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Exploring the Use of Common Effluent Treatment Plant (CETP) Sludge as an Eco-Friendly Substitute for Fine Aggregates to Develop Advanced Concrete Paver Blocks

Ajith Kumar N[1], Dr Usha S[2], Dr Shivaraju G D[3]

Department of Civil Enginnering, Sri Siddhartha Institute of Technology, Tumkur-05. Department of Civil Enginnering, Sri Siddhartha Institute of Technology, Tumkur-05. Department of Civil Enginnering, Sri Siddhartha Institute of Technology, Tumkur-05

Abstract:- Concrete is among the most widely used materials in construction worldwide, yet its conventional manufacturing and the extraction of its raw ingredients lead to significant environmental concerns, including resource depletion and elevated greenhouse gas emissions. Disposal of industrial waste such as Common Effluent Treatment Plant (CETP) sludge creates further ecological challenges due to its content of hazardous heavy metals and complex management requirements. This research investigates the potential of utilizing CETP sludge as a partial substitute for fine aggregates in M30 grade concrete to produce resilient, eco-friendly paver blocks. The study encompasses detailed chemical analysis, assessments of mechanical performance and durability, workability evaluation, and environmental safety checks through leaching tests. Additionally, it examines the economic advantages and explores prospects for sustainable industrial adoption in the future.

Keywords: *CETP sludge, Concrete paver blocks, Fine aggregate replacement, Sustainable construction, Mechanical properties, Environmental safety*

1. Introduction

1.1 Background

Concrete serves as an indispensable material in the development of infrastructure, owing to its remarkable durability, adaptability, cost efficiency, and widespread availability across both urban and rural regions. Nevertheless, escalating demand for concrete production has given rise to considerable environmental concerns, necessitating critical evaluation and mitigation strategies.

The extraction of raw materials, including sand and gravel, contributes to the depletion of natural resources and causes significant damage to ecosystems

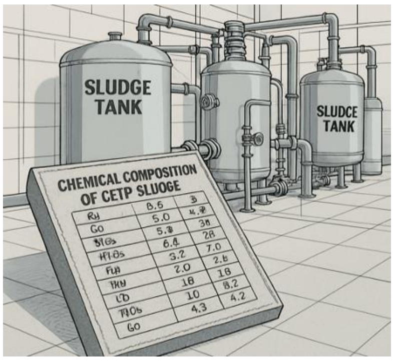

Fig.1.1:Chemical Composition of CETP Sludge in Sludge Tanks

Energy consumption: Cement production, a major component of concrete, requires intensive energy use and emits substantial carbon dioxide (CO2), contributing to climate change.

At the same time, industrial growth has caused a rise in the buildup of industrial waste. A major concern is the sludge produced by Common Effluent Treatment Plants (CETPs), which treat wastewater from groups of industries. This sludge frequently contains hazardous heavy metals such as chromium, lead, cadmium, and others. Ensuring the safe and sustainable disposal of this sludge remains a challenge, leading to environmental contamination and potential health hazards.

This research seeks to repurpose CETP sludge as a partial fine aggregate replacement in concrete paver blocks, aiming to reduce environmental impact by recycling industrial by-products and conserving natural resources.

2. Objectives

- **Evaluate the feasibility** of using CETP sludge as an eco-friendly substitute for fine aggregates in M30 grade concrete paver blocks to reduce environmental impact and resource depletion.
- **Analyze the chemical composition** and physical properties of CETP sludge to determine its suitability for incorporation into concrete mixes.
- **Assess mechanical properties** such as compressive, tensile, and flexural strength of concrete containing various proportions of CETP sludge over different curing periods.
- **Monitor durability** of concrete paver blocks incorporating CETP sludge, including resistance to sulfate/chloride attack and wet-dry cycling.
- **Examine workability and water demand** for concrete mixes with CETP sludge and evaluate the need for admixtures like superplasticizers.
- **Ensure environmental safety** by performing leaching tests to confirm there is no hazardous metal release from paver blocks containing sludge.
- **Evaluate economic benefits** of CETP sludge usage in concrete, including cost savings and waste management advantages.
- **Explore industrial relevance and adoption**, recommending future work for scaling up and integrating sustainable waste reuse practices into construction.

3. Methodology

3.1 Sample Collection and Chemical Analysis

- CETP sludge samples were procured from Eco Green Solutions, located in the KIADB Industrial Area, Doddaballapura, Karnataka.

- The sludge underwent chemical characterization via Energy Dispersive X-ray Analysis (EDAX) to quantify elemental composition, especially heavy metals content.

- Environmental safety was assessed through leaching tests conducted by an accredited laboratory (TCPL) to detect any potential release of toxic substances.

3.2 Concrete Mix Design and Preparation

- M30 grade concrete was designed with a conventional mix ratio of 1:0.75:1.5 (cement:fine aggregate:coarse aggregate).

- Fine aggregates were replaced by CETP sludge at varying proportions: 0% (control), 5%, 10%, 15%, 20%, and 25% by weight.

- Hexagonal paver blocks with thicknesses ranging from 60 to 80 mm were cast and cured for 28 days for testing.

Fig.3.1: Casting of Hexagonal Concrete Paver Blocks Using CETP Sludge

3.3 Mechanical Testing

- Concrete samples underwent compressive strength testing after curing for 7, 21, and 28 days.

- Additionally, tensile and flexural strength assessments were performed at these same curing periods.

- Workability was measured using the slump test.

- Water absorption tests assessed porosity by submerging specimens in water for 24 hours and measuring weight gain.

Fig.3.2: Compressive Strength Testing of Concrete Paver Blocks

3.4 Durability Tests

- Durability evaluations included resistance under sulfate attack, chloride attack, and wet-dry cycling to simulate environmental conditions and assess long-term performance.

4. Results

4.1 Chemical and Physical Properties of CETP Sludge

4.1.1 Elemental Composition by EDAX

Tabel 4.1: Elemental Composition by EDAX

Element	Percentage (%)	Notes
Chromium (Cr)	85.57	Enhances corrosion resistance, hardness
Iron (Fe)	4.99	Strength, density, abrasion resistance
Sodium (Na)	5.58	High amounts may reduce durability
Lead (Pb)	0.92	Trace element reducing strength/durability
Nickel (Ni)	1.23	Improves wear resistance and durability
Copper (Cu)	0.74	Enhances mechanical properties
Zinc (Zn)	0.59	Corrosion resistance
Cadmium (Cd)	0.18	Weakens concrete longevity
Potassium (K)	0.19	May contribute to alkali-silica reactions

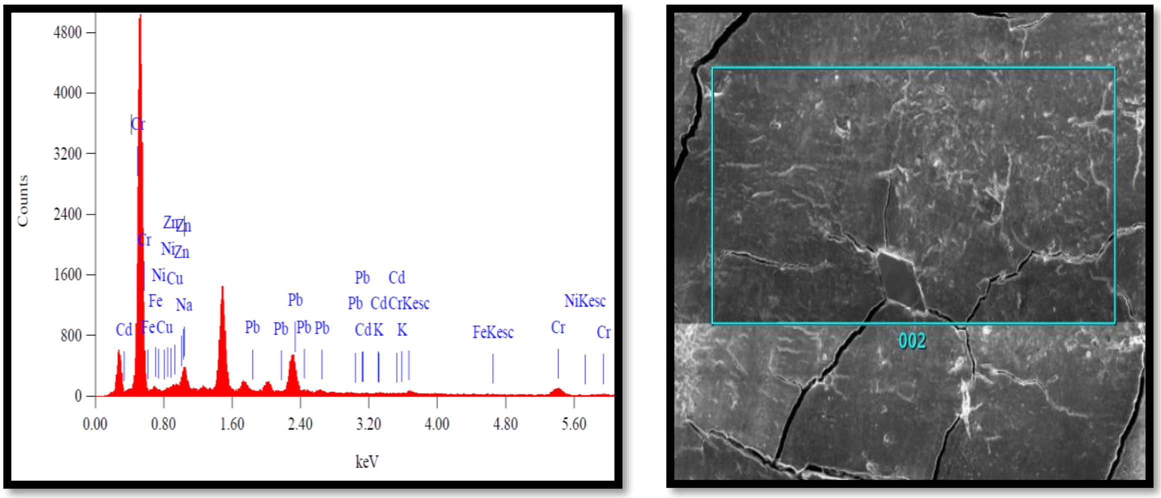

Fig.4.1: Elemental Composition Result by EDAX

4.1.2 Physical Properties Comparison

Tabel 4.2: Physical Properties Comparison

Material	Water Absorption (%)	Bulk Density Loose (g/cc)	Bulk Density Compacted (g/cc)	Specific Gravity	Sieve Analysis (mm)
Cement	-	1500	1550	3.15	< 0.09

Fine Aggregate	1.01	1580	1800	2.65	2.69
CETP Sludge	3.05	675	750	1.49	4.05
Coarse Aggregate	1.25	1500	1680	2.65	6.5

- CETP sludge exhibits higher water absorption and lower bulk density than conventional fine aggregates, influencing the water demand and strength of concrete.

4.2 Mechanical Properties with Varying CETP Sludge Replacement

Tabel 4.3: Mechanical Properties with Varying CETP Sludge Replacement

Sludge %	Compressive Strength (N/mm²)	Tensile Strength (N/mm²)	Flexural Strength (N/mm²)						
	7d	21d	28d	7d	21d	28d	7d	21d	28d
0%	22.88	31.68	35.20	2.06	2.85	3.17	2.97	4.12	4.58
5%	**23.73**	**32.85**	**36.50**	**2.14**	**2.96**	**3.28**	**3.08**	**4.27**	**4.75**
10%	17.43	24.13	26.81	1.57	2.17	2.41	2.27	3.14	3.49
15%	12.06	16.70	18.56	1.09	1.50	1.67	1.57	2.17	2.41
20%	10.00	13.85	15.39	0.90	1.25	1.39	1.30	1.80	2.00
25%	5.84	8.08	8.98	0.53	0.73	0.81	0.76	1.05	1.17

- The optimal replacement percentage is 5%, delivering better strength performance than control.

- Increasing sludge content beyond 10% results in significant strength reductions, attributed to increased brittleness and poor workability.

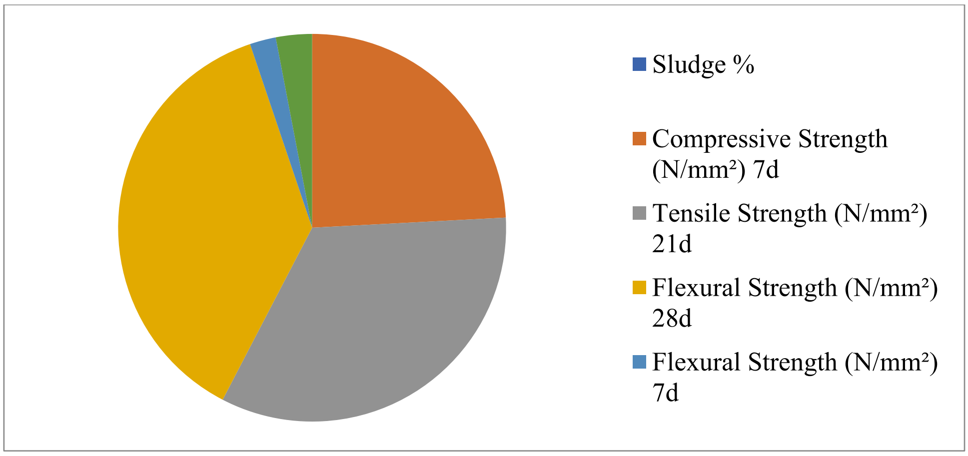

Fig.4.2: Comparision of Mechanical Properties with Varying CETP Sludge Replacement

4.3 Durability Assessment

Tabel 4.4 Durability Assessment

Sludge %	Normal Strength (MPa)	Sulfate Attack (MPa)	Chloride Attack (MPa)	Wet-Dry Cycles (MPa)
0%	35.20	33.50 (-4.8%)	34.00 (-3.4%)	34.20 (-2.8%)
5%	36.50	36.80 (+0.8%)	37.00 (+1.4%)	36.90 (+1.1%)
10%	26.81	27.30 (+1.8%)	27.40 (+2.2%)	27.20 (+1.5%)
15%	18.56	19.20 (+3.4%)	19.50 (+5.1%)	19.10 (+2.9%)
20%	15.39	16.10 (+4.6%)	16.40 (+6.6%)	15.90 (+3.3%)
25%	8.98	9.60 (+6.9%)	10.00 (+11.3%)	9.40 (+4.7%)

- Paver blocks with 5% sludge content show slight improvements in resistance to sulfate and chloride attacks compared to normal strength.

- Higher sludge percentages exhibit increased relative durability loss but maintain resistance proportional to reduced base strength.

4.4 Workability & Water Demand

Tabel 4.5 Workability & Water Demand

Sludge %	Water/Cement Ratio	Slump (mm)
0%	0.45	105
5%	0.45	100
10%	0.50	98
15%	0.50	96
20%	0.55	98
25%	0.55	95

- Increased CETP sludge content causes higher water demand due to sludge's porous nature and water absorption properties.

- Workability reduces as indicated by slump values; hence, superplasticizers are necessary for mixes with sludge content beyond 5% to maintain workable consistency.

4.5 Environmental Safety: Leaching Tests

Tabel 4.6 Leaching Tests

CETP Sludge %	Chromium (Cr)	Sodium (Na)	Lead (Pb)	Copper (Cu)	Cadmium (Cd)	Potassium (K)	Iron (Fe)

5%	0.066	0.179	0.283	0.486	0.667	2.842	1.803
10%	0.057	0.681	0.174	2.148	0.722	3.158	0.859
15%	0.046	1.894	0.043	0.216	0.741	0.789	0.575
20%	0.037	3.14	1.043	1.581	0.694	2.368	0.391
25%	0.041	2.798	0.861	1.378	0.867	3.158	0.351

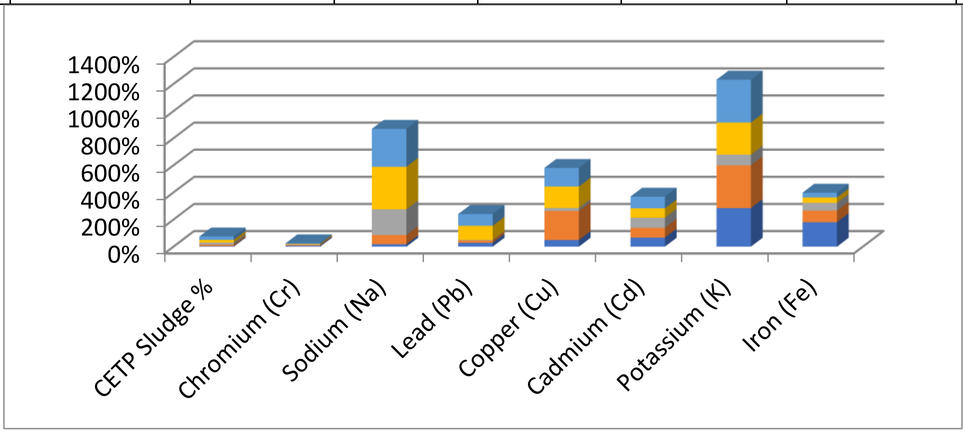

Fig.4.3: Leaching Tests

- Leaching evaluations demonstrate that concrete paver blocks incorporating CETP sludge do not emit harmful concentrations of toxic heavy metals, guaranteeing their environmental safety for practical applications.

- The use of CETP sludge supports sustainable waste reuse while mitigating potential environmental health risks.

4.6 Economic Benefits and Industrial Relevance

- Partial replacement of fine aggregates with 5% CETP sludge reduces the overall material cost by up to 8% due to lowered natural aggregate demand and disposal savings.

- The developed concrete mix with CETP sludge can be adopted by ready-mix concrete plants and paving block manufacturers with minimal process changes.

- This innovative material solution aids in reducing landfill dependency and aligns well with green building practices and low carbon initiatives.

- The approach presents a practical waste management solution offering cost-effective, durable, and environmentally sustainable building materials.

5. Future Scope and Recommendations

Pre-treatment of CETP sludge to improve consistency and allow higher replacement levels without compromising mechanical or durability properties.

- Perform detailed microstructural investigations using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD) to enhance the interfacial characteristics between sludge and concrete.

- Implement field testing and long-term monitoring to evaluate real-life performance under varied climatic and loading conditions.

- Establish collaborations with industry and environmental agencies for large-scale trials promoting sustainable building material adoption.

- Safeguard innovations through Intellectual Property Rights (IPR), including patents, to promote efficient usage methods and environmentally friendly formulations.

CONCLUSION

The partial substitution of fine aggregates with CETP sludge in M30 grade concrete paver blocks, limited to an optimal level of 5%, results in enhanced mechanical properties, increased durability, and improved environmental safety, alongside notable cost reductions. This sustainable strategy effectively addresses waste disposal concerns, minimizes natural resource consumption, and aligns with environmental preservation objectives. Continued investigation and collaboration with industry stakeholders are essential to optimize the performance and broaden the adoption of this innovative eco-friendly construction material.

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