material (CLSM) is a self-compacted, cementitious material used primarily as a backfill as an alternative to compacted fill. Several terms are currently used to describe this material, including flowable fill, unshrinkable fill, controlled density fill, flowable mortar, plastic soil -cement, soil-cement slurry, and other various names. Controlled low-strength materials are defined by ACI 116R as materials that result in a compressive strength of 8.3 MPa (1200 psi) or less. Most current CLSM applications require unconfined compressive strengths of 2.1 MPa (300 psi) or less at 28 days. This lower- strength requirement is necessary to allow for possible future excavation of CLSM. It costs more per cubic meter when compared with conventional soil backfill; however its advantages result in lower in-place costs.

The primary application of CLSM is as a structural fill or backfill in lieu of compacted soil. As CLSM needs no compaction and can be designed to be fluid, it is ideal for use in tight or restricted-access areas where placing and compacting fill is difficult. If future excavation is anticipated, the maximum long-term compressive strength should generally not exceed 2.1 MPa (300 psi).

1.1 What is CLSM?

CLSM is a relatively new technology whose use has grown in recent years. CLSM is a highly flowable material typically composed of water, cement, fine aggregates, and, often times, fly ash. Other by-product materials—such as foundry sand and bottom ash— and chemical admixtures—including air-entraining agents, foaming agents, and accelerators—also have been used successfully in CLSM.

2. METHODOLOGY

The aim of this project is to optimize the mixture proportions for performance using various fillers and cementitious materials for CLSM. The idea is to use the maximum amount of Ground Granulated Blast Slag (GGBFS) and PS Sand as filler materials so that the fresh and hardened state properties of CLSM are satisfied. For the fresh state of CLSM, it must possess sufficient flow ability, consistency and density while avoiding heavy bleeding as well as any significant segregation. Flowability is particularly an important aspect of CLSM as it allows the materials to be self-compacting as well as readily flow into and fill a void. Flowability of a CLSM mix is measured by means of flow test; the adequate target flow from the test is between 600 and 700 mm.

In the hardened state, the material will have a target 7 day compressive strength of not more than 1MPa, which allows it to be excavated at a future date. The consistency of the mix is equally important. This aspect will heavily depend on the quantity of fines present in the mix. The finer a material is, the greater surface area-to-volume ratio, which means there is more surface area available to hold and absorb water in the mix.

3. MATERIALS USED

31 Cement

Cement is the material that provides the CLSM with its early age strength and also, due to its fineness, provides cohesion to the mix. The Cement that we used in our project is Ordinary Portland Cement, Grade 53.

3.2 Fly Ash

Fly ash is finely divided residue resulting from the combustion of powdered coal and transported by the flue gases and collected by the electrostatic precipitator. Fly ash obtained from Naively thermal power plant was used in the investigation. The fly ash used in this investigation conforms to IS: 3812 (Part 2)-2003. The Chemical composition and physical properties of fly ash are given in Table 3.1 & 3.2 respectively.

Table 3.1 Chemical composition of Fly Ash

Material	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2	SO_3	Cl	
Fly ash	2.11	62.88	26.23	4.23	1.43	1.15	0.30	0.11	0.011	0.21

Table 3.2 Physical Properties of Fly Ash (Bureau Veritas (INDIA) Private Limited)

S no.	Physical properties	Values
1	Fineness Blaine, m2/kg	474
2	Specific Gravity	2.11
3	Lime reactivity, N/mm2	4.90
4	Soundness Autoclave, %	0.03

3.3 Ground Granulated Blast-Furnace Slag (GGBFS).

Ground granulated blast-furnace slag (GGBFS) can also be used in CLSM in combination with other cementitious materials such as Portland cement. GGBFS is similar to Pulverized Fly Ash (PFA), in that it is a by-product, but of iron and steel making. The molten slag lying on top of the molten iron in the blast furnace comprises silicates (glass) which is the raw material for GGBFS cement. The molten slag is cooled and then finely ground to form GGBS cement. GGBFS is a recycled product. It has similar chemical constituents as Portland cement.

GGBFS is frequently used in mix designs for concrete, and from comparing the strength versus time graph for mixes of Portland cement on its own and a GGBFS/Portland mix, it has been found that the GGBS/Portland cement mix will gain its strength much more slowly when compared with that of Portland cement mix. This lower strength is desirable for CLSM mixes, however the ultimate compressive strength of a GGBS/Portland cement mix has also been found to be higher. The reason for this is due to the fact that there is a higher content of Calcium-Silicate-Hydrate (CSH) gel and a lot less Calcium Hydroxide (lime) in the resulting concrete.

Table 3.3 Properties of GGBFS (Bureau Veritas (INDIA) Private Limited)

Specific Gravity	2.91
Fineness	358
Residue on 45 micron sieve %	2.3
Manganese Oxide (Max) %	0.27
SiO2 (%)	36.00
CaO (%)	36.45
Fe2O3 (%)	1.36
Al2O3 (%)	17.59

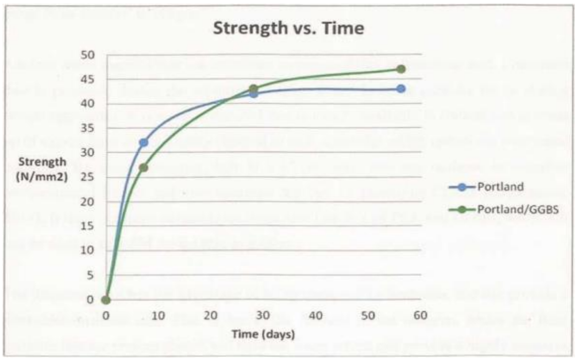

Fig. 3.1: Strength vs. Time for Portland and Portland/GGBS mixes PS Sand

The most common fine aggregate found in CLSM is sand. Sand makes up approximately 25% of the CLSM. Its proportion in the mix can vary between 1200kg/m3 and 1840kg/m3. Course aggregates such as gravel are not commonly used in CLSM mixes, as they provide strength to the concrete. However, for CLSM mixes one wants to deliberately make concrete weak, so the use of course aggregates will not be needed.

3.4 Stone Quarry Dust

Quarry dust is a by-product of the crushing process which is a concentrated material to use as aggregates for concreting purpose, especially as fine aggregates. In quarrying activities, the rock gets crushed to various sizes; the dust generated during the process is called quarry dust and it is formed as waste. So, it becomes a useless material and also results in air pollution. Quarry dust when used in construction works, will reduce the cost of construction, the construction material is saved and the natural resources are used properly. Most of the developing countries working to replace fine aggregate in concrete by an alternate material, partially or fully without compromising the quality of concrete. The sieve Analysis of Quarry Dust was conducted in the laboratory, which is shown in table 3.4

Table 3.4 Sieve Analysis of Stone Quarry Dus

Is Sieve Designation	Cumulative Percent	
4.75 mm	**Retained**	**Passing**
2.36 mm	0	100.0
1.18 mm	8.2	91.80
600 microns	34.8	65.20
300 microns	59.0	41.00
150 microns		7.00
Pan		1.00
	100	0.00

3.5 Water

Water is the primary constituent present in the mix. When the clinker is in contact with water, a series of chemical reactions take place. Hydration occurs where a Calcium-Silicate-Hydrate (CSH) gel forms rapidly on the surface of the cement grains and begins to bind the aggregates together.The water is also necessary to achieve adequate flow ability and workability. Water contents in CLSM mixes vary from 190 to 340kg/

3.6 Proportions of Materials

Table 3.5: Quantity and Material Proportions used in each series

Series	Cement (gms)	Fly Ash (gms)	GGBFS (gms)	PS Sand (gms)	Quarry Dust (gms)
S1	100	200	800	550	550
S2	150	200	800	575	575
S3	200	200	800	600	600
S4	250	200	800	625	625
S5	300	200	800	650	650
S6	350	200	800	675	675

3.7 Experimental Testing

3.7.1 Flowability Test: Immediately after mixing, the flow was measured following ASTM D 6103. This method, which measures the diameter of a CLSM "pancake" after a 75 × 150 mm cylinder is slowly lifted, was found to be generally easy to perform and was also quite reproducible.

3.8 Test Details

- Mould shape is cylindrical with dimensions 75mm*150 mm.
- Specified values for Rate of Flow Area (RFA) is between 5-15.
- Total number of series are 6.
- Selected water-solid ratios are 35%, 38%,41% and 44%.
- Formula:

$$RFA= (D/75)^2-1$$

3.8 Test Procedure

- Required quantity of materials is taken and is dry mixed first, then the calculated water is added to mix so that the mix becomes flow able.
- The CLSM mix is then poured in the greased cylindrical mould placed on the flow-table and then mould is slowly lifted upwards so that the mix flows
- The diameter of the flow is measured by taking average of 5-6 readings.
- By knowing the diameter of the flow, the rate of flow area can be calculated using the above mentioned formula.

Fig. 3.8: Specimen kept for air drying

3.9 Method of Testing

3.9.1 Test Details: Unconfined Compressive Strength

This section describes the basic procedures followed to test the unconfined compressive strength of the mixtures prepared.

Test Procedure:

- After demoulding the specimens are left for air curing at room temperature for required number of day.
- After the curing period is over the specimens are taken for unconfined compression test on their specified days.
- Before starting the test, the dimensions of the specimens are measured.
- The specimen is kept in CBR testing machine with the surface levelled and smooth, at the centre.
- The Proving Ring is adjusted to zero.
- The machine is started and the load is applied till the failure of specimen occurs.
- At the failure point the Proving Ring Reading is noted down.
- Knowing the Proving Ring Reading the compressive strength of the specimen can be found.

4. TEST RESULTS OF FLOW ABILITY TEST:

The flow test was performed on the all the series as mentioned in chapter 3 Table 3.6. Different water content for each series were selected by trial and error method to conduct the flow test. The water content was selected such that the rate of flow area (RFA), lies in the range of 5-15. For each series the quantity of material is varied (increased). Quantity of cement was increased. The quantity of PS Sand quarry dust was also increased keeping the proportion of PS sand and Quarry Dust as 1:1.

For series 1, the quantity of material are mentioned in Table 4.1 and the water content was varied accordingly to get the rate of flow area (RFA) between 5-15. As the water content is increased, flow also increases thereby increasing the RFA value. The variation of rate of flow area for different water contents for series 1 is as shown in Fig. 4.1

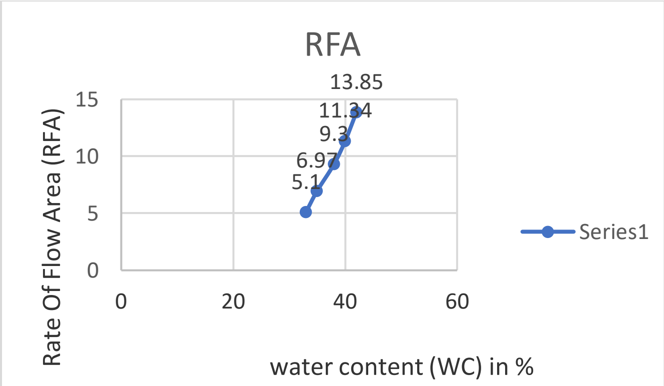

Fig. 4.1: Graph showing variation of Rate of Flow Area (RFA) Vs Water Content (WC) series 1.

In series 2 the quantity of materials is increased, keeping the proportion of PS Sand and Quarry Dust 1:1. The cement is increased by 50 gms and PS Sand and Quarry Dust 25 gms each. So, the total quantity of the materials is more than that series 1. The water quantity is selected accordingly to meet the rate of flow area (RFA) requirements. Variation of rate of flow area (RFA) with respect water content for series 2 is as shown

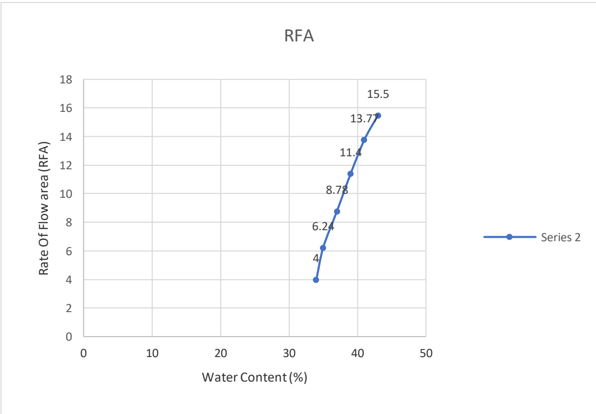

Fig. 4.2: Graph showing variation of Rate of Flow Area (RFA) Vs Water Content (WC) series 2.

The quantity of the materials in series 3 is increased as mentioned in Table 4.3. The water content is selected according to the quantity of materials. The rate of flow area (RFA) is calculated by measuring the diameter of the spread from flow table test. Knowing the rate of flow area (RFA) the water quantities are selected. If the RFA is more than 15 then selected water quantity is decreased so that the RFA lies between 5-15. The flow of the mix is increased with increase in water content. The variation of the RFA with the water content is as given in the graph (Fig. 4.3) below.

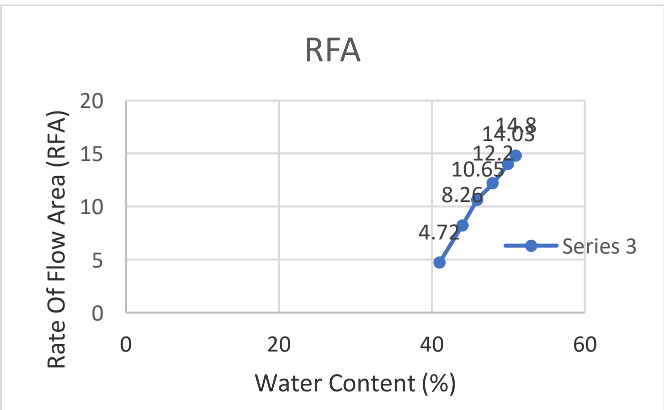

Fig. 4.3: Graph showing variation of Rate of Flow Area (RFA) vs Water Content (WC) series 3.

Similarly, for series 4, there was an increase in the flow of the mix as water content was increased. Initially the mix was not able to flow, then on increasing the water contents by 3% to the previous water content, mix started flowing. Knowing the diameter of the spread, the RFA values were calculated. The variation of RFA with the water content is given in the graph in (Fig. 4.4) below.

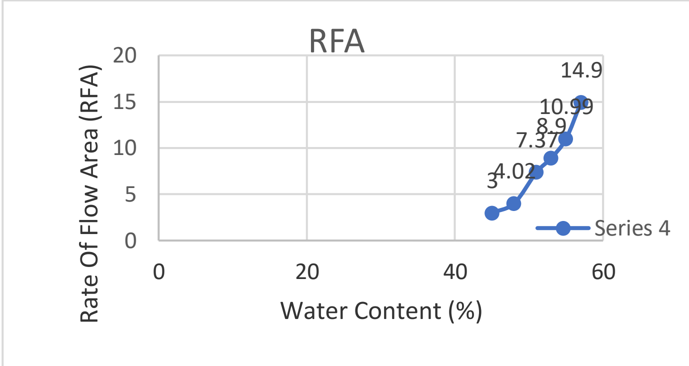

Fig. 4.4: Graph showing variation of Rate of Flow Area (RFA) Vs Water Content (WC) series 4.

For series 5, as the quantity of the materials is more, the water content required to get the flow is more. So we can say that with increase in the quantity of the material the water content also increases. Same procedure is followed for this series also to get the RFA value between 5-15. The variation of the RFA with different water contents is shown in the graph (Fig. 4.5) below.

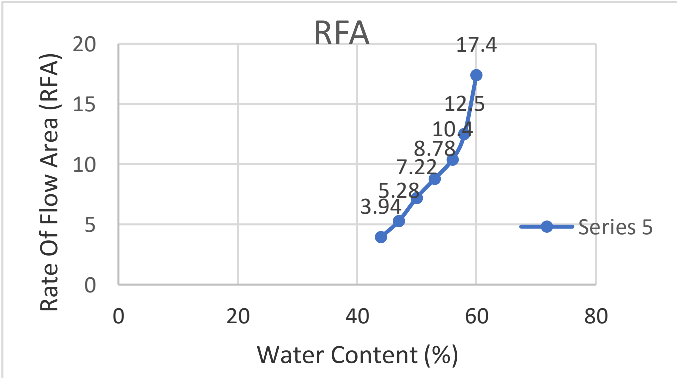

Fig. 4.5: Graph showing variation of Rate of Flow Area (RFA) Vs Water Content (WC) series 5.

For series 6 the results obtained in the form of RFA values is plotted in the graph against the variation in water content. There is a considerable increase in flow as we are adding more quantity of water. The variation of the flow is shown in the graph (Fig. 4.6) below.

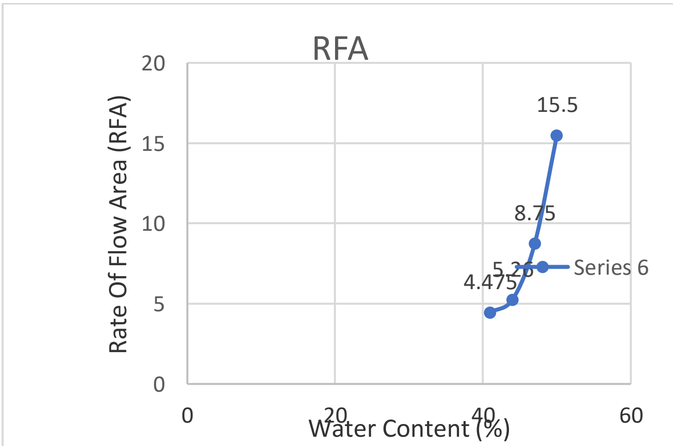

Fig. 4.6: Graph showing variation of Rate of Flow Area (RFA) Vs Water Content (WC) series 6

4.2 Test Results of Unconfined Compression Test

The unconfined compression test was performed on all the series as mentioned in chapter 3, Table 3.6. The unconfined compression test was conducted on each series for different water contents. For series 1, compressive strength for water contents (35%, 38%, 41% and 44%), after 3 days, 7 days and 28 days is shown in the Table 4.1 given below.

Table 4.1: Showing Compressive strength of series 1.

Mix	W/C(%)	Unconfined Compressive Strength(MPa)		
		3 Days	7 Days	28 Days
	35	0.173	0.26	0.271
	38	0.15	0.162	0.224
	41	0.132	0.157	0.21
Series 1	44	0.114	0.122	0.164

For all the series, the variation of strengths for different water contents is as shown in the graphs. The different compressive strengths of series 1 for different water contents are shown in the Fig. 4.7. The below graph indicates the rapid gain in strength during the first 7 days and after 7 days the rate of gain in compressive strength is very less. The graph also indicates the decrease in compressive strength as we go on increasing the water content.

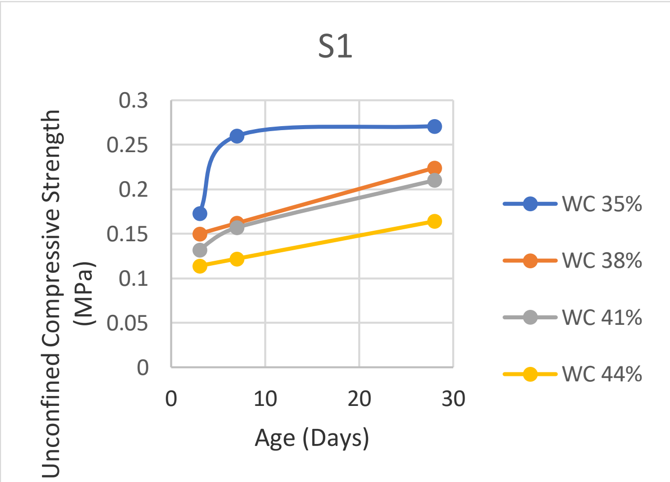

Fig. 4.7: Graph showing Compressive Strength of CLSM series 1 for different water contents.

For series 2, compressive strength for water contents (35%, 38%, 41% and 44%), after 3 days, 7 days and 28 days is shown in the Table 4.2 given below.

Table 4.2 Showing Compressive strength of series 2

MIX	W/C (%)	Unconfined Compressive Strength(MPa)		
		3 Days	7 Days	28 Days
Series 2	35	0.2	0.23	0.37
	38	0.18	0.235	0.271
	41	0.14	0.22	0.25
	44	0.122	0.18	0.21

The different strengths of series 2 for the different water contents are shown in the figure 4.8. The below graph indicates the rapid gain in strength during the first 7 days and after 7 days rate of gain in compressive strength is very less. The graph also indicates the decrease in compressive strength as we go on increasing the water content.

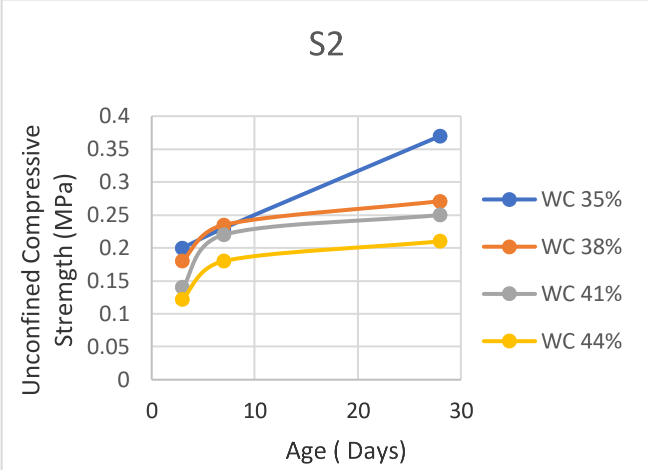

Fig. 4.8: Graph showing Compressive Strength of CLSM Series 2 for different water contents.

For series 3, compressive strength for water contents (35%, 38%, 41% and 44%), after 3 days, 7 days and 28 days is shown in the Table 4.3 given below.

Table 4.3 Showing Compressive Strength of series 3

MIX	W/C (%)	Unconfined Compressive Strength(MPa)		
		3 Days	7 Days	28 Days
Series 3	35	0.167	0.31	0.34
	38	0.136	0.21	0.281
	41	0.134	0.3	0.32
	44	0.1	0.157	0.24

The different strengths of series 3 for the different water contents are shown in the figure 4.9. The below graph indicates the rapid gain in strength during the first 7 days and after 7 days rate of gain in compressive strength is very less. The graph also indicates the decrease in compressive strength as we go on increasing the water content.

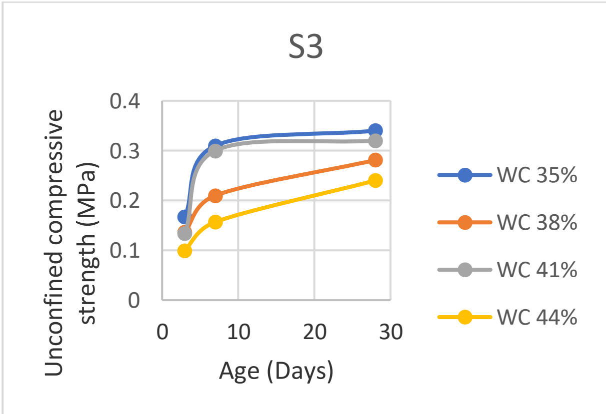

Fig. 4.9: Graph Showing Compressive Strength of CLSM Series 3 for different water contents.

For series 4, compressive strength for water contents (35%, 38%, 41% and 44%), after 3 days, 7 days and 28 days is shown in the Table 4.4 given below.

Table 4.4 Showing Compressive Strength of series 4.

MIX	W/C (%)	Unconfined Compressive Strength(MPa)		
		3 Days	7 Days	28 Days
Series 4	35	0.214	0.266	0.286

	38	0.183	0.243	0.252
	41	0.167	0.21	0.231
	44	0.137	0.175	0.21

The different strengths of series 4 for the different water contents are shown in the figure 4.10. The below graph indicates the rapid gain in strength during the first 7 days and after 7 days rate of gain in compressive strength is very less. The graph also indicates the decrease in compressive strength as we go on increasing the water content.

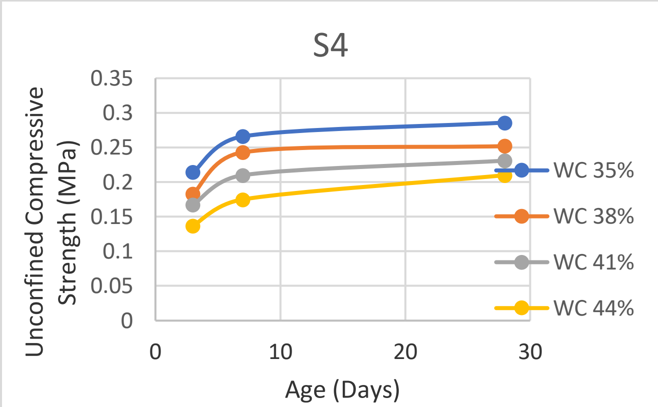

Fig. 4.10: Graph Showing Compressive Strength of CLSM series 4 for different water contents.

For series 5, compressive strength for water contents (35%, 38%, 41% and 44%), after 3 days, 7 days and 28 days is shown in the Table 4.5 given below.

Table 4.5: Showing Compressive Strength of series 5.

MIX	Water-Content (%)	Unconfined Compressive Strength(MPa)		
		3 Days	7 Days	28 Days
Series 5	35	0.203	0.39	0.42
	38	0.161	0.305	0.321
	41	0.116	0.24	0.252
	44	0.165	0.254	0.262

The different strengths of series 5 for the different water contents are shown in the figure 4.11. The below graph indicates the rapid gain in strength during the first 7 days and after 7 days rate of gain in compressive strength is very less. The graph also indicates the decrease in compressive strength as we go on increasing the water content.

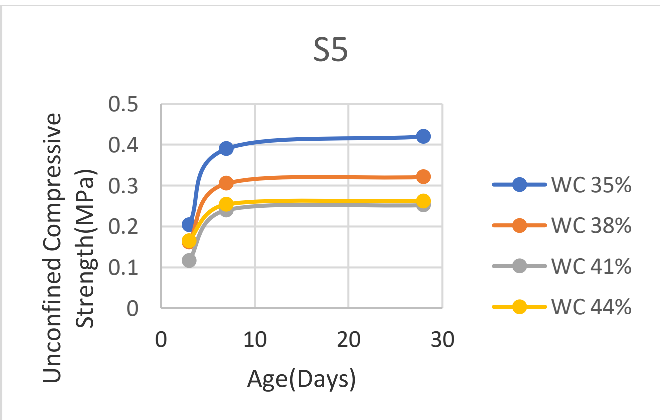

Fig. 4.11: Graph Showing Compressive Strength of CLSM Series 5 for different water contents.

For series 6, compressive strength for water contents (35%, 38%, 41% and 44%), after 3 days, 7 days and 28 days is shown in the Table 4.6 given below.

Table 4.6 Showing Compressive Strength of series 6.

MIX	Water-Content (%)	Unconfined Compressive Strength(MPa)		
		3 Days	7 Days	28 Days
Series 6	35	0.231	0.335	0.372
	38	0.173	0.326	0.353
	41	0.174	0.27	0.291
	44	0.12	0.21	0.225

The different strengths of series 6 for the different water contents are shown in the figure 4.12. The below graph indicates the rapid gain in strength during the first 7 days and after 7 days rate of gain in compressive strength is very less. The graph also indicates the decrease in compressive strength as we go on increasing the water content.

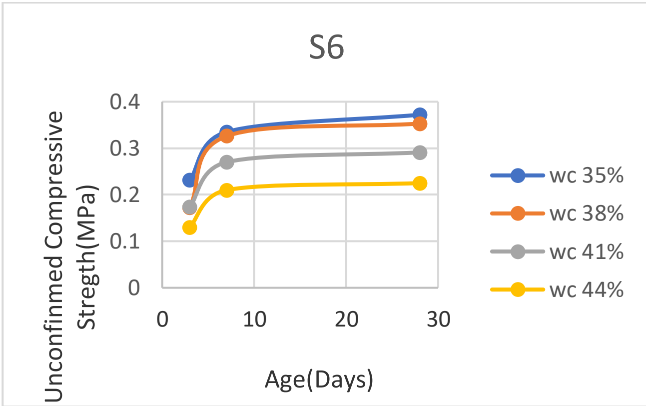

Fig.4.12: Graph Showing Compressive Strength of CLSM Series 6 for different water contents.

4.3 Comparison between unconfined compressive strength of various series

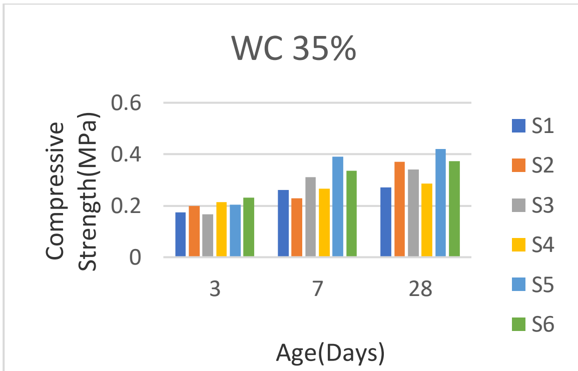

Fig. 4.1:3 Comparison between unconfined compressive strength of various series for 35% water content

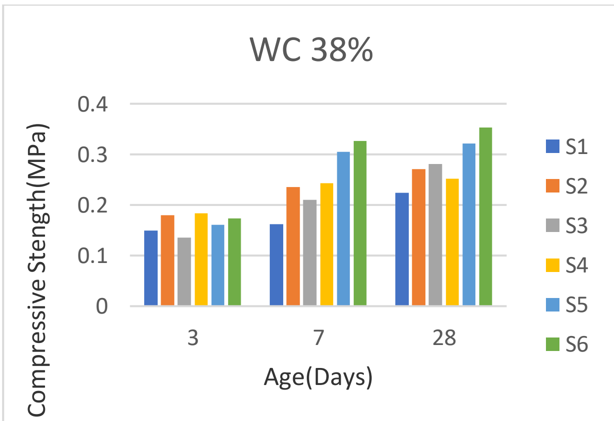

Fig. 4.14: Comparison between unconfined compressive strength of various series for 38% water content.

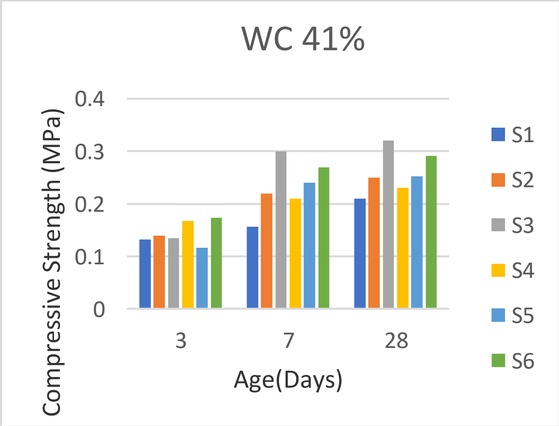

Fig. 4.15: Comparison between unconfined compressive strength of various series for 41% water content

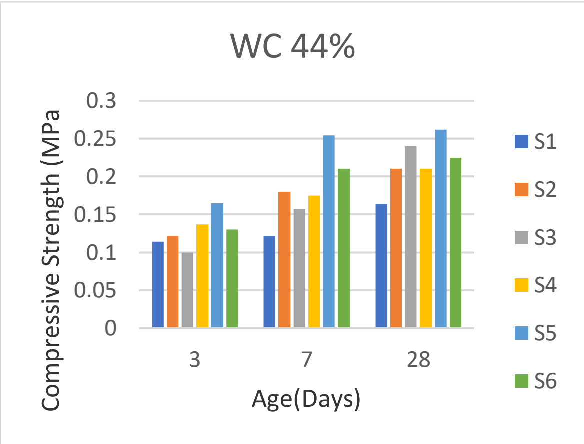

Fig. 4.16: Comparison between unconfined compressive strength of various series for 44% water content.

It was observed that by slightly varying the cement content along with higher water/fines, highly flowable and consistent mixes were achieved. The strength of these mixes were not more than 0.5MPa which makes it ideal for applications were future hand excavation is required. For low water-solids ratio, it was found that the strength gained by Controlled Low Strength Material (CLSM) after 3 days, 7 days and 28 days was quite higher than the strength gained by CLSM on higher water-solids ratio.

5. CONCLUSION

The aim of this project was to optimize the mixture proportions using various filler and cementitious material for Controlled Low Strength Material (CLSM). The mix proportions of the various filler and cementitious materials were tested.

The result obtained from the experimental studies are summerized as follows:

The present study evaluated the use of Thermal Power Plant Fly Ash (FA), pozzolanic cement and crushed stone quarry, fine aggregate in flowable fill mixes. CLSM mixtures with a low pozzolanic cement content and high class C FA, GGBS content can produce excellent flowability and a compressive strength in the range of 0.30-0.50 Mpa at 28 days age.
Initially the pozzolonic cement was kept about 50% of FA by weight and then the quantity increased with the increment in PS Sand and Quarry dust for the higher series.

Higher strengths can be achieved by increasing Pozzolanic Cement content or by decreasing the amount of mixing water.

A relatively comprehensive laboratory study was conducted to investigate the laboratory properties and performance of CLSM and the relationship between different properties. Based on the results from this study, following conclusion can be summarized:

- Water solids ratio and fly ash has a significant effect on the flow of CLSM, whereas cement exhibited little effect on the flow of CLSM.
- Fly ash and GGBS have a significant effect on segregation whereas cement has no effect on it. Mixes made with PS Sand and Quarry Dust are less liable to segregation.
- The strength of CLSM continued to increase over time, However, the increase rate became very slow after 7 days.

6. FUTURE SCOPE

- During trial mixing process, it was noted that the particle size of the sand and quarry dust has a significant effect on the behaviour of the material. The sand used in this project was PS Sand. As sand and Stone Quarry Dust approximately make 50% of CLSM, it is important to focus on the type and grade of the sand and Quarry Dust used. Medium fine aggregates are more prone to segregation and bleeding in CLSM mixes, as high water/cement ratio are used. The coarseness of sand and Quarry dust also effect the compressive strength of CLSM. Future work can be done using finer sand and quarry dust to understand its effect on behaviour of the mixes the mixes.

- There are various other filler materials which are waste/ co-product from various industries like kiln dust, limestone dust, rice husk ash and silica fumes. These filler material could be used in the ternary mixes with cement/GGBS mixes to impart the required workability and target compressive strength to the CLSM mixes.
- The particle packing, effecting density of the mixes could be studied. It is believed that the particle packing efficiency has an enormous effect on the properties of the fresh and hardened concrete. As workability and consistency are important parameters for CLSM, particle packing of various fines used could be very essential.

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