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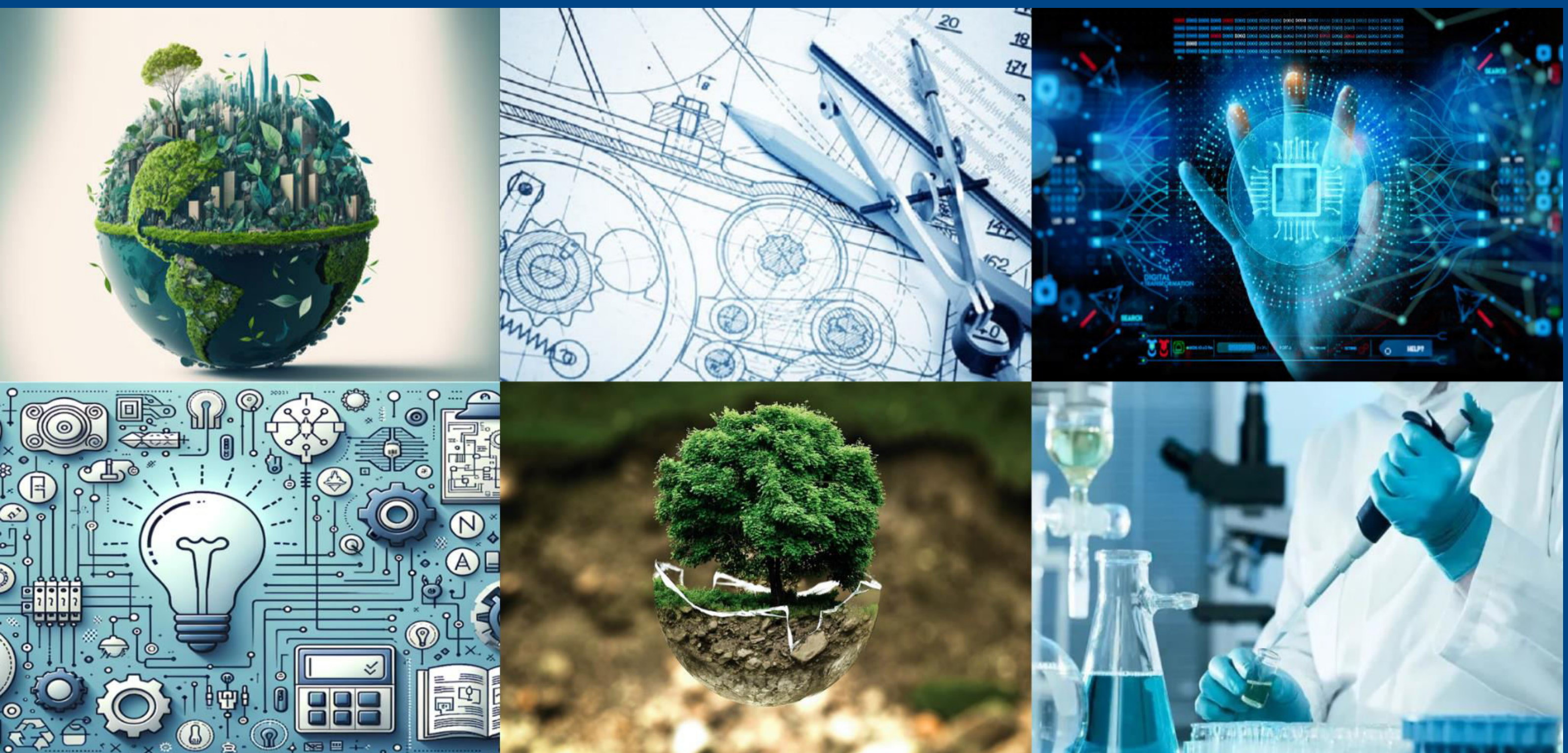

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Study on Mechanical Properties of Various Cementitious Materials

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ABSTRACT: This study Investigates the Mechanical Properties of concrete modified with ETP sludge, comparing its structural characteristics with different cement proportions. By partially replacing Ordinary Portland Cement (OPC) with ETPS reduces carbon emissions and enhances strength. The cement in the concrete mix was replaced by 5,10,15,20 and 25 weight percentage of ETP sludge and concrete blocks (15cm x 15cm x 15cm) replaced by cement and concrete blocks (15cm x 15cm x15cm) were prepared. The concrete blocks were subjected to unconfined compressive strength at 28 days to access the strength.

KEYWORDS: Ordinary Portland Cement (OPC), Concrete blocks, ETP Sludge , Compressive Strength, Structural characteristics, Partial replacement**.**

I. INTRODUCTION

The increasing global emphasis on sustainability in construction has driven the exploration of industrial wastes as viable alternatives to traditional materials. Textile effluent treatment plant (ETP) sludge, ceramic waste, sewage sludge, and iron ore tailings (IOT) have garnered attention as supplementary cementitious materials (SCMs) due to their potential to reduce environmental impact and improve resource efficiency. Recent studies have highlighted the feasibility of incorporating these industrial byproducts into concrete, bricks, and other construction materials. These materials can contribute to waste management solutions, decrease the carbon footprint of cement production, and enhance the durability of construction elements. However, the effectiveness of these waste materials often depends on the substitution level and their impact on the mechanical properties and durability of the final product.

This review explores the use of various industrial wastes in construction, summarizing key research findings and their implications for sustainable building practices.

II. LITERATURE REVIEW

M. Mottakin et al. (2023) evaluated the use of textile effluent treatment plant (ETP) sludge as a supplementary cementitious material (SCM) in concrete. The results showed that increasing the percentage of ETP sludge (TES) in the concrete mix reduced both workability and mechanical properties, including compressive and tensile strength. The optimal substitution level was found to be 5% TES, which provided the best balance of strength and workability. Beyond 10% substitution, the strength declined significantly. The study also established a strong correlation between compressive and tensile strength in TES-incorporated concrete, with a linear relationship suggesting that splitting tensile strength can be predicted based on compressive strength. Overall, 5% TES substitution offers a sustainable alternative to cement with minimal environmental impact, while higher percentages are less effective.

Pooja Jain et al. (2022) stated the growth of the ceramic tile industry has led to environmental challenges, including resource depletion and ceramic waste accumulation, while cement production contributes significantly to CO_2 emissions. Using ceramic waste (CW) as a partial cement replacement in concrete can reduce these impacts, with workability and compressive strength improving up to 20% substitution. CW enhances durability by refining pore structure, though its pozzolanic reaction may reduce resistance to carbonation. Limited research exists on using sludge from ceramic effluent treatment plants (ETPs), and this study explores its potential as a cement replacement. The findings suggest up to 20% ETP sludge can be used without major workability loss, but higher levels reduce slump and compaction.

Zhan Bao Jian et al. (2020) the impact of textile effluent sludge (TES) on ordinary Portland cement (OPC) was investigated, focusing on hydration, mechanical strength, microstructure, and metal leachability. The results revealed that increasing TES dosages (up to 20%) delayed OPC hydration, reducing the portlandite content at both 7 and 28 days. Mechanical strength was significantly impaired, with compressive and flexural strength decreasing by up to 71% and 42%, respectively, at 28 days. Scanning electron microscopy and porosity analysis showed that TES increased the porosity, particularly macropores, due to the formation of weak interfaces. However, leachability tests indicated that the toxic metals in TES were effectively stabilized in the OPC matrix, showing very low mobility and posing no environmental risk.

Kaling Taki et al. (2020) investigates the potential of lime-stabilized sewage sludge (SS) for use in construction, specifically for subbase material in flexible pavements. The results demonstrate significant improvements in the geotechnical properties of SS after lime treatment, including a marked increase in unconfined compressive strength (UCS) and reduced swelling behaviour. The swelling pressure and differential free swell index (DFSI) decreased with increasing lime content, indicating a reduction in the expansive nature of SS. This was attributed to the pozzolanic reactions that resulted in the formation of cementitious compounds. The study also highlights the formation of new mineral compounds, as confirmed by various characterization techniques such as SEM, XRD, TGA, and FTIR. Overall, lime treatment offers a viable solution for stabilizing SS, making it suitable for geotechnical applications in construction, particularly as a subbase material for pavements, and it provides an alternative to traditional waste disposal methods.

M. Gunavel et al. (2019) explores the use of Effluent Treatment Plant (ETP) sludge, a textile industry byproduct, as a sustainable material for brick-making. Testing two sludge-to-cement ratios (0.75:1.5 and 0.75:1.7), the research evaluates compressive strength, water absorption, and efflorescence. Bricks with a 0.75:1.7 ratio show superior compressive strength (over 10 N/mm^2), lower water absorption, and negligible efflorescence compared to fly ash bricks. These findings highlight ETP sludge bricks as an economical and eco-friendly alternative for construction, addressing both material sustainability and waste management issues.

C. Mariappan et al. (2018) ETP sludge-based concrete meets the essential properties of conventional concrete when optimized with a water-to-binder ratio of 0.45. While its initial strength development is slower, it achieves comparable performance to conventional concrete after 28 days. Experimental results indicate that replacing up to 10% of cement with textile ETP sludge has no adverse effects. However, replacing more than 20% gradually reduces the strength. This demonstrates the potential of ETP sludge as a sustainable partial replacement for cement.

HARPREET KAUR et al. (2017) examines the use of Textile Mill Sludge (TMS) as a partial replacement for fine aggregates in M20 grade concrete, along with the use of plasticizers to improve workability. It finds that replacing fine aggregates with up to 35% TMS maintains acceptable workability and compressive strength. Beyond 35%, the workability significantly reduces, and the compressive strength declines, becoming unsuitable for structural applications. At 28 days of curing, concrete with up to 35% TMS achieves comparable strength to the control mix, demonstrating its potential as an eco- friendly material for sustainable construction and effective waste management.

Prashant Ray1 et al. (2019) explores the feasibility of incorporating CETP (Common Effluent Treatment Plant) sludge into concrete as a partial replacement for cement. It highlights the potential of CETP sludge to address environmental and public health issues associated with its disposal, particularly in areas with limited land. Experimental results indicate that CETP sludge can replace up to 15-20% of cement in concrete without significant strength loss, although higher replacement levels negatively affect compressive, tensile, and flexural strength. Incorporating sludge up to 15% is viable for non-structural and some structural applications, contributing to sustainable waste management and resource utilization. Further research is recommended to evaluate long-term durability and reinforced concrete performance.

Shweta Goyal et al. (2022) investigates the stabilization of hazardous textile sludge, rich in heavy metals, using low-grade magnesium oxide (LG-MgO) as a sustainable and environmentally friendly alternative to traditional calcium-based stabilizers. LG-MgO effectively stabilizes heavy metals, reducing their leachability and improving the sludge's mechanical and chemical properties. Stabilized sludge was used to produce mortar specimens with enhanced compressive strength, densified microstructure, and increased pH, making it suitable for potential use in reinforced concrete. Optimal results were achieved with up to 10% cement replacement by stabilized sludge, maintaining favourable performance without adverse effects. This approach offers a sustainable method for recycling textile sludge while mitigating environmental hazards associated with its disposal.

Sivasankara Rao Meda et al. (2021) discusses the challenges of hazardous waste sludge disposal, emphasizing the environmental and health risks of traditional methods like landfilling and incineration. With the growing volume of waste, particularly from industrial and sewage sources, there is a pressing need for sustainable disposal alternatives. Research highlights the potential of converting waste sludge into construction materials, including cement, bricks, tiles, and concrete, by replacing conventional raw materials. Studies have shown that up to 30% replacement of cement with various sludge types is feasible without significantly compromising material properties, offering an eco-friendly solution to waste management challenges while reducing dependency on natural resources.

Geng Yao, et al.(2019) The study demonstrated that mechanical activation significantly enhances the pozzolanic activity and cementitious properties of iron ore tailings (IOTs). Through mechanical grinding, the particle size of IOTs was reduced, the specific surface area increased substantially (from 103 m^2/kg to 463 m^2/kg after 20 minutes and 581 m^2/kg after 40 minutes), and crystalline structures were disrupted, resulting in enhanced reactivity. Mechanically activated IOTs exhibited improved pozzolanic activity, reacting with calcium oxide to form hydration products such as ettringite and calcium silicate hydrate (C–S–H) gels. Prolonged grinding induced lattice distortions, creating active sites that promoted hydration reactions and enhanced cementitious potential. Blending 10–30% activated IOTs with Portland cement produced composites that met the mechanical and physical standards for 32.5-grade composite Portland cement. This highlights the feasibility of using IOTs as supplementary cementitious materials (SCMs), reducing reliance on traditional SCMs, promoting waste recycling, and supporting sustainable construction practices.

T Raghunathan , et al. (2010) This paper proposes the creation of a new composite material derived from existing non-degradable and hazardous waste materials, specifically combining Ordinary Portland cement and Dyeing Industry Effluent Treatment Plant Sludge (DIETP-S). This composite material addresses the scarcity of natural building materials, such as sand and aggregates, by offering a method to extract value from waste. In Phase I of the research, various mixtures are tested, and the composite with a 1:1.7 ratio is selected due to its sufficient strength according to IS codes for bricks. This high-quality, low-cost mixture is named Synthetic Sludge Aggregate (SSA) and is used to create synthetic fine aggregates, which can replace sand in M20, M30, and M40 concrete. The compressive strength and split tensile strength of the concrete mixtures are evaluated as per BIS standards. The proposed composite material not only reduces environmental hazards caused by dyeing industries but also offers a sustainable solution for construction and development activities.

NU Sandesh, et al. (2014) The textile industry generates significant waste, producing about 70- 90 grams of sludge per person per day from effluent treatment plants (ETP), which poses environmental challenges. This sludge, containing silica and calcium, shows potential as a partial replacement for cement in concrete. In this study, textile ETP sludge from KSIC Mysore was sun-dried, powdered, and characterized according to IS 1727-1967 standards. The research focused on optimizing the water-to- binder ratio for concrete made with partial cement replacement using this sludge and examined its compatibility with admixtures. Results indicate that concrete incorporating textile ETP sludge performs comparably to conventional concrete under compression and tension, offering a sustainable way to reduce cement use and manage industrial waste effectively.

MAH Chowdhury, et al. (2022) The study on concrete incorporating eggshell powder (ESP) and incinerated eggshell powder (IESP) as partial cement replacements demonstrated enhanced performance compared to conventional concrete at a 20 MPa mix strength. Experimental results showed improvements in compressive, split tensile, and flexural strength, as well as workability and durability, with optimal replacement levels of 20% ESP or 30% IESP. Regression analysis confirmed these improvements with over 95% correlation, supported by SEM and EDAX tests. Similarly, research on utilizing textile effluent treatment plant (ETP) and tannery sludge as partial cement replacements in cement mortar found that up to 10% replacement with either material, or 20% replacement with a mixed mode of both, could produce mortars suitable for different applications while mitigating environmental waste issues and reducing cement demand. Both studies highlight the potential of using industrial and agricultural waste materials to produce environmentally friendly, cost-effective, and high-performance cementitious composites.

Mr Arul, et al .(2015) Studies have shown that ceramic waste (CW) enhances concrete durability by refining pore structure, reducing macropores, and improving resistance to water absorption and chloride penetration. The secondary pozzolanic reaction of CW increases CSH gel formation, which boosts electrical resistivity but also reduces $Ca(OH)_2$, potentially lowering carbonation resistance. Existing research has only used ceramic waste from post-consumer products, not from the ceramic manufacturing process. This study investigates the use of dried effluent treatment plant (ETP) sludge from Simpolo Ceramics as a partial cement replacement in concrete. Results showed that at a 0.35 water–binder ratio, adding 10–20% ETP sludge improved workability, but higher content reduced it.

III. METHODOLOGY

This review paper employs a structured and systematic approach to analyze existing literature on the partial replacement of cement with effluent treatment plant sludge (ETPS) at varying levels of 10%, 20%, and 30%. The primary objective is to assess how different proportions of ETPS influence the mechanical, physical, and durability properties of cement-based materials. To gather relevant sources, an extensive literature search was conducted using major academic databases such as Scopus, ScienceDirect, SpringerLink, Google Scholar, IEEE Xplore, and ResearchGate. The search included peer-reviewed journal articles, conference proceedings, and academic theses published between 2010 and 2025. Keywords used in the search process included terms like "ETP sludge as cement replacement," "cement replacement with industrial waste," "ETPS concrete properties," and "sustainable construction materials." Boolean operators and advanced filters were applied to enhance the relevance and precision of the results.

Studies were selected based on defined inclusion and exclusion criteria. Only research that focused on ETPS used as a partial replacement for cement at 10%, 20%, or 30% levels was considered. These studies also needed to present data on mechanical properties such as compressive strength, tensile strength, and flexural strength, as well as on durability-related aspects like water absorption, permeability, and chemical resistance. Experimental studies and those offering comparative analyses with control concrete mixes were prioritized. Papers that lacked experimental validation, used ETPS for purposes other than cement replacement, or were not published in English were excluded.

After identifying the relevant literature, key data were extracted from each study. This included information on the source and chemical composition of ETPS, mix design details, replacement ratios, curing conditions, testing methods, and the performance metrics of the modified cementitious materials. The extracted information was then categorized according to the percentage of ETPS used to facilitate comparison across different studies. A critical analysis was carried out to identify trends, performance variations, and limitations at each replacement level. Comparative evaluations with control mixes (0% ETPS) were emphasized to understand the potential advantages or drawbacks of using ETPS in construction materials.

Finally, a quality assessment of the reviewed studies was conducted to ensure the reliability and validity of the findings. Each paper was evaluated for its methodological clarity, adherence to standardized testing procedures (such as ASTM or IS codes), reproducibility of results, and publication in peer-reviewed sources. This multi-step approach ensures that the review provides a comprehensive and unbiased synthesis of current research on the use of ETPS as a sustainable alternative in cementitious composites.

IV. RESULTS

Based on the compressive strength data for varying percentages of ETPS replacement, it is evident that incorporating ETPS up to 10% has minimal impact on concrete strength, with values remaining close to the control mix. At 5% and 10% replacement, the strength reduction is less than 4%, indicating suitability for structural applications. However, beyond 10%, a noticeable decline in compressive strength is observed. At 15% replacement, the strength drops by over 10%, and at 20% and 25%, the reduction becomes more significant, reaching 27.3% at 25% ETPS. These results suggest that while low- level replacement (up to 10%) is viable, higher percentages adversely affect strength and may limit structural use without performance-enhancing modifications.

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ETPS Replacement (%)	Curing Period (Days)	Compressive Strength (MPa)	% Change from Control Mix	Remarks
0% (Control)	28	33.0	–	Standard OPC concrete
5%	28	32.7	−0.9%	Nearly identical to control
10%	28	31.8	−3.6%	Slight strength reduction
15%	28	29.5	−10.6%	Noticeable reduction, still usable
20%	28	27.2	−17.6%	Significant reduction
25%	28	24.0	−27.3%	Below acceptable structural limits

Compressive Strength of Concrete with Varying Percentages of ETPS Replacement

V. CONCLUSION

This review highlights the growing interest in utilizing effluent treatment plant sludge (ETPS) as a partial replacement for cement in concrete, motivated by environmental sustainability and waste management goals. Based on a systematic evaluation of existing literature, it is evident that incorporating ETPS at low levels—particularly up to 10%—can produce concrete with mechanical and durability properties comparable to conventional mixes, making it a viable and eco-friendly alternative. However, increasing the replacement level beyond 10% generally leads to a decline in compressive strength and durability, with 30% replacement showing significant performance limitations. The findings underscore the importance of careful proportioning, mix optimization, and quality control when using ETPS in cementitious materials. Additionally, the review points to the need for further research on pre-treatment methods and supplementary additives that could improve the performance of higher ETPS content mixes. Overall, the partial replacement of cement with ETPS presents a promising approach toward sustainable construction, provided it is applied within technically and structurally acceptable limits.

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