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A COMPARATIVE ASSESSMENT ON PARTIAL REPLACEMENT OF CEMENT BY SEWAGE TREATMENT & ALUM BACKWASHING PLANT SLUDGE-BASED CONCRETE

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ABSTRACT

This study looks into using sewage sludge from the Nashik Tapovan Plant and alum backwashing sludge from Malegaon City to replace some of the cement in M25 grade concrete. They tried different amounts (0%, 5%, 10%, 15%) of sludge, with and without heating it to 400°C. The goal was to see if these waste materials could be used in regular construction projects in villages and small-scale work. Results showed that replacing up to 10% of the cement with either sludge worked well for normal construction. They also checked how heating the sludge affected the concrete. Heating it seemed to help a bit, making the concrete stronger and more durable. This study emphasizes the importance of using alternative materials in making concrete to help the environment and promote recycling. They suggest more research to see how using sludge in concrete affects it over a long time and to figure out if it makes financial sense for big projects.

Keywords: Comparative Assessment, Low-Cost Housing, Sewage Treatment (STP) Sludge, Water Filter (WFP) Sludge, Mechanical Characterization, Resource Optimization.

I. INTRODUCTION

Concrete is a key part of modern construction, made from materials like cement, sand, and gravel. Cement, a historic binding agent used since ancient times, has played a big role in shaping our built environment. But the traditional way of making cement causes big environmental problems. It releases gases, like CO2 (about 8% of total emissions), which add to global warming. Also, making cement creates dust that adds to environmental issues. When we add up the impact of these gases in terms of CO2 emissions,

Figure 1: Greenhouse Emission

Figure 2: Sewage Sludge Wet Form at Nasik Sewage Plant

It has profound environmental repercussions and enormous power losses. With approximately eighty of building operations currently reliant on concrete and its excessive creation value (Rs.4300 in step per cubic meter), there arises a pressing need to explore alternative methodologies to alleviate construction costs and mitigate environmental effects.

India faces a big problem with waste management, producing a whopping 62 million tonnes of waste every year. And it's only getting worse. Predictions say that by 2030, we'll be making three times as much waste as we did in 2023, which means we urgently need better ways to deal with it. Among all this, sewage sludge is a major concern. It's a kind of thick leftover material that comes from treating industrial or city wastewater, and figuring out what to do with it is a big challenge. When wastewater goes into a settling tank, about half of the solid stuff sinks to the bottom within an hour and a half, making what's called raw sludge. This study focuses on collecting sludge from treatment plants, often in a heated form.

One big problem with sewage sludge is that it's not good for using as fertilizer because it has too many heavy metals in it. This makes the usual ways of getting rid of it not so good, making environmental problems worse. Also, as cities grow quickly, we need more cement, which adds to carbon dioxide emissions. The cement industry is a big part of this problem, so we need to find better ways to make it. That's why it's important to study how we can use sewage sludge and backwashing sludge instead of some of the cement. This research can give us ideas on how to make things more sustainable, reduce our impact on the environment, and manage waste better..

Figure 3: Backwashing Sludge at Malegaon Filter Plant

In addition to the environmental worries associated with cement production and waste control, the social and financial dimensions of these demanding situations cannot be neglected. The high creation value of conventional concrete no longer only places economic burdens on developers and developers but additionally hinders the affordability and accessibility of housing for a broader populace. As we strive for sustainable answers, it turns critical to address the monetary implications and social fairness factors of creation practices. By exploring options such as a partial alternative of cement with domestic sewage sludge and backwashing sludge, this comparative study seeks to not only reduce environmental effects but also make contributions to the development of value-powerful building materials. The integration of sustainable creation practices aligns with broader desires of fostering resilient communities and promoting inclusivity inside the constructed surroundings.

Objectives & Scope of Study

- Evaluate Suitability: To assess the viability of domestic sewage sludge and backwashing sludge as partial replacements for cement at varying chances (5%, 10%, 15%) in concrete mixes.
- Performance Analysis: To conduct a comparative analysis of the mechanical Strength.
- Environmental Impact Assessment: To investigate the environmental implications of the usage of sewage sludge and backwashing sludge as cement substitutes, thinking about factors like carbon footprint discount, and waste control.
- Cost-Benefit Analysis: To evaluate the monetary feasibility of incorporating domestic sewage sludge and backwashing sludge in concrete production, inspecting ability value savings, and comparing them against traditional concrete.
- Recommendations for Implementation: To provide realistic hints for the implementation of sewage sludge and backwashing sludge as partial replacements for cement in actual global production situations, considering technical, economic, and environmental factors.

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II. LITERATURE REVIEW

Effects of Sewage Sludge & Alum Backwashing Sludge on Cement Concrete Properties:

1. Y. Ansari, et al: "Ecological footprint assessment of concrete: partial replacement of cement by water treatment sludge and stone dust reusing sludge as cement replacement (2023)''. It was confirmed in the study up to 10% of sludge can be replaced without compromising compressive strength.
2. C.M. A, Fontes, R.D. Toledo Filho & M.C. Barbosa: "A comprehensive analysis on optimization of Sewage sludge ash as a binding material for a sustainable construction practice: A state of the art review (2022)", Studied the effects of using sewage ash in higher performance concrete, in this study, replacement of cement by sludge is done at 0%, 5%, 10%. Results show that a mixture with 5% ash cement replacement showed better behavior.
3. R A Barakwan, et.al: "Performance of alum sludge as a partial replacement for cement adding superplasticizer (2019)''. The optimum quantity can be used without any change.
4. Gunalaan Vasudevan: "Performance of alum sludge as a partial replacement for cement adding superplasticizer (2019)''. The study suggested that cement replacement in diffraction can be suitable according to different usage to reduce the overall carbon emission.
5. Thevaneyan Krishta David & Sivasan Karan Nair: "Compressive strength of concrete with sewage sludge(2018)''. In this study, the study replaced cement with sewage sludge. At 0% & 10% of weight of cement. results show that the compressive strength of a combination of 10% cement & fine aggregate replacement is significantly higher than the control sample.
6. A. D. Mandlik, S. A. Karale: "Sludge use in concrete as a replacement of cement (2018)''. They carried out experimental work on water treatment sludge as fine aggregate replacement in concrete mixes & evaluated the result on compressive strength.
7. A. B M Amrul Kaish, et, al: "Influence of Pre-treated Alum Sludge on Properties of High-Strength Self-compacting Concrete (2018)''. Experimental results revealed the encouraging effects of TAS on the fresh, hardened, and durability properties of HSSCC with a maximum of 15% of the cement component partially replaced with TAS. Meanwhile, losses of mass and strength were observed to be higher in the TAS-incorporated SCC than in the control concrete.
8. Ghada Mourtada Rabie: "Using of Wastewater Dry and Wet Sludge In Concrete Mix (2016)''. Studied the effects of using wastewater dry & wet sludge in the concrete mix. In this study, replacing cement with dry sludge at 5%,10%,15% & 20% of weight or sludge led to a significant decline in compressive strength.
9. Aubert J.E., Husson B, Sarramone N: "Utilization of municipal solid waste incineration (MSWI) fly ash in blended cement (2016)''. The physical characterization of the two TFAs shows that these ashes can be considered as fine additions. The size distributions of the two ashes are similar. The main difference concerns the porosity.
10. Shayan Pirouz, Sayed Mostafa Khezri: "Using Urban Sewage Filtration Sludge for Producing Construction Material (2015)''. Conducted a study on sludge from a filtration plant. The dry sludge was taken as 0%, 10%, 20%, 30%, 40% & 50%, mix proportion to the weight of cement and 50%, mix proportions to the weight of cement with water to cement ratio = 0.60.
11. A.J Patel et al: "Review on partial replacement of cement in Concrete(2015)". This study includes previous investigations done on the mechanical and chemical properties of concrete produced using partial replacement of cement by waste materials.
12. Khalid Mohameed Breesem: "Sludge use as a partial replacement of cement(2014)''. They have carried out a study on the behavior of self-compacting concrete using different sludge and waste materials. The alum sludge from water treatment can be used in the production of cement and as an ingredient in concrete mixes.
13. Haider Mohammad Owaida, et.al: "Physical and Mechanical Properties of High-Performance Concrete with Alum Sludge as Partial Cement Replacement (2013)''. They carried out experimental work on the use of alum sludge as partial cement replacement & compressive strength, splitting tensile strength & flexural strength of concrete block was the ordinary Portland cement and admixture as added and gave fair results.

14. Maha Alqam et al: "Utilization of cement incorporated with water treatment sludge (2011)''. Investigated the use of water treatment sludge for cement replacement in the production of paving tiles for external use. They utilized sludge cement replacement percentages of 10%, 20%, 30%, 40%, and 50% and concluded that all tiles produced are non-veterans, with a water absorption that is around 10%. The breaking strength results showed development with age, and that except 50% sludge cement replacement. All of the tiles produced comply with the minimum breaking strength of 2.8 Mpa required by the standards.
15. A Jamshidi, Mehrdadi N, Jamshidi M: "Application of sewage dry sludge as fine aggregate in concrete (2011)". It was observed that the dry sludge of the wastewater treatment plant of Alborz City has a satisfying compatibility with concrete materials, due to the high contents of SiO2.
16. Alqedra, M., Arafa, M., Mattar: "Influence of low and high organic wastewater sludge on physical and mechanical properties of concrete mixes (2011)''. The results showed that a percentage of 5% low organic and high sludge by cement content could be used as an additive or as a sand replacement (in the case of low organic sludge) to concrete mix without causing a significant reduction in compressive strength.
17. Shehdeh Mohammed Ghannam: "Use of Waste Water Sludge in Concrete Mixes with Treated Water (2007)". In this study, the replacement of cement with sludge is done at the water at the water. In this study, replacement of cement by sludge is done at 0%,2.5%, 5% & 10%. Results show that increasing the percentage of the mix. Also, the compressive strength of concrete is more than in concrete using tap water.
18. Patel H., Pandey, S: "Evaluation of physical stability and leachability of Portland Pozzolana Cement (PPC) solidified chemical sludge generated from textile wastewater treatment plants (2011)''. The results were obtained by performing sequential extraction on raw sludge samples as well as on selected S/S mixtures.
19. Barrera-Díaz, C., Martínez-Barrera, G., Gencel, O., Bernal-Martínez, L.A., Brostow: Use of sludge from water and wastewater treatment plants in the production of concrete: an effective end-of-waste alternative (2010)''. Processed wastewater sludge for improvement of mechanical properties of concretes found that enough Strength
20. Siddique: "Use of municipal solid waste ash in concrete (2010)''. SW bottom ash could be suitably used as an aggregate in concrete manufacturing.

III. METHODOLOGY

Introduction to Sewage Treatment Plant Sludge: The residue that accumulates in sewage treatment plants is called sludge (or biosolids). Sewage sludge is the solid, semisolid, or slurry residual material that is produced as a by-product of wastewater treatment processes. This residue is commonly classified as primary and secondary sludge. Primary sludge is generated from chemical precipitation, sedimentation, and other primary processes, whereas secondary sludge is the activated waste biomass resulting from biological treatments. Some sewage plants also receive septage or septic tank solids from household on-site wastewater treatment systems. Quite often the sludges are combined for further treatment and disposal.

Rapid Sugar Test for Lime Content in STP Sludge in Calcinated Form Sewage Sludge:

1. The volume of HCl used in the titration is 2.8 mL.

According to the test, 1 mL of HCl represents an equivalent amount of available lime (Cao) in 1%.

Therefore, the lime content represented by 2.8 mL of HCl is 2.8%.

2. Calculate the lime content in the sludge sample

Given that the sample weight is 0.0015 g and the lime content represented by the titrated HCl solution is 2.8% of the lime content in the sludge (i.e., the pink color disappears),

we can calculate the total lime content as follows

Lime content (in grams) = (0.0015 g) * (2.8/100) = 0.000042 g

3. Convert the lime content to a percentage

Percentage of lime content = (Lime content in grams / Total sample weight) * 100

Percentage of lime content = (0.000042 g / 0.0015 g) * 100 = 2.8%

So, based on the calculations, the lime content present in the sludge sample is approximately **0.000042 grams or 2.8% by weight**.

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Figure 4: Lime Test in the Laboratory (Titrate Until the Pink Color Disappears)

Chemical Characterization:

Table 1: Comparison of oxides between Sewage Sludge & Portland Cement(Ref- ARPN,2006-15)

Sr. NO	Oxides	Sewage Sludge	Portland Cement
1	Iron Oxide	14.6%	2.3%
2	Silicon Dioxide	10.2%	21.0%
3	Phosphorus pentoxide	10.1%	0.0%
4	**Calcium Oxide**	**3.3%**	**66.0%**
5	Aluminium Oxide	3.1%	4.6%

Introduction to Alum Back Washing Sludge/ Water Filter Sludge : Alum sludge is a typical by-product of the drinking water industry. The heterogeneous sludge waste is formed when the aluminum-based coagulant is combined with suspended solids, dissolved colloids, organic matter, and microorganisms in raw water. It isestimated that global sludge production has exceeded 10,000 tonnes per day, and the rapid population growth and economic development may result in a significant increase in its amount in future decades. In Australia, most sludge is disposed of at landfill sites, which may cause severe environmental issues because of land wastage and secondary pollution. Given the transition toward a circular economy, vast-available sludge should be considered as a resource with the potential to be valorized instead of a waste.

Most alum sludge has 20–63 wt% Al_2O_3 and 17–41 wt% SiO_2. Its aluminosilicate nature makes sludge can be recycled as cement replacement, proposing a possible solution to reuse sludge in large quantities. Also, reducing cement usage may contribute to achieving the target of carbon neutrality. Some previous studies have already investigated the feasibility of alum sludge as a cement replacement in concrete products. In general, raw alum sludge exhibits no pozzolanic reaction, and the high organic matter in sludge may hinder the cement hydration, resulting in deteriorated mechanical and durability performance of concrete products. Treating sludge with high temperatures, ranging from 600 °C to 800 °C, can efficiently improve the pozzolanic reactivity of sludge because crystal phases of silicon and aluminum were dehydroxylated to form disordered phases with high reactivity. However, the optimum temperature to activate sludge activity is still controversial.

Figure 5: Water Filter Sludge

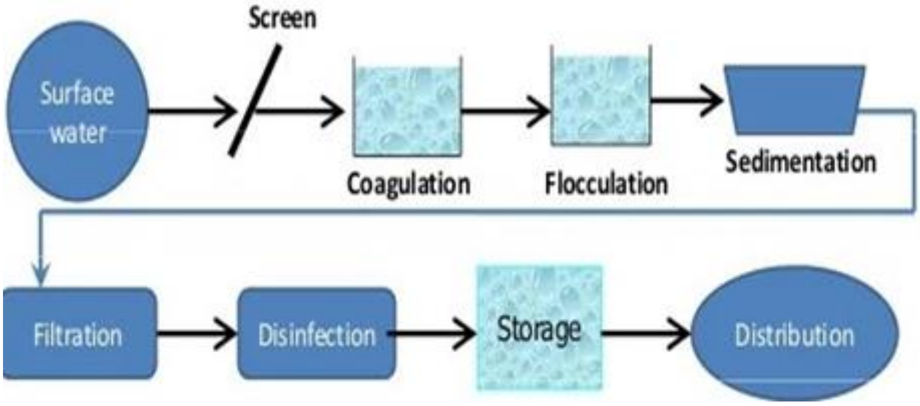

Figure 6: Water Filter Sludge Treatment Process

Chemical Analysis, (%)

Physical Tests

SiO2 Al2O3 Fe2O3 CaO MgO SO3 Na2O K2O P2O5 LOI Specific gravity Mosture content (%)

42.38 35.03 4.94 0.13 0.29 0.14 0.10 1.87 0.26 11.86 2.34 0.85

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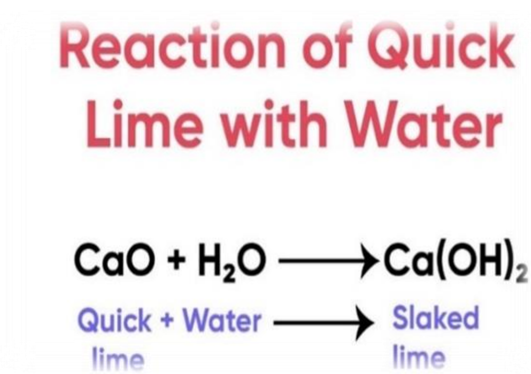

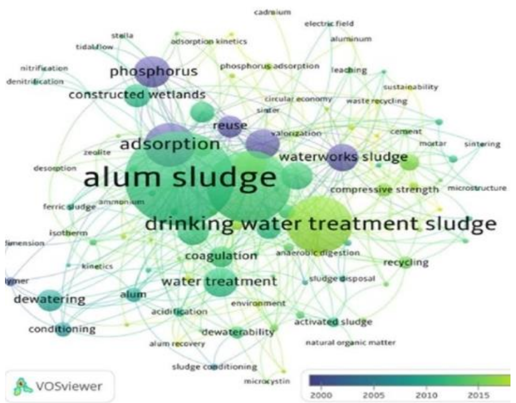

Figure 7: STP Sludge Bonding Mechanism with Lime **Figure 8**: Alum Sludge Binding Mechanism

Table No. 2 Physical Properties & Chemical Composition Alum Sludge (Ref- ARPN,2006-15)

Chemical Analysis, (%)					**Bogue Composition, (%)**					**Physical Tests**	
SiO2	Al2O3	Fe2O3	Cao	MgO	SO3	Na2O	K2O	P2O5	LOI	Specific Gravity	Moisture Content
42.38	35.03	4.94	0.13	0.29	0.14	0.10	1.87	0.26	11.86	**2.34**	**0.85**

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IV. MIX DESIGN CALCULATION

Table 3: Common Mix Proportion for Design Mix

STP & WFP Sludge	STP & WFP (Incl, Cal Non-Cal) Kg/m³	Cement Kg/m³	FA Kg/m³	CA Kg/m³	Water liter	W/C Ratio
0%	**0**	382	693	1067	191	0.5
5%	**19.1**	362.9	693	1067	191	0.5
10%	**38.2**	343.8	693	1067	191	0.5
15%	**57.3**	324.7	693	1067	191	0.5

V. EXPERIMENTAL RESULTS

Workability Test: The workability of all concrete mixtures is examined using the slump cone test. A metallic slump cone test. A metallic slump mold was used to perform a slump cone test. The height difference between the mold and the concrete's highest point was measured.

Figure 9:

Table No. 4 Slump Cone Value

Sludge % by weight of cement	Slump cone values at different % of sludge (mm)			
	STP Sludge (Calcinated)	STP Sludge (Non-Calcinated)	WFP Sludge (Calcinated)	WFP Sludge (Non-Calcinated)
0%	73	70	76	73
5%	70	79	**71**	71
10%	**78**	**80**	69	**73**
15%	68	82	66	72

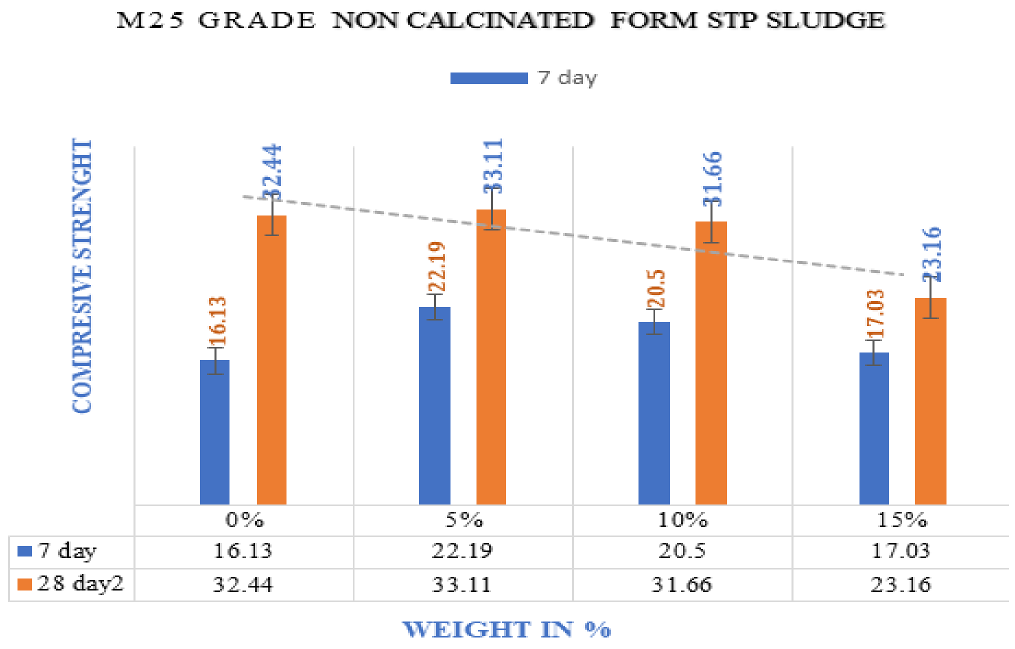
Figure 10: Slump Cone Test

Compressive Strength Test:

Table 5: Compressive Strength of Non Calcinated Form STP Sludge

SR NO	Compressive strength of M25 grade concrete					% Variation of strength concerning controlled concrete		
	Control Mix	**0%**	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**
Average Weight Comparison		8.4	9.06	9.31	9.46			

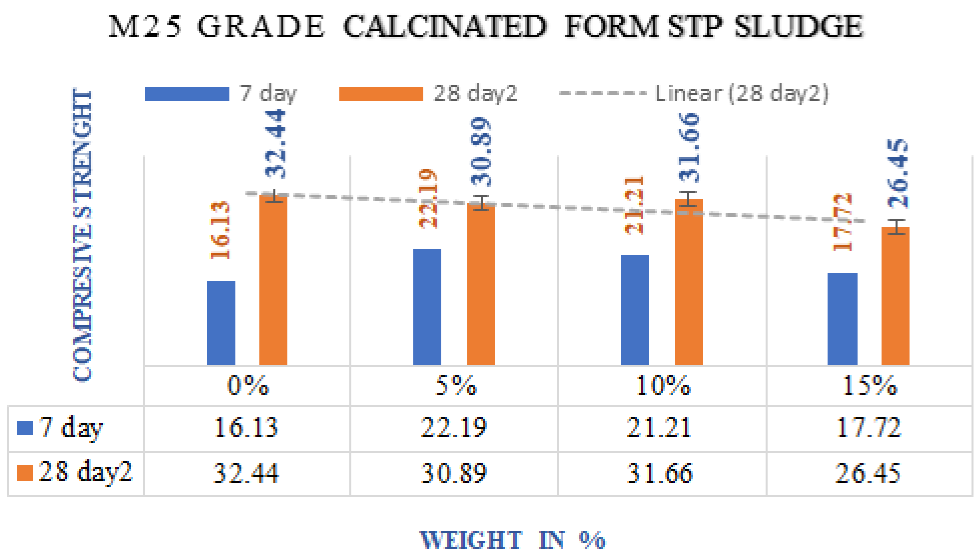
1	7 days	16.13	**22.19**	**20.5**	17.03	37.56	27.09	5.57
2	28 days	32.44	**33.11**	**31.67**	23.16	2.06	2.37	28.60



Graph 1: Compressive Strength of Non-Calcinated M25 Grade

Table 6: Compressive Strength of Calcinated Form STP Sludge

SR NO	Compressive strength of concrete					% Variation of strength concerning controlled concrete		
	Control Mix	**0%**	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**
Average weight comparison		8.63	**8.64**	8.7	8.97			
1	7 days	16.13	**22.19**	**21.21**	17.72	37.56	31.49	9.85
2	28 days	32.44	**30.89**	**31.66**	26.45	4.78	2.40	18.46



Graph 2: Compressive Strength of Non-Calcinated M25 Grade

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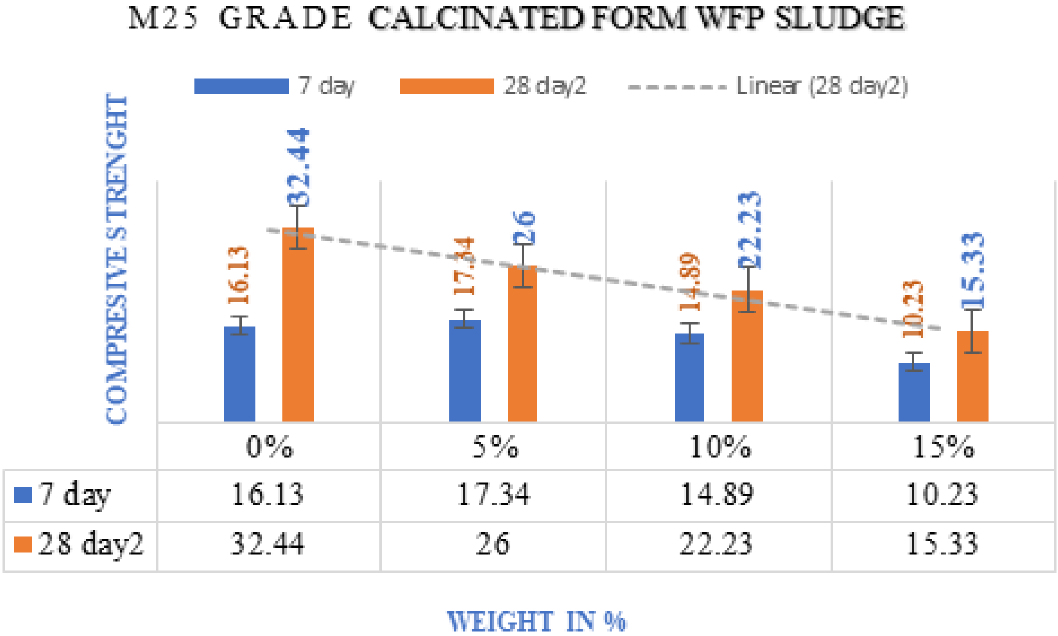
Table 7: Compressive Strength of Calcinated Form WFP Sludge

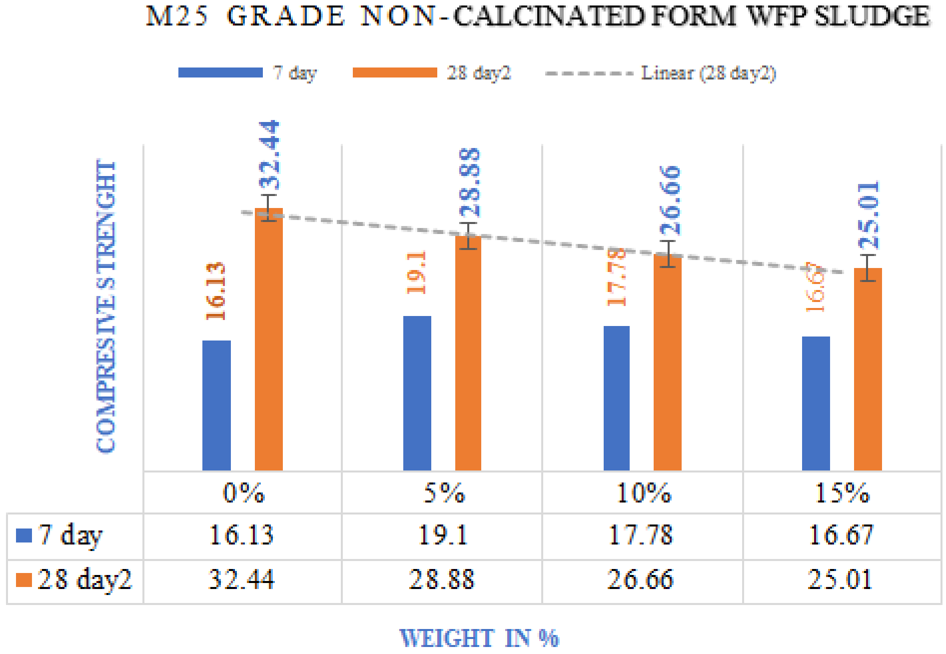
SR NO	Compressive strength of M25 grade concrete					% variation of strength concerning controlled concrete		
	Control Mix	**0%**	**5%**	**10%**	**15%**	**5%**	**10%**	**15%**
Average weight comparison		8.63	8.14	8.56	8.82			
1	7 days	16.13	**17.34**	14.89	10.23	7.5	7.6	36.57
2	28 days	32.44	**26**	22.33	15.33	19.85	31.16	52.74



Graph 3: Compressive Strength of Calcinated M25 Grade

Table 8: Compressive Strength of M25 Grade Non-Calcinated Form WFP Sludge

SR NO	Compressive strength of M25 grade concrete					% variation of strength concerning controlled concrete		
	Control Mix	0%	5%	10%	15%	5%	10%	15%
Average weight comparison		8.63	8.14	8.56	8.82			
1	7 days	16.13	**19.1**	17.78	16.67	18.41	10.23	3.34
2	28 days	32.44	**28.88**	26.66	25.01	10.97	17.81	22.90

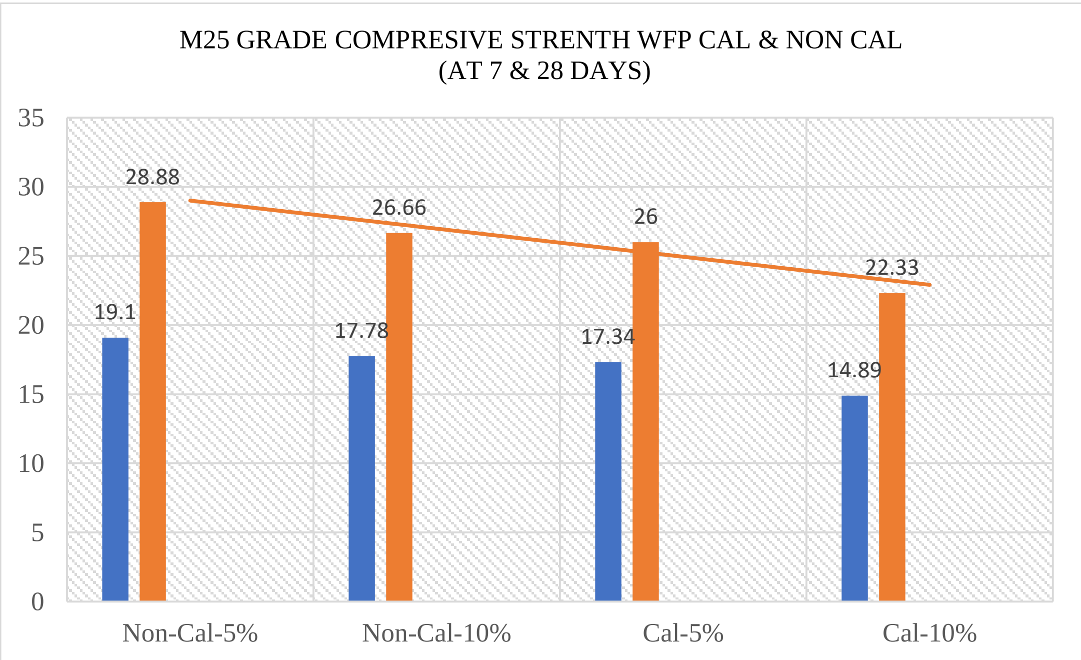


Graph 4: Compressive Strength of Calcinated M25 Grade

Performance analysis: It indicates that up to a 10% replacement of cement with (Non-Calcinated) sludge has good results based on concrete **Compressive strength** and **workability**.

Suitability Criteria: Up to a 10% replacement of cement with sludge yields satisfactory results, making it suitable for various construction applications Eg, **Low-cost housing, Slum area redevelopment, Rural construction,** etc. Beyond this threshold, further testing and optimization may be required to ensure continued performance and suitability.

Environmental Impact Assessment: We found that it is a better alternative based on Resource conservation, Waste management, Utilization of waste, Saving of energy & Ecological footprint & found to be fair in terms of Economic sustainability, Social sustainability, and Environmental sustainability.



Graph 5: Compressive Strength of Calcinated & Non-Calcinated M25 Grade (STP)

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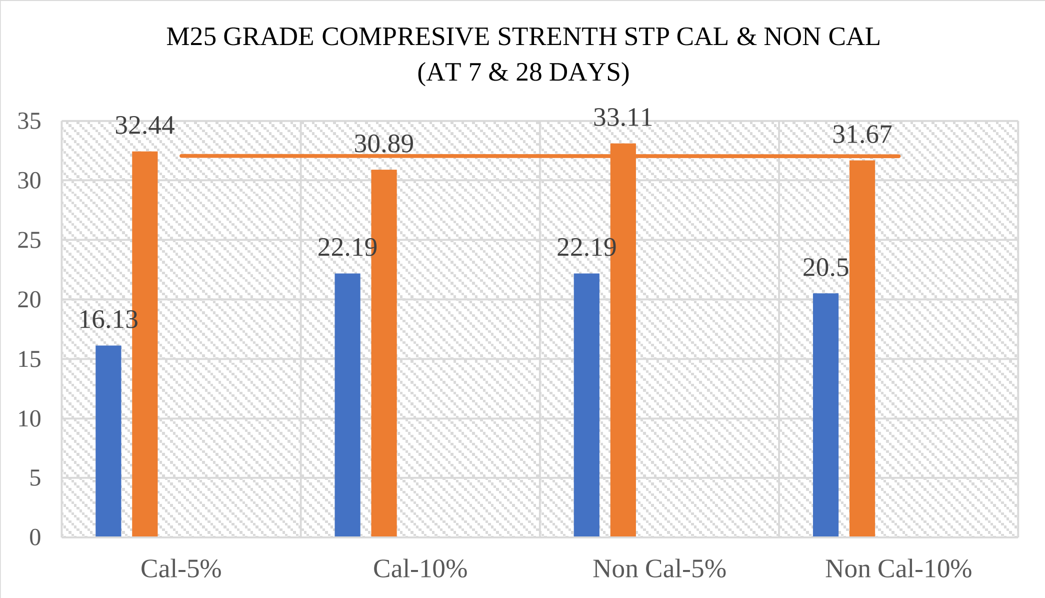

Graph 6:

Cost Benefit Analysis: Performance analysis indicates that up to a 10% replacement of cement with sludge yields satisfactory results in terms of concrete compressive strength, and workability.

Eg: - The cost of sundried sewage sludge & water filter sludge is estimated 68.60$/m^3 . the cost will be reduced upto 6%[7].

VI. CONCLUSION

- In the study it was found that upto 5%, 10% Result of non calcinated type of sludge of STP have better results as compare to calcinated sludge on the basis of compressive strength.
- Optimum content we can use upto 15% of non calcinated of STP sludge.
- In the same fesion we found that upto 5% & 10% of non calcinated sludge have better results in terms of compressive strength as compare to calcinated water filter sludge.
- Optimum content we can use of water filter sludge of non calcinated sludge was 10%.
- Based on study we conclude that STP non calcinated sludge have better results as to.

These findings have significant implications for sustainable waste management and construction practices. By repurposing waste materials in concrete production, this research contributes to reducing environmental pollution and conserving natural resources. Furthermore, it emphasizes the importance of exploring alternative materials to mitigate the ecological footprint of construction activities. Moving forward, further research is recommended to investigate the long-term effects of sludge incorporation on concrete properties, including durability and environmental impact. Additionally, conducting comprehensive cost-benefit analyses will be crucial for assessing the economic viability of scaling up the use of sludge in concrete production. Overall, this study underscores the potential of integrating waste materials into construction practices to promote a more sustainable built environment.

VII. FUTURE SCOPE

The future scope of this study encompasses several key areas for further exploration and development. Firstly, there is a need for optimization studies to determine the ideal percentage of sludge replacement for maximizing concrete performance while minimizing environmental impact. Long-term performance evaluation is essential to assess the durability and stability of sludge-incorporated concrete over extended periods. Additionally, exploring alternative treatment methods for sludge, such as different calcination temperatures or chemical treatments, could enhance its compatibility with concrete. Investigating the environmental and health impacts associated with sludge-based concrete is crucial for ensuring sustainability and safety. Scaling up production and utilization requires comprehensive studies on logistics, economics, and regulatory aspects to facilitate commercialization. Incorporating guidelines for sludge-based materials in building codes and standards will provide a framework for ensuring quality and safety in construction practices. Finally, initiatives to raise public awareness and promote acceptance of sludge-based construction materials are necessary for fostering widespread adoption and overcoming potential barriers to implementation.

There will be several aspects that can be provided in-depth inside of the study for further proceeding;

1) Thermal characterization & Thermal conduction study (Fire Hazard)
2) Flexure test with different permutations and combinations of various percentages of sludge
3) MES (Micro Scopic Structure View)
4) XRD (Xray Diffraction)
5) Life cycle assessment (LCA)

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