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USING STEEL AND ALUMINA INDUSTRIAL WASTE FOR THE DEVELOPMENT OF CONTROLLED LOW STRENGTH MATERIALS

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ABSTRACT
The goal of the project was to include Ground Granulated Blast Furnace Slag (GGBS), a byproduct of the steel industry, and Red Mud, a result of the extraction of bauxite ore, into Controlled Low Strength Materials (CLSM). These components were mixed with cement and M Sand to create an affordable and environmentally friendly building material. By improving CLSM qualities and addressing waste disposal issues, the use of Red Mud and GGBS makes CLSM a more environmentally responsible choice. The research supports the circular economy and sustainable development by turning industrial waste into useful building materials.
Five distinct dry mix combinations are made using varied ratios of Red Mud, GGBS, M Sand, and cement as part of the research technique. To assess each combination's engineering and dynamic qualities, four distinct water contents were used for testing. The goal of this systematic technique was to determine the ideal mixture that strikes a balance between workability and strength. By examining these characteristics, the study advanced the development of more effective building materials by offering a useful understanding of how CLSM behaves in different scenarios. The generated CLSM mixes satisfied the performance requirements for real-world applications thanks to the methodical testing.
The study's main goal was to create a phenomenological model using the strength and flow values that were discovered. Future studies will use this model as a predictive tool to help create CLSM combinations with the necessary properties. The research highlights Red Mud's potential to provide affordable and sustainable solutions for a range of engineering applications by proving its viability in CLSM. This creative strategy not only encourages the use of waste but also creates new opportunities to enhance building methods. The created model will expedite the development process for upcoming projects by assisting researchers and engineers in forecasting the performance of novel CLSM formulations. This creative method not only encourages the use of garbage but also creates new opportunities for better building techniques. To expedite the development process for next projects, the proposed model will assist researchers and engineers in forecasting the performance of novel CLSM formulations.
Key Words: Red Mud, Ground Granulated Blast Furnace Slag (GGBS), M-Sand, Cement, compressive strength. Electron microscopy (SEM) for Scanning,X-Ray Diffraction (XRD).

1.INTRODUCTION
Soil is commonly employed as the primary material in rudimentary backfilling operations. However, the conventional backfilling process, which involves laying and compacting the material in layers, often fails to achieve the same level of compaction as the original ground [1]. From a practical standpoint, the standard method for backfilling is both time-consuming and energy-intensive [2]. Controlled Low Strength Materials (CLSM) is emerging as one of the substitutes for such a laborious process.
Controlled Low Strength Materials (CLSM), also known as flowable fill or controlled density fill, represent a versatile and crucial component in construction and engineering projects due to their unique properties and applications. This study aims to comprehensively evaluate the fresh and hardened properties of CLSM, highlighting its significance in various construction scenarios. One of the defining characteristics of CLSM is its limited unconfined compressive strength, typically capped at 8.23 MPa.
This controlled strength is pivotal in facilitating future excavation operations, providing a balance between stability and ease of removal. However, the utility of CLSM extends far beyond its strength limitation, encompassing a spectrum of properties that contribute to its widespread application.

Its application ranges from simple backfilling operations to erosion and corrosion control materials. Its supreme strength properties make this material suitable to be used as pavement base [1], [2], [3].
One key ingredient often utilized in CLSM mixtures is Ground Granulated Blast Furnace Slag (GGBS). GGBS, a by-product of the iron-making process, imparts several beneficial properties to CLSM [4]. Firstly, it enhances the flowability of the mixture, ensuring ease of placement and distribution within confined spaces. Additionally, GGBS improves the long-term durability of CLSM by mitigating alkali-silica reactions and reducing permeability, thereby enhancing resistance to chemical attack and moisture ingress [5].
Another noteworthy additive employed in CLSM formulations is red mud, a residue generated from alumina production. Incorporating Red mud into CLSM blends not only offers a sustainable solution for waste management but also augments the engineering properties of the material. Red mud contributes to the overall stability and cohesion of CLSM [6], [7] enhancing its load-bearing capacity and reducing settlement over time. Furthermore, its pozzolanic properties complement those of GGBS, synergistically improving the strength and durability of the hardened CLSM.

Objectives:

- Determining the mechanical properties of controlled low strength materials. 1.3 Research Gap.
- Studying its flowability and subsidence parameters an essential metric when used as backfill material.
- Analyze water absorption and sorptivity of CLSM to understand its behavior in wet conditions.
- To determine the fresh and hardened densities of CLSM samples.

2.MATERIALS USED

Cement: Cement of grade OPC 53 (Bharathi) was used in the research process. The XRD results of the cement used in the mixture is provided. The specific gravity of the cement was found to be 3.15. Ground Granulated Blast Furnace Slag: XRD Image of Cement GGBS of JSW brand was utilized for this experimental program. The specific gravity of the material was found to be 2.8 and its SEM images are presented in the Fig 2.2 provided. Red Mud: Red mud was procured from Belgaum and its SEM images are provided. Various properties like grain size distribution, pH, chloride content and sulphate content were tested and the results are provided. M-Sand: M Sand having a specific gravity of 2.68 was used in this research program.

3. METHODLOGY

In thisstudy, over400ControlledLow-Strength Material (CLSM)samples were preparedusing five different dry mix combinations, each with four varying water contents. These sampleswere cast to undergo a comprehensive series of tests to evaluate their engineering properties (mohd auqib, 2023). The properties tested included flowability, which measures how easily the material flows; setting time, which indicates how long it takes to harden; and compressive strength, which assesses the material's ability to withstand loads. Both fresh and hardened densities were measured to determine the material's mass per unit volume before and after setting. Additionally, water absorption and sorptivity tests were conducted to evaluate the material's ability to absorb and transmit water, respectively. Subsidence, or the settlement of the material, was also tested. All tests were performed following the respective codal guidelines to ensure accuracy and reliability of the results. Fig 3.1 indicates casted CLSM samples.

Fig3.1CastedCLSMsamples

3.1MIX DESIGN

The mix designs with varying proportions are as presented in the table 3.1.

Mix ID	C (g)	GB (g)	RM (g)	S (g)
M1-M4	210	910	920	2000
M5-M8	310	860	870	2000
M9-M12	410	820	820	2250
M13-M16	510	770	755	1000
M17-M20	610	720	710	2000

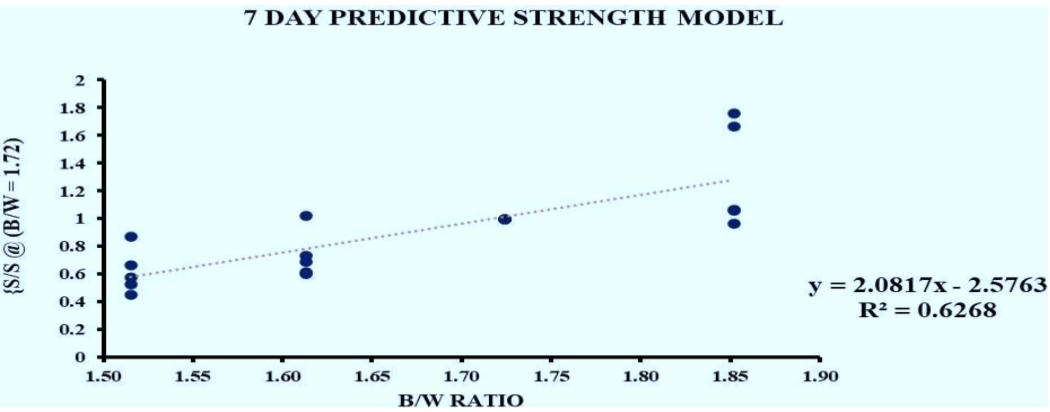
Watercontentisvariedfrom27%to33%intheincrementsof2%

*ReadasC-Cement, GB-GroundGranulatedBlastFurnaceSlag,RM-RedMud,S-M-Sand

4.RESULTS

4.1 Compressive Strength: The hardened CLSM samples were tested for their compressive strength at 7, 14 and 28 days of age. A phenomenological model was trained from the obtained compressive strength values. This predictive model would aid future studies on the topic. The strength values obtained are in accordance to the Abram's law. The samples attained highest strength at 7th day and the strength deteriorated by approximately 30% by the age of 28th day. However, over the various mix combinations, the strength increased with the increase in the cement content from M1 to M20.The early strength of the mix could be attributed with a high alkaline content of red mud enabling the formation of CSH gel. The chemical composition of red mud indicates the presence of Al2O3, Na2O and Cao in comparatively higher quantities [18]. As the presence of GGBS in the mix increases, it tries to impede the strength development in CLSM mixes due to the reduced cement content [18] [51]. Furthermore, the compressive strength decreased with the increase in water to cement ratio.

The predictive equations obtained from the strength models are y = 2.0817x - 2.5763 for 7 days, y = 1.9542x - 2.3556 for 14-days and y = 2.1842x - 2.7056 for 28- days where x is the binder water ratio and y is the normalized strength parameter. The UCS values of all the mixes were normalized with respect to one B/W ratio (1.72 in this case) to generate the phenomenological model. Figs. 4.1 - 4.6 represent the predictive strength models for the 7th, 14th, and 28th day respectively.



The table 4.1 presents the UCS values of all samples.

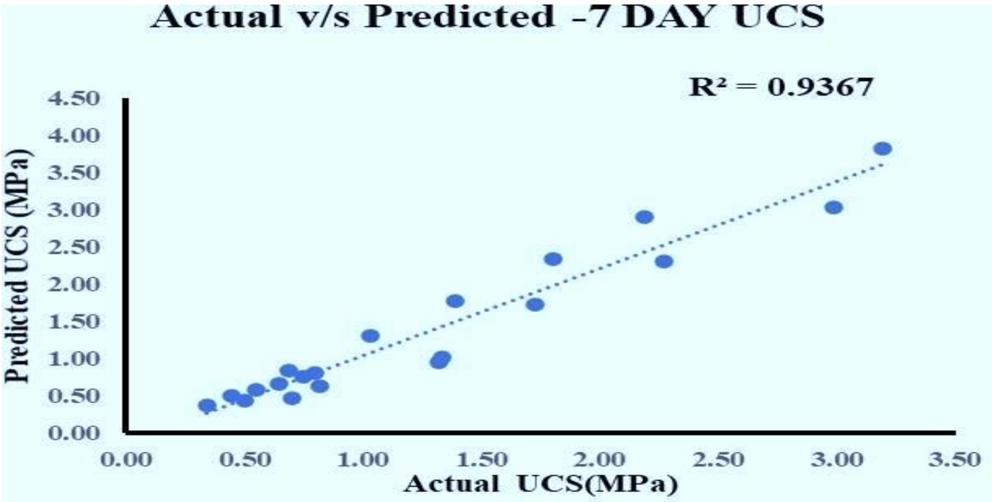


Fig4.2:Actualv/sPredicted7-DayUCS

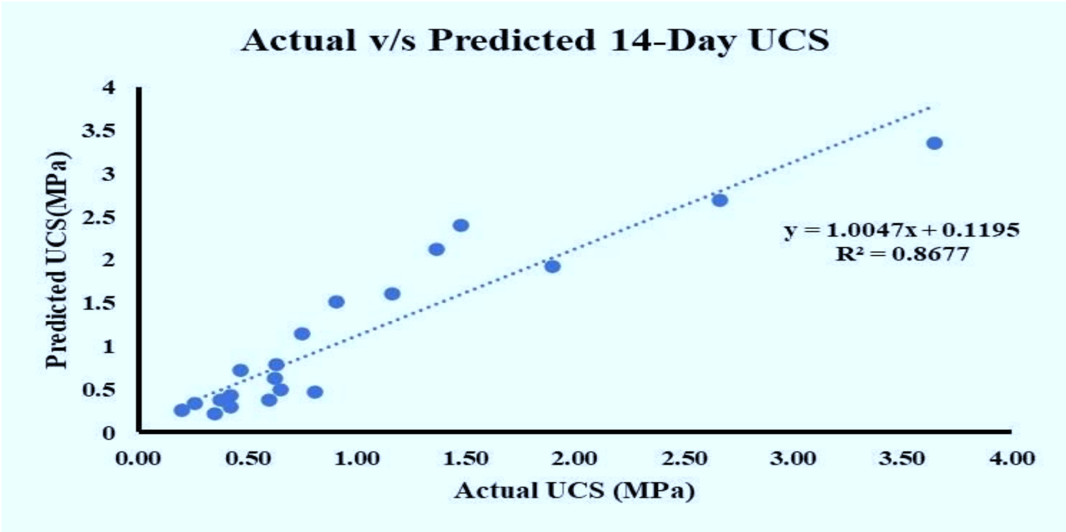


Fig4.3:NormalizedStrengthv/sBinderWaterRatio

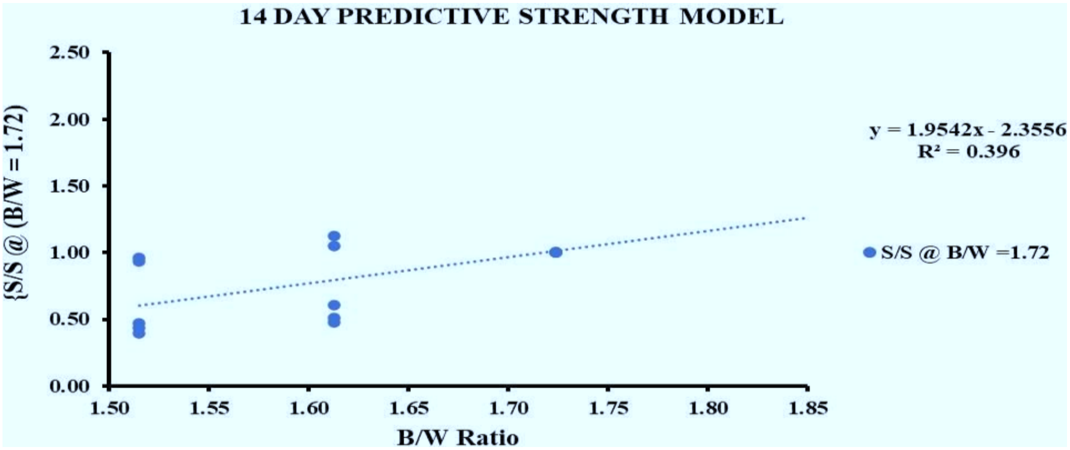


Fig4.4:Actualv/sPredicted14-DayUCS

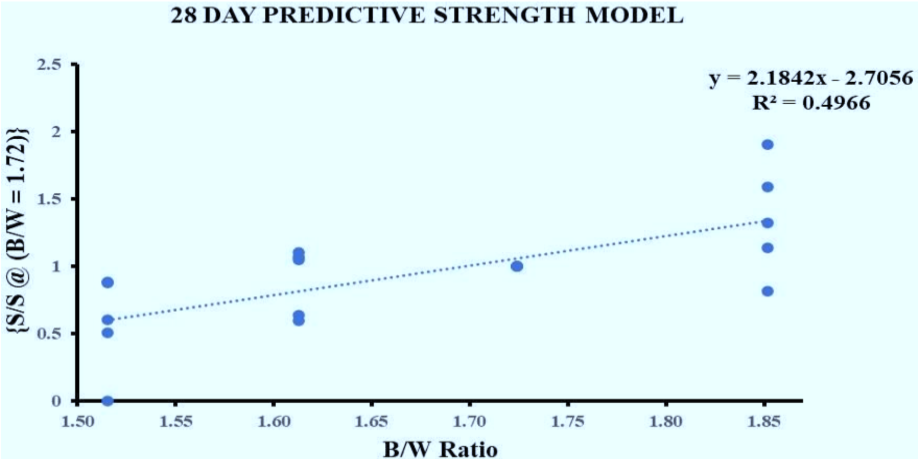


Fig4.5:Normalized Strengthv/sBinderWaterRatio

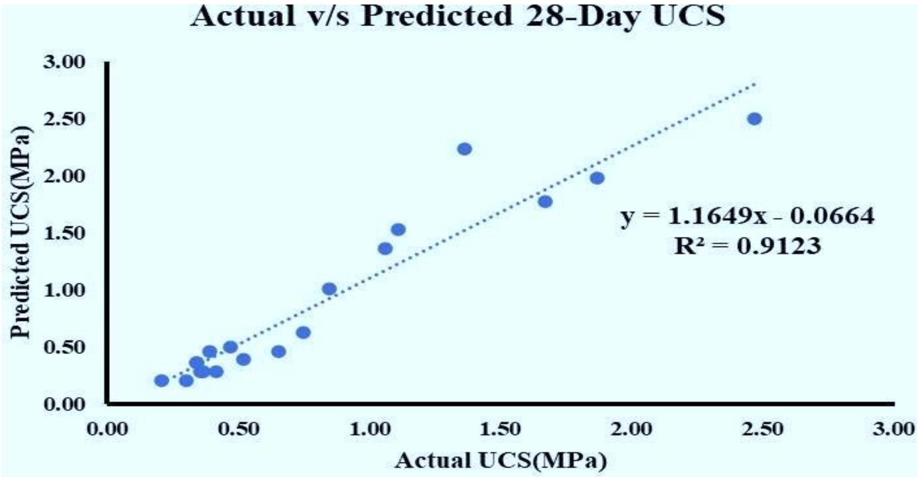


Fig4.6:Actualv/sPredicted28-DayUCS

Table4.1:Unconfined CompressiveStrength andSpreadflowResultsovermix variations

MIX ID	7 DAY(MPa)	14 DAY(MPa)	28 DAY(MPA)
M1.5	0.66	0.37	0.33
M2	0.65	0.42	0.34
M3	0.45	0.26	0.36
M4	0.34	0.20	0.21
M5	1.32	0.81	0.65
M6	0.75	0.37	0.34
M7	0.55	0.42	0.37
M8	0.50	0.35	0.30
M9	1.33	0.63	0.75
M10	0.80	0.62	0.47
M11	0.82	0.65	0.52
M12	0.70	0.60	0.41
M13	2.19	1.48	1.36
M14	2.27	1.90	1.67
M15	1.39	0.91	1.06
M16	1.03	0.75	0.85
M17	3.19	3.64	2.46
M18	2.99	2.66	1.87
M19	1.80	1.36	1.11
M30	2.73	3.16	2.55

4.2 Densities: The density of the mix is associated with its strength [52], mixes with higher density are said to have better strength properties. The suggested fresh density of CLSM ranges from 1840 to 2320 kg/m3 [1]. Similarly, the mix has a reduced dry density due to the loss of water over the later ages of 7,14 and 28 days. Thetable 4.2 below represents the fresh and hardened density of CLSM mixes. The fresh density of all the mixes fromM1 to M20 lie within this range. The highest being 2050.3kg/m3 and the least being 1841.16kg/m3. In certain samples the hardened density reduced in the later ages of 28 days. This is due to the presence of pores and cracksfound on the red mud particles [6]. Another visible trend seen is that the mixes having higher cement content exhibited higher fresh and hardened densities.

MIXID	Fresh Density(kg/m3)	7Day(kg/m3)	14Day(kg/m3)
M1.1	20235.2	1631.67	2571.45
M2.5	1950.64	1491.88	2471.99
M3.5	1980.97	1832.21	1722.37
M4.5	1871.02	1392.43	1372.53
M5	2000.4	1541.61	1621.51
M6	1871.02	1412.32	1402.37
M7	1851.11	1922.26	1542.05
M8	1841.16	1392.43	1422.26
M9	1990.45	1551.56	1531.67
M10	1980.49	1531.67	1531.67
M11	2830.24	1491.88	1521.72
M12	1910.83	1452.10	1422.26
M13	1980.49	1561.51	1541.61
M14	1990.45	1551.56	1881.56
M15.1	1890.59	1951.94	1901.83

M16	1905.85	1432.21	1462.05	1432.21
M17	1995.42	1651.02	1551.56	1631.13
M18	2050.16	1541.61	1541.61	1571.45
M19	1950.64	1501.83	1462.05	1501.83
M20	1890.92	1501.83	1471.99	1402.37

Table4.2:FreshandHardenedDensitiesofCLSMSamples

4.3 Flowability: The characteristic property of controlled low strength materials are its self-flowing and self levelling capabilities [1]. Relative flow area is the metric used to gauge the flowability of CLSM samples [10]. An RFAbetween 5 and 15 is considered ideal for the flowability of the mix [10]. The RFA of the mix samples from M1 to M20lies between 5.1 and 26.7. The RFA and flow diameter of the CLSM samples are shown in the table 4.3 provided below. Flow varied with water content linearly, this is in accordance to lyse's rule [10]. The increase in red mud content decreased the flow, this is seen as a response to the high specific surface area of red mud with high water absorbing property [12], [53]. Further the generation of a phenomenological model enabled the formulation of a predictive equation given by $y = 0.1666x - 3.88$, where x is the water content percentage and y are normalized flow results [10]. The graph of normalized RFA v/s water content is presented in Figs 4.7 and 4.8.

MixID	FlowDia (mm)	RFA
M1	125	4.5
M2	123	10.12
M3	150	10.1
M4	265	11.5
M5	185	5.1
M6	254	10.5
M7	265	11.5
M8	320	17.2
M9	200	6.1
M10	285	13.4
M11	300	15
M12	345	20.2
M13	230	8.4
M14	300	15
M15	355	21.4
M16	390	26
M17	228	8.2
M18	285	13.4
M19	345	20.2
M20	395	16.7

Table4.3: Flow diameterandRFAofCLSMmixtures

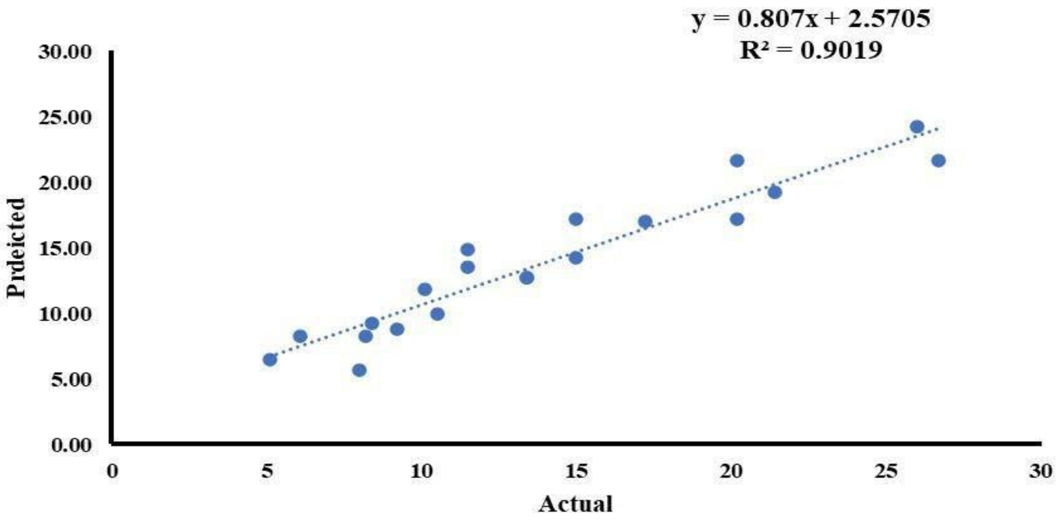


Fig4.8: Predictedv/sActual RFA

4.4 Setting Time: The setting time of all the CLSM samples varied from 2 hours to 4.5 hours. The guidelines suggestthat CLSM has a setting time lying between 3-5 hours [1]. This is ideal in bustling metro cities. The presence of red mud in the sample accelerates the setting time due to its high content of Al2O3 and Na2O [30]. Mixes with high water content had higher setting time and vice versa. The slag content in the sample could assist in reducing the setting time of CLSM [29], a higher replacement of slag with cement tends to retard the setting process due to the reduced cement content in the mixture [51]. A shorter setting time is highly relevant when considering practical applications. The bar graph representing the setting time of CLSM samples are in the Fig 4.9.

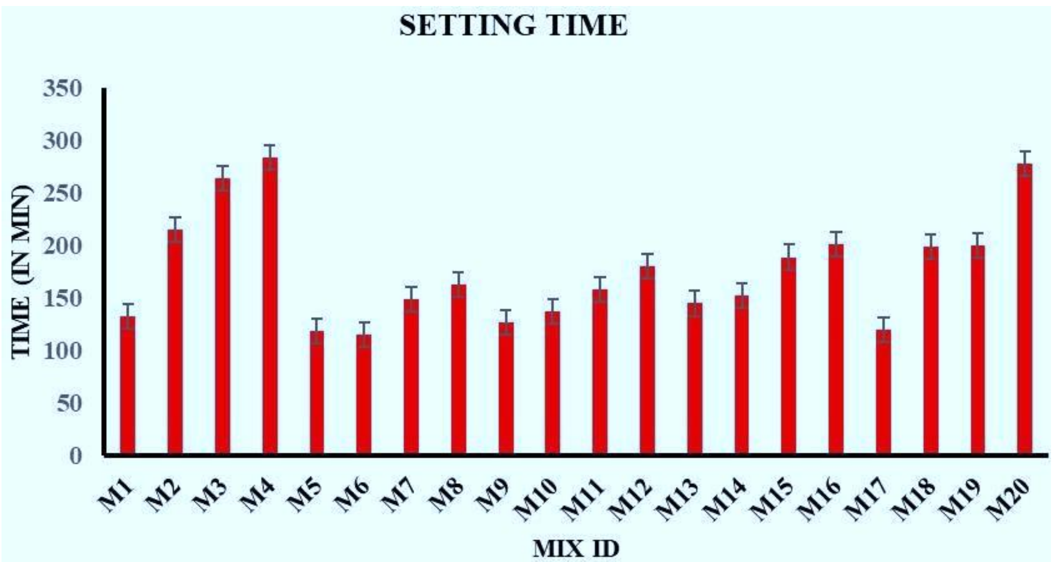


Fig4.9:SettingTimeofCLSM

4.5 Water Absorption: Fig 4.9: Setting Time of CLSM Water absorption test was conducted for all 20 mixes at 28 days. The water absorption values ranged from 12% to 18% by weight. It is observed that there is an increase in waterabsorption value with increase in water content from 27% to 33%. Further, with a decrease in red mud content for a fixed water content of 27%, increasing water absorption values are observed up to M9 and then decreases up to M20. Among the materials used, red mud is found to have maximum water absorption owing to its high specific surface area [6]. Fig 4.10 represents the bar graph plotted with water absorption v/s mix id.

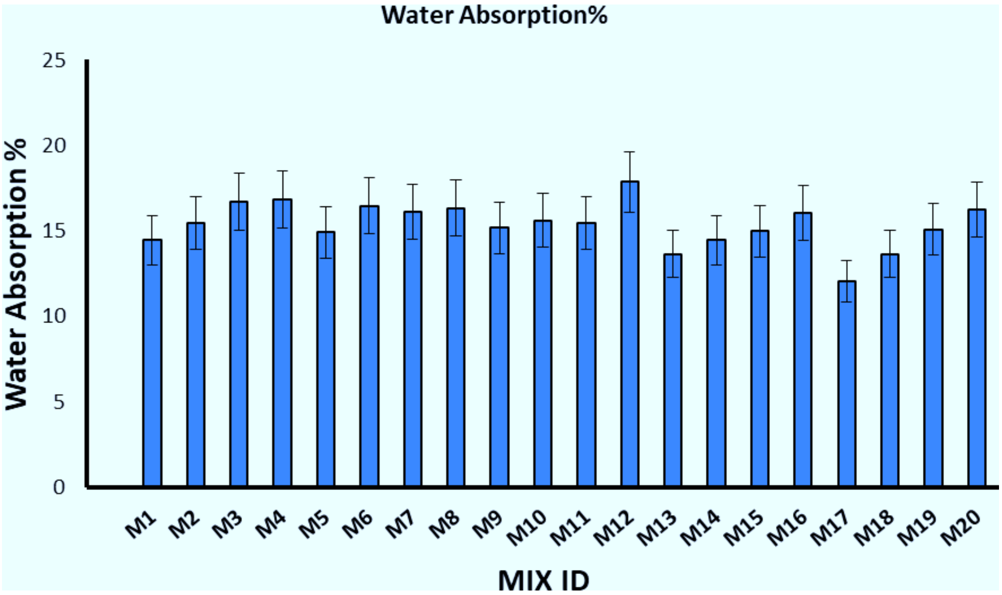


Fig4.10:WaterAbsorptionofCLSMsamples

4.6 Sorptivity: Sorptivity test helps elucidate the rate of absorption of water through capillary action with no head of water [32]. The sorptivity test yielded the Initial Rate of Absorption (IRA) and the Secondary Rate of Absorption (SRA). The test was conducted on samples having same water content (29%) and variable dry mix proportion as mentioned in Table ("mix proportion table"). The IRA values are observed to decrease with increase in Cement content and decrease in Red Mud content. On the same lines, SRA values decreased with increase in Cement content and Red Mud content. This capillary action of water through the pore structure of the materials negatively impacts its overall integrity, as water fills the voids and creates weak spots. The Fig 4.11 represents the IRA and SRA for selectedCLSM samples.

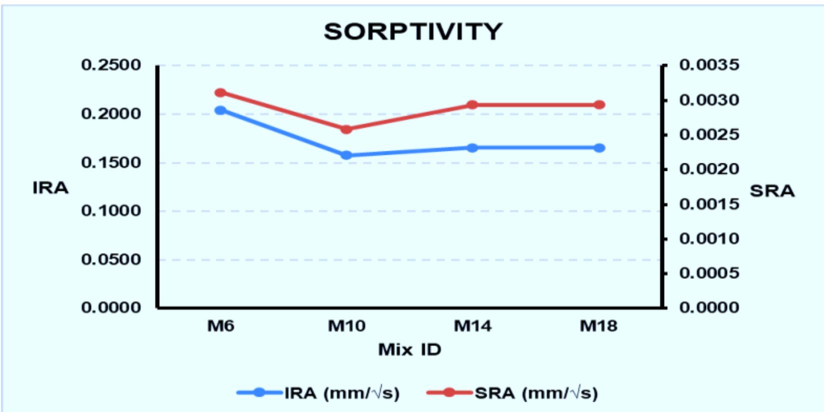


Fig4.11:SorptivityofCLSMsamples

4.7 Subsidence: Subsidence indicates the reduction in volume of samples. This occurs due to the loss of water, called bleeding. Bleeding is ideal to an extent as it inhibits the formation of cracks. It is essential to check the subsidence of samples as, excess bleeding can be detrimental as it leads to irregular settlement. The subsidence was observed for cylindrical samples of diameter of 40 mm and height of 80 mm are mentioned in Table (No). The values ofsubsidence varied from 0 – 2 mm. An irregular trend is observed and mixes with 33% Water Content (Max) yielded higher subsidence values. The Fig 4.12 represents the graph of subsidence plotted against mix id of CLSM samples.

Fig4.12: Subsidencev/sMixID

5.Conflict of Interest Statement:
The authors have no competing interests to declare that are relevant to the content of this article.

6.Credit Authorship Contribution Statement Preetpal Singh: research, conceptualization, validation, formal analysis, visualization, writing — review and editing; Amer Uddin, Preetpal Singh: review and editing. Amer Uddin conceptualization, supervision, visualization, writing — original draft. association with businesses or organizations that could profit or lose financially from the publishing of this study. Every funding source used for this research is openly revealed.

7.CONCLUSION

1.The CLSM samples exhibited highest compressive strength at 7 days and the strength deteriorated by up to 30% in the later stages of 28 days. The early strength is associated with the high alkaline nature of red mud that facilitated the formation of CSH gel. As the GGBS content increased in the mixture, the strength decreased due to the decrease in the cement content and an increased w/c ratio to adhere to the flowability stipulation of controlled low strength materials.

2.The strength values are in accordance to the Abram’s law. The UCS values obtained were used to train a phenomenological model that assists future researchers in their scope of work. These predictive models displayed appreciable accuracy when put under testing.

3.The fresh densities of the CLSM mix lies well within the stipulations, ranges between 2050.3kg/m3 and 1841.16kg/m3. The hardened densities are lower than the fresh density due to the loss of water over the hardening phase.

4.The 28-day density of certain samples were lesser than 7 and 14 days due to the presence of pores and formation of larger cracks on the surface of the red mud specimen. The mixes with higher cement content had higher densities in the fresh and the hardened state.

5.The increase in presence of red mud in CLSM reduced the flowability, due to the large specific surface area of red mud particles. However, all the mixes from M1 to M20 had an RFA that classified the mix as controlled low strength materials. A predictive flow model was generated from the obtained results.

6.The shorter setting time of CLSM is a major advantage, particularly in applications like cityscapes where minimizing disruption is critical. With a setting time of 2 - 4.5 hours, CLSM allows for quicker return to normal trafficflow compared to traditional materials that may require a longer curing period.

7. Water Absorption values were observed to vary from 12% – 18%, which helps in deducing the porous structure of the samples. It can also be concluded that water absorption % increased directly with increase in water content of 27% - 33%. Further, mixes with higher red mud content were observed to have larger water absorption % owing to its high-water absorption tendency due to its large specific surface area.
8. Samples tested for sorptivity were observed to yield IRA values which decreased with simultaneous increase in Cement and decrease in Red Mud and GGBS content. Further, a similar trend was observed with SRA values where, SRA values tend to decrease with a simultaneous increase in Cement and decrease in Red Mud content and GGBS content. The capillary action of water hinders material stability and structural integrity of the CLSM mix like that of conventional soil samples.
9. CLSM mixes incorporating red mud and GGBS portray minimal subsidence values ranging from 0 mm – 2 mm. This indicates minimal loss of water due to bleeding which is in turn essential in impeding the formation of cracks. Owing to the high-water absorption capacity of red mud, limited bleeding also helps in preventing irregular settlement of the CLSM strata hence making it an ideal back fill material.

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