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Innovative Waste Management: Incorporating CETP Sludge in Concrete for Sustainable Construction

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ABSTRACT
In response to growing concerns about environmental sustainability and waste management, the exploration of alternative construction materials has gained prominence. One such alternative is common effluent treatment plant (CETP) sludge, a by-product of industrial wastewater treatment that poses significant environmental challenges. This study aims to evaluate the feasibility of substituting conventional fine aggregate with CETP sludge in concrete mixtures, addressing waste disposal issues and enhancing the sustainability of concrete construction. The research investigates the physical, chemical, and mechanical properties of CETP sludge to determine its suitability as a partial replacement for fine aggregate. Concrete mixtures with varying percentages of CETP sludge (0%, 10%, 20%, 30%, 40%, 50%) will be prepared and evaluated for compressive strength, durability, and workability. The study examines the potential benefits and challenges of incorporating CETP sludge, including its environmental impact, cost-effectiveness, and regulatory compliance. Initial findings suggest that CETP sludge possesses properties that make it a promising candidate for partial fine aggregate replacement. Further investigation will focus on its effect on the fresh and hardened properties of concrete, determining the optimal replacement ratio for desired performance. Environmental assessments will also be conducted to gauge the overall sustainability of concrete mixtures containing CETP sludge. This study aims to provide a novel solution for the responsible disposal of CETP sludge and promote environmentally friendly alternatives in construction. The research will explore the specific mechanical and durability properties of concrete with 10% CETP sludge replacement, aiming to identify an optimal balance between environmental benefits and structural integrity. The outcomes will contribute valuable insights into sustainable construction practices, encourage waste utilization in a circular economy, and reduce the environmental footprint of concrete materials.

Keywords: *industrial waste, sustainable construction, fine aggregate replacement, cetp sludge*

I. INTRODUCTION

This research investigates the use of CETP (common effluent treatment plant) sludge as a partial replacement for fine aggregate in concrete, aiming to promote sustainable construction practices. The study begins by exploring the elemental composition of CETP sludge and its potential suitability for use in concrete mixes. Previous research has shown that various industrial waste materials, including textile sludge [1][2], textile effluent treatment plant sludge [3][4], and alum sludge [5], can serve as effective alternatives to conventional fine aggregates in concrete. These studies highlight both the advantages and challenges of incorporating industrial waste materials into concrete formulations. This research seeks to address the gap in the literature by providing a comprehensive analysis of how CETP sludge impacts concrete properties such as workability, strength, and durability. It draws from earlier studies that have focused on the effects of industrial waste on concrete strength and microstructure [6][7][8]. Furthermore, the research aims to develop optimized mix designs that can enhance concrete performance. Environmental concerns associated with concrete production are also examined, with the goal of assessing the broader implications of using waste materials like CETP sludge in construction, contributing to the growing body of knowledge on sustainable building materials [9][10][11]. Ultimately, this study intends to provide valuable insights into integrating waste materials into concrete manufacturing, paving the way for more environmentally conscious construction practices.

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Figure 1: Source of CETP sludge

Initially, wastewater from various industrial sources is collected and directed to a CETP for treatment. Within the treatment plant, the wastewater undergoes a series of physical, chemical, and biological processes aimed at removing pollutants and contaminants. These processes may include sedimentation, filtration, chemical precipitation, biological degradation, and disinfection. As the wastewater moves through the treatment stages, solid materials, organic matter, and other contaminants are separated and accumulated as sludge. This sludge typically consists of a mixture of organic and inorganic substances, including suspended solids, organic compounds, heavy metals, and other pollutants. Once the treatment process is complete, the resulting sludge is collected and processed further to meet regulatory standards and environmental requirements. This may involve dewatering to reduce moisture content, stabilization to minimize Odors and pathogens, and sometimes further treatment to remove specific contaminants or pollutants. After processing, the CETP sludge may be disposed of in various ways, including land application, landfilling, or incineration. However, there is growing interest in exploring alternative uses for CETP sludge, such as incorporating it into construction materials like concrete, to promote resource recovery and sustainability

II. LITERATURE REVIEW

Recent studies have investigated the potential of various industrial waste materials as substitutes in concrete production, highlighting promising advancements in sustainability and concrete performance. Chen and Wang (2023) explored the incorporation of textile sludge into polypropylene fibre concrete, finding notable improvements in compressive strength, reduced drying shrinkage, and enhanced microstructure, along with effective heavy metal solidification. These findings suggest environmental benefits and practical applications in engineering projects. Similarly, Kaish and Zakaria (2021) examined the use of industrial waste as a partial replacement for fine aggregate, achieving workable and dense concrete mixes with satisfactory strength properties, contributing to sustainable construction practices and reducing disposal hazards. In contrast, research by Rajkumar and Pavthra (2020) on textile effluent sludge as a fine aggregate substitute in concrete yielded unfavourable results. The study reported increased water demand, lower strength, and delayed setting, indicating the need for further investigation into the chemical composition of the sludge and its influence on concrete properties. Meanwhile, an earlier study by Zhan and Poon (2015) confirmed the feasibility of using textile effluent sludge in concrete block production, achieving environmental and economic benefits, satisfactory engineering properties, and alignment with sustainable development goals, suggesting the potential for broader adoption after further optimization. In another relevant study, Kaish and Breesem (2018) explored the effects of pre-treated alum sludge on high-strength self-compacting concrete. Their findings demonstrated significant improvements in concrete properties, supporting the use of alum sludge as a sustainable material that enhances performance while mitigating environmental impact. Collectively, these studies underscore the potential of waste materials in concrete applications, advancing the construction industry's move towards sustainable practices and resource conservation.

III. OBJECTIVES

As such, the objectives of this research are:

- To analyse the elemental composition of CETP sludge through EDAX analysis.

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- To assess the physical and mechanical properties of CETP sludge for suitability in concrete applications.
- To investigate the potential of CETP sludge as a fine aggregate substitute in concrete with varying replacement percentages.
- To determine the optimal CETP sludge percentage in concrete by evaluating its impact on mechanical properties and durability.
- To conduct a range of tests on concrete specimens containing different CETP sludge percentages in both fresh and hardened states, focusing on mechanical strength, durability, and environmental resistance.
- To evaluate the economic feasibility of using CETP sludge in concrete production, considering costs related to waste handling, processing, and overall manufacturing impact.
- To develop practical recommendation for incorporating CETP sludge into concrete formulation effectively.

IV. METHODOLOGY

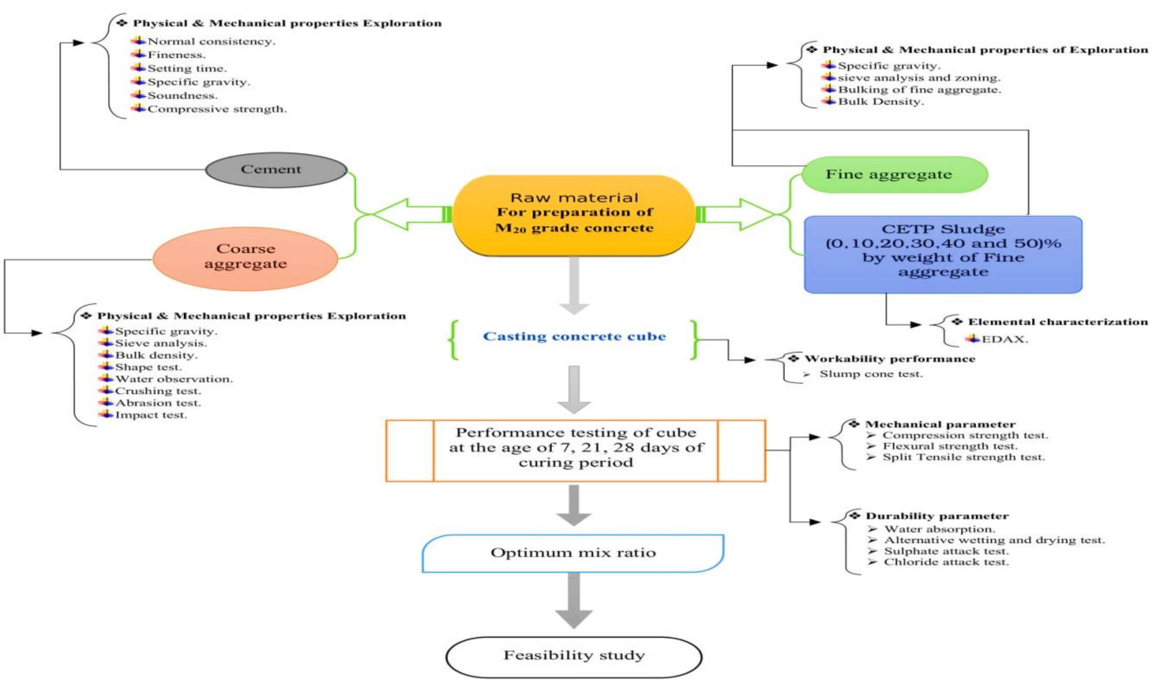

Figure 2: Flowchart of experimental procedure for CETP sludge-concrete integration

The methodology for this study involves several key stages to explore the utilization of CETP sludge in concrete production. The first step involves the collection and preparation of CETP sludge samples. Representative samples are obtained from the treatment plant, followed by preparation through drying, grinding, and sieving to ensure uniformity and readiness for analysis. The elemental characterization of CETP sludge is conducted using energy dispersive x-ray analysis (EDAX) to identify both major and trace elements present in the sludge. This provides valuable insights into the chemical composition, which is crucial for understanding the potential effects of these elements on the properties of concrete. Next, the physical and mechanical properties of the CETP sludge are assessed. Physical properties such as density and particle size distribution are measured using appropriate techniques. Mechanical properties, including compressive strength, tensile strength, and flexural strength, are evaluated through standard testing procedures. These data are then correlated to understand the relationships between the physical characteristics of the sludge and its influence on concrete performance.

For optimized concrete formulations, concrete mixtures are prepared with varying percentages of CETP sludge (0%, 10%, 20%, 30%, 40%, and 50%) as a replacement for fine aggregate. Laboratory tests are conducted to evaluate both fresh properties, such as workability, and hardened properties, including compressive strength, flexural strength, split tensile strength, and durability parameters. The results from these tests are analysed to identify the optimal percentage of CETP sludge that demonstrates the best performance in terms of mechanical strength and durability. Concrete specimens are cast according to the optimized formulations, and standard tests are performed on the fresh concrete. Mechanical properties are assessed through compressive strength, tensile strength, and flexural strength tests, while durability is evaluated by subjecting the concrete to tests such as sulphate attack, chloride attack, and an alternate wetting and drying test to simulate real-world environmental conditions.

The economic viability of using CETP sludge in concrete production is assessed by collecting data on costs associated with the handling, processing, and incorporation of the sludge into concrete mixes. This helps determine the feasibility of integrating CETP sludge from a cost perspective. Finally, based on the findings, practical recommendations are formulated for the implementation of CETP sludge in concrete formulations. These recommendations aim to promote the sustainable use of industrial waste in concrete production, contributing to both environmental and economic benefits in the construction industry.

V. RESULTS AND DISCUSSION

5.1.1 Energy Dispersive X-Ray Analysis for CETP Sludge

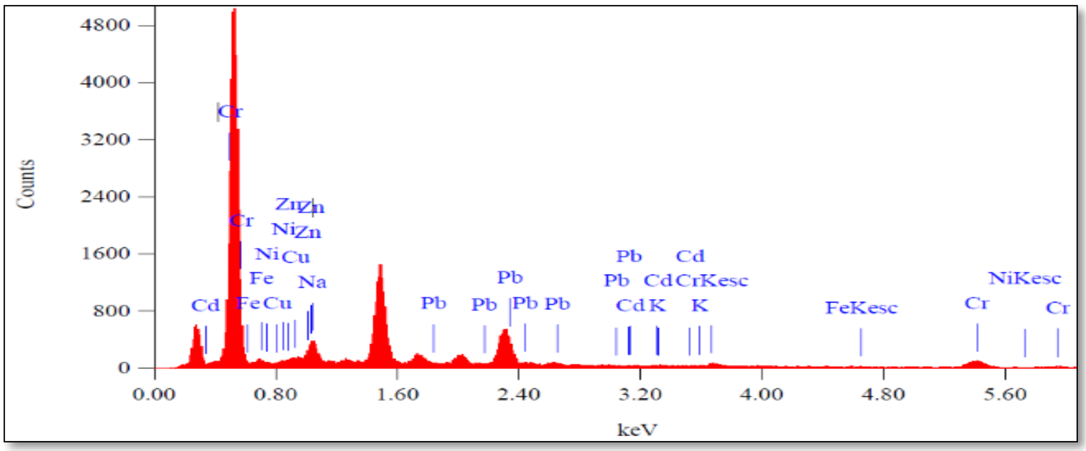

Figure3: EDAX analysis for CETP sludge

The energy dispersive x-ray analysis (EDAX) of CETP sludge highlights both beneficial and challenging elements for concrete production, which can inform optimal formulation strategies. Elements such as Chromium (Cr)and Zinc (Zn) are advantageous, as they enhance corrosion resistance, contributing to the durability and lifespan of reinforced concrete structures. Nickel (Ni) further strengthens concrete, improving wear resistance, while Copper (Cu), in trace amounts, boosts the mechanical properties and compressive strength of the mix. Iron (Fe), similarly, reinforces the structural integrity of concrete, enhancing its hardness and wear resistance, making it suitable for high-durability applications.

However, some elements in CETP sludge require careful consideration due to their potentially adverse effects. Sodium (Na) can contribute to structural damage and decrease concrete durability if present in excessive amounts. Lead (Pb) and Cadmium (Cd) have a weakening effect, potentially lowering compressive strength and resilience. Additionally, high concentrations of Potassium (K) may lead to alkali-silica reactions (ASR), causing expansion and cracking over time, which could compromise the structural integrity.

To safely incorporate CETP sludge in concrete production, controlling these elements concentrations is crucial. Strategies such as limiting sludge content to optimal replacement levels. This approach allows producers to enhance concrete's durability, corrosion resistance, and strength, contributing to cost-effective and sustainable concrete production.

5.1.2 Material Quantities for Concrete with Varying CETP Sludge Replacements

Table 1: Quantity estimation of raw materials per meter cube

Sl. No.	Sludge percentage	Cement in kg	Coarse aggregate in kg	CETP sludge	Fine aggregate in kg
1.	0%	403.2	1512	0	672
2.	10%	403.2	1512	67.2	604.8
3.	20%	403.2	1512	134.44	537.56
4.	30%	403.2	1512	201.6	470.4
5.	40%	403.2	1512	268.8	403.2
6.	50%	403.2	1512	336	403.2

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Table 1 provides an estimation of raw material quantities per cubic meter of concrete with varying levels of CETP sludge replacing fine aggregate. Starting with a conventional mix that includes 672 kg of fine aggregate, 403.2 kg of cement, and 1512 kg of coarse aggregate, the table illustrates how the fine aggregate is progressively reduced as CETP sludge is added, while cement and coarse aggregate quantities remain unchanged. With each increase in sludge content, the corresponding reduction in fine aggregate quantity creates a balanced mix. For instance, at a low sludge replacement level, the concrete mix includes a modest quantity of sludge, while the reduction in fine aggregate remains within an optimal range. At the highest sludge substitution level, a significant portion of the fine aggregate is replaced by CETP sludge, resulting in a mix that maximizes sludge utilization without compromising cement and coarse aggregate ratios. This incremental approach allows for an effective integration of CETP sludge into concrete production, promoting sustainable practices by reducing the dependency on natural sand resources.

5.1.3 Physical Properties of Fine Aggregate and CETP Sludge

Table 2: Physical properties of fine aggregate and CETP sludge

Sl. No.	Tests	Fine aggregate	CETP sludge
1.	Moisture uptake	1.05%	2.95%
2.	Specific gravity	2.60	1.52
3.	Fineness modulus	2.50	3.75
4.	Loose bulk density	1500 g/cc	670 g/cc
5.	Compacted bulk density	1800 g/cc	750 g/ cc

This table 2 presents a comparison of the physical properties of fine aggregate and CETP sludge. The characteristics assessed include moisture uptake, specific gravity, fineness modulus, and bulk density (both loose and compacted). These properties are critical in evaluating the suitability of CETP sludge as a partial replacement for fine aggregate in concrete mixes, as they influence the material's performance in terms of workability, strength, and durability.

5.1.4 Slump Test Results for Concrete Mix with Varying CETP Sludge Content

Table 3: A slump cone test was conducted on the concrete mixture

Sl. No.	Sludge %	Slump value in millimeter	Water/ Cement ratio
1.	0%	110	0.35
2.	10%	108	0.40
3.	20%	95	0.40
4.	30%	92	0.50
5.	40%	80	0.55
6.	50%	89	0.55

Table 3 presents the slump values for concrete mixtures with varying percentages of CETP sludge and their corresponding water-cement (W/C) ratios. The data indicates that as the sludge percentage increases, the slump values decrease, reflecting a reduction in the workability of the mix. This is likely due to the changes in the particle size distribution and the specific properties of the CETP sludge. Furthermore, the W/C ratio increases with the sludge content, influencing the consistency and flow of the mix. Graph 1.2 visually represents this trend, showing a clear decrease in slump values as the percentage of CETP sludge rises, underscoring the impact of higher sludge content on concrete workability. This information is essential for optimizing the mix design, ensuring a balance between workability and strength for practical use in concrete production.

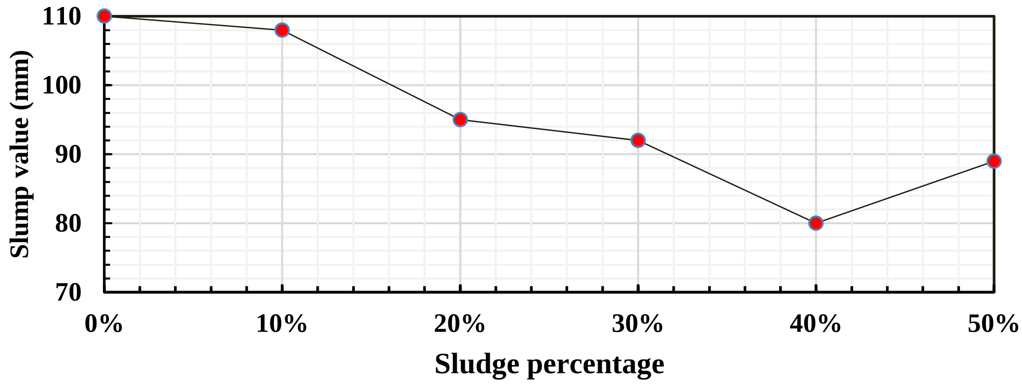

Figure 4: Graphical representation of concrete slump values (mm)

5.1.5 Mechanical Properties

Table 4: Mechanical properties of concrete with varying CETP sludge percentages

Sl. No.	Sludge percentage	Compression strength in N/mm^2			Tensile strength in N/mm^2			Flexural strength in N/mm^2		
		7 days	21 days	28 days	7 days	21 days	28 days	7 days	21 days	28 days
1.	0%	16.44	25.77	27.11	1.83	2.68	2.97	1.11	1.88	2.18
2.	10%	9.77	18.33	21.77	1.55	2.4	2.26	1.07	1.53	1.51
3.	20%	7.55	12	11.55	1.13	1.55	1.69	0.72	1.02	0.97
4.	30%	3.11	5.11	3.55	0.70	0.7	0.70	0.26	0.56	0.44
5.	40%	2.66	2.22	4.0	0.28	0.28	0.56	0.21	0.34	0.43
6.	50%	2.66	3.11	3.11	0.14	0.28	0.56	0.24	0.23	0.32

The mechanical properties of concrete, as observed through compression, tensile, and flexural strength tests, reveal a significant decline in strength with increasing CETP sludge content. Concrete with 0% sludge content exhibited the highest strengths, with compression strength reaching 27.11 N/mm^2 at 28 days. As the sludge percentage increased, all strength parameters (compression, tensile, and flexural) experienced a notable reduction. At 50% sludge replacement, the compression strength decreased to just 3.11 N/mm^2, indicating a substantial decline in structural integrity. However, the results show that incorporating up to 10% CETP sludge as a fine aggregate replacement has minimal impact on the mechanical properties of concrete, with only a slight reduction in strength. This suggests that 10% sludge can be used effectively in concrete mixtures, offering a sustainable solution for waste management by utilizing CETP sludge as an alternative to fine aggregates.

In addition to enhancing the sustainability of concrete production, the use of CETP sludge helps address waste management concerns, particularly by reducing the environmental impact of sludge disposal. The optimized use of 10% CETP sludge can thus strike a balance between maintaining adequate concrete performance and promoting eco-friendly practices in construction. These findings encourage further research into optimizing sludge content and other waste materials for future concrete formulations.

5.1.6 Durability Parameters

Table 5

Sl. No.	Sludge percentage	Compression strength in Mpa	Alternative wetting and drying test	Sulphate attack test	Chloride attack test
1.	0%	27.11	28.00	28.44	27.50
2.	10%	21.77	25.33	24.44	23.12
3.	20%	11.55	18.66	16.14	13.84
4.	30%	3.55	7.55	5.33	5.60
5.	40%	4.00	4.44	4.00	2.43
6.	50%	3.11	2.66	2.55	2.20

The durability results in Table 5 and Graph 7 indicate that concrete with 10% CETP sludge replacement shows reasonable resistance to sulfate and chloride attacks as well as alternative wetting and drying cycles, maintaining a compression strength of 21.77 MPa. Higher sludge percentages, however, lead to significant reductions in durability and strength, making 10% an optimal balance for durability in concrete mixes.

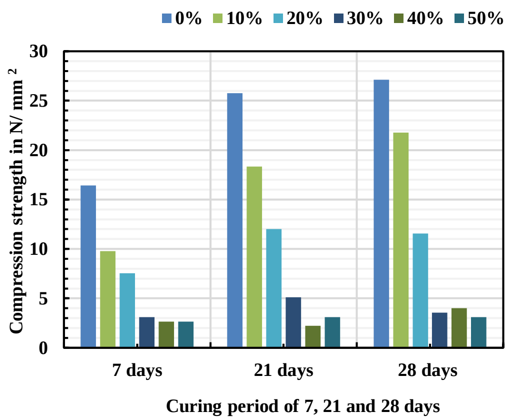

Figure 5: Concrete sample compressive strength results(N/mm^2)

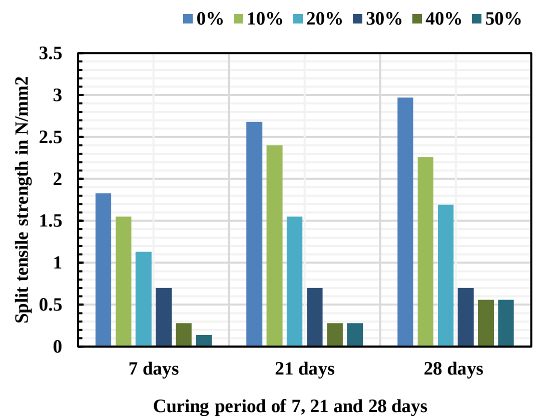

Figure 6: Concrete sample split tensile strength results (N/mm^2)

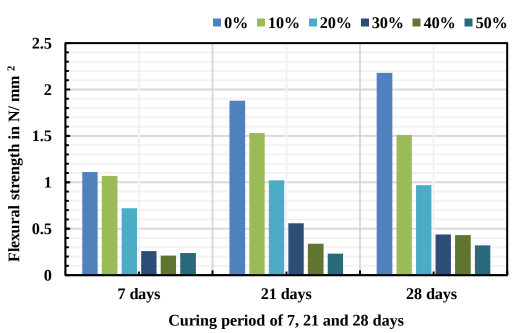

Figure 7: Concrete sample flexural strength results (N/mm^2)

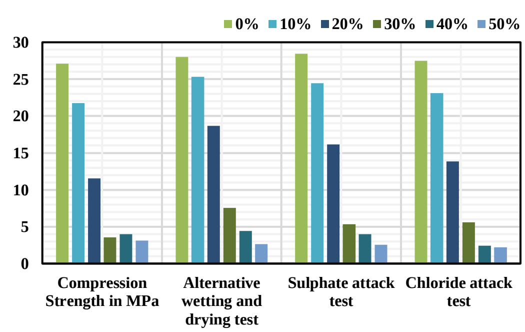

Figure 8: Durability characteristics of concrete

VI. CONCLUSION

- EDAX analysis shows that beneficial elements (Chromium, Zinc, Copper) enhance concrete's corrosion resistance and strength, while detrimental elements (Sodium, Lead, Cadmium) must be controlled to avoid negative impacts on concrete properties.
- Increasing CETP sludge percentage reduces compressive, tensile, and flexural strengths, with a 10% replacement offering the optimal balance between strength and sustainability.
- A 10% CETP sludge replacement in concrete provides optimal durability, showing good resistance to sulphate, chloride attacks, and alternate wetting-drying cycles, while higher percentages significantly reduce durability.
- Using CETP sludge as a partial fine aggregate replacement reduces reliance on natural sand, promoting sustainability and supporting cost-effective production through optimized material quantities.
- A 10% replacement of fine aggregate with CETP sludge optimally balances environmental benefits with acceptable mechanical properties, making it a viable option for concrete production.

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