ANovel Approach on Usage of Textile Effluent Treatment Plant Sludge in concrete as partial replacement of cement

Himalay D. Bhatt, Mahmmad Dodhiya
Department of civil engineering, R K University, Rajkot, Gujarat, India

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ABSTRACT

The management of hazardous textile Effluent Treatment Plant (ETP) sludge and the depletion of natural geological aggregates represent a severe dual environmental crisis. This investigation systematically evaluates the structural, physical, microstructural, and environmental viability of incorporating dewatered, pulverized textile ETP sludge from the Jetpur industrial cluster (Gujarat, India) into M20 grade structural concrete, mortar systems, and precast paver blocks. Raw and sieved sludge (<150 μm) was evaluated as a direct mass replacement for Ordinary Portland Cement (OPC 53 Grade) and fine aggregate (Manufactured Sand) across controlled replacement thresholds of 0%, 5%, 10%, and 15%. Fresh workability, Vicat hydration kinetics, volume soundness, mechanical strength (compressive, third-point flexural, and splitting tensile), transport sorptivity, and heavy metal immobilization were comprehensively analyzed.

The empirical results demonstrate that high Loss on Ignition (85.80%) within the Jetpur sludge increases mix water demand and retards clinker setting. In pure mortar systems, cement replacement induces clinker dilution, reducing 28-day compressive strength. However, in full aggregate concrete mixtures, a 10% cement replacement level (Mix CS10) optimizes particle packing and heterogeneous nucleation catalysis, increasing 28-day compressive strength by 7.72% (34.90 MPa vs. 32.40 MPa control). Conversely, tensile stress states exhibit a drop in flexural (-13.72%) and split-tensile (-16.67%) strength due to organic matter migration weakening the Interfacial Transition Zone (ITZ). Toxicity Characteristic Leaching Procedure (TCLP) testing via ICP-MS confirmed heavy metal fixation efficiencies exceeding 99.8%, proving that the hydrated cement matrix safely locks mobile zinc, lead, and chromium cations well below US EPA safety thresholds.

1. Introduction

The global textile industry is a major economic driver, but it simultaneously represents one of the most resource-intensive and polluting manufacturing sectors. Transforming raw fibers into garments requires extensive chemical treatments including washing, bleaching, dyeing, and finishing, generating massive volumes of complex wastewater laden with synthetic dyes, heavy metals, surfactants, and organic solvents. While Effluent Treatment Plants (ETPs) and Common Effluent Treatment Plants (CETPs) purify this wastewater using chemical coagulants predominantly ferrous sulfate ($FeSO_4$), alum, and polyelectrolytes they convert dissolved pollutants into a dense, semi-solid hazardous byproduct known as ETP sludge filter cake.

Conventional disposal routes for hazardous textile sludge face critical barriers. Landfilling consumes vast land areas, incurs high dumping fees, and poses a continuous threat of subterranean water pollution through toxic leachate seepage. High temperature incineration reduces waste volume but consumes significant energy, releases greenhouse gases and toxic emissions, and produces hazardous residual ash. Concurrently, the global construction industry faces severe sustainability challenges: Ordinary Portland Cement (OPC) manufacturing accounts for approximately 8% of global carbon dioxide (CO_2) emissions, while excessive extraction of natural river sand severely degrades riverine ecosystems.

This environmental conflict is sharply mirrored in the Jetpur textile process cluster in Gujarat, India, where over 1,200 dyeing and screen-printing units generate hundreds of metric tons of dewatered ETP sludge daily. The proximity of these industrial units to the Bhadar River basin creates an urgent regional need for sustainable waste management. Utilizing Jetpur ETP sludge as a supplementary component in concrete matrices offers a dual solution: permanently locking away toxic contaminants within a durable cementitious network while preserving natural aggregate reserves. This study establishes a comprehensive lab-to-theory framework evaluating the fresh, mechanical, durability, and leaching performance of Jetpur ETP sludge in M20 concrete, binder mortars, and paver units.

2. Materials used

2.1. Jetpur Effluent Treatment Plant (ETP) Sludge

Hazardous dewatered ETP sludge filter cake was collected directly from Common Effluent Treatment Plants (CETPs) operating in Jetpur, Gujarat. The raw sludge was sun-dried, oven-dried at 105°C, pulverized, and sieved to fine particle size distributions (<150 μm and <90 μm). The baseline physical properties and chemical composition of the sieved Jetpur sludge are detailed in Table 1.

Table 1: Physical and chemical properties of sieved Jetpur ETP sludge.

Parameter / Property	Experimental Test Method	Observed Value	Test Standard / Reference
Physical Appearance	Visual Inspection	Dark Grey / Black Powder	Physical Appearance
Specific Gravity	Le-Chatelier Bottle	1.95	Le-Chatelier Bottle (IS 4031)
Moisture Content	Gravimetric Drying	8.50% (as-received dry state)	Gravimetric Drying (105°C)
Loss on Ignition (LOI)	Heating at 950C (IS 1727) Chemical composition	85.80%	XRF / ICP-OES / IS 4032
Magnesium oxide	Chemical composition	0.81	XRF / ICP-OES / IS 4032
Silica	Chemical composition	1.51	XRF / ICP-OES / IS 4032
Calcium Oxide	Chemical composition	1.64	XRF / ICP-OES / IS 4032
Aluminium Oxide	Chemical composition	1.75	XRF / ICP-OES / IS 4032

2.2. Cementitious Binder

Commercial Ordinary Portland Cement (OPC), 53 Grade, conforming strictly to IS 269:2015 was utilized. Standard physical characterization tests conducted per IS 4031 are summarized in Table 2.

Table 2: Physical parameters of OPC 53 Grade Cement

Physical Parameter Tested	Laboratory Test Method	Experimental Result	IS 269:2015 Specification Limits
Normal Consistency	IS 4031 (Part 4)	29.5%	No standard limit (Standard reference)
Initial Setting Time	IS 4031 (Part 5)	65 minutes	Minimum 30 minutes
Final Setting Time	IS 4031 (Part 5)	245 minutes	Maximum 600 minutes
Specific Gravity	IS 4031 (Part 11)	3.15	Standard target value
Soundness (Le-Chatelier)	IS 4031 (Part 3)	1.5 mm	Maximum 10.0 mm

2.3. Fine and Coarse Aggregates

- **Fine Aggregate:** Commercially washed Manufactured Sand (M-Sand) sourced near Rajkot, Gujarat, conforming to Grading Zone II of IS 383:2016. Specific gravity = 2.64, water absorption = 1.85%, silt content = 1.20%, and fineness modulus derived via mechanical sieve analysis.
- **Coarse Aggregate:** Crushed angular granite aggregates (10 mm and 20 mm combined at a 40:60 ratio) conforming to IS 383:2016. Specific gravity = 2.71–2.74, water absorption = 0.55%, Aggregate Crushing Value (ACV) = 18.42%, Aggregate Impact Value (AIV) = 14.15%, and combined flakiness/elongation index = 22.50%

3. Methodology

3.1. Concrete Mix Design and Replacement Series

Structural concrete mixes (M20 Grade) were proportioned in accordance with IS 10262:2019 and IS 456:2000 under a constant water-to-binder ratio ($w/b = 0.50$). Standard mortar cubes were prepared at a 1:3 binder-to-sand ratio ($w/b = 0.50$) per IS 4031 (Part 6). Processed Jetpur sludge was introduced as a direct mass replacement for OPC 53 at dosages of 0% (Control), 5%, 10%, and 15%.

Table 3: Concrete mix designations and replacement percentages.

Concrete Mix ID	Mortar Mix ID	Cement Content	Sludge	W/C Ration
CC (Control)	MS-Control	100 %	0 %	0.5
CS5	MS5	95 %	5 %	
CS10	MS10	90 %	10 %	
CS15	MS15	85 %	15 %	

3.2. Specimen Preparation, Casting, and Curing

Dry constituents were homogenized in a pan mixer to prevent sludge particle agglomeration. Fresh concrete was compacted on a vibrating table in three equal lifts using standard steel molds:

- **150 mm Cubes:** Compressive strength evaluation at 7, 14, and 28 days.
- **150 × 300 mm Cylinders:** Splitting tensile capacity testing at 28 days.
- **100 × 100 × 500 mm Prisms:** Third-point flexural strength testing at 28 days.

Cast specimens were demolded after 24 hours (27°C, >90% RH) and water-cured until testing.

3.3. Standardized Testing Protocols

3.3.1. Fresh Rheology and Setting Kinetics

- **Workability:** Slump cone testing on fresh concrete per IS 1199:1959.
- **Setting Times & Consistency:** Vicat apparatus testing on neat paste blends per IS 4031 (Parts 4 & 5).
- **Soundness:** Le-Chatelier split-cylinder testing under forced boiling per IS 4031 (Part 3).

3.3.2. Hardened Mechanical Evaluation

- **Compressive Strength (F_{cu}):** Evaluated on 70.6 mm mortar cubes (IS 4031 Part 6) and 150 mm concrete cubes (IS 516:1959) using a digital compression testing machine:

$$F_{cu} = \frac{P_{max}}{A}$$

Where P_{max} is failure load (N) and A is bearing area (22,500 mm^2 for 150 mm cubes).

- **Third-Point Flexural Strength (f_{cr}):** Evaluated on 100 × 100 × 500 mm prisms under third-point loading across a 400 mm clear span per IS 516:1959:

$$f_{cr} = \frac{P \cdot L}{b \cdot d^2}$$

Where P is ultimate load (N), L is span length (400 mm), b is width (100 mm), and d is depth (100 mm).

- **Split-Tensile Strength (f_t):** Tested on 150 × 300 mm cylinders per IS 5816:1999:

$$f_t = \frac{2P}{\pi \cdot D \cdot L}$$

Where P is ultimate compressive line load (N), D is cylinder diameter (150 mm), and L is cylinder length (300 mm).

3.3.3. Durability Kinetics and Environmental Safety

- **Water Absorption & Capillary Sorptivity:** Tested per ASTM C642 and ASTM C1585 to quantify permeable pore volume and unidirectional moisture ingress rates.
- **Leaching Safety (TCLP):** Executed on pulverized 28-day cured concrete samples using US EPA Method 1311. Heavy metal concentrations in leachates were quantified via Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

4. Results and discussion

4.1. Cement Paste Normal Consistency and Vicat Setting Times

Incorporating sieved Jetpur ETP sludge progressively escalated binder water demand and retarded setting kinetics, as logged in Table 4.

Table 4: Consistency, setting kinetics, and soundness of sludge-cement paste blends.

Mix ID	Cement Substitution (%)	Normal Consistency (%)	Initial Setting Time (min)	Final Setting Time (min)	Le-Chatelier Soundness (mm)
MS- Control	0 %	29.5%	65	245	1.5 mm
MS5	5 %	31.2% (+1.70%)	82	278	1.8 mm
MS10	10 %	33.5% (+4.00%)	104	315	2.2 mm
MS15	15 %	36.8% (+7.30%)	135	380	2.6 mm

The water demand escalation is driven by the high Loss on Ignition (85.80%) of the sludge, reflecting porous organic residues and unburnt carbon fractions that absorb free mixing water. Hydration retardation occurs because dissolved organic colorants, surfactants, and fixing agents from the Jetpur textile cluster adsorb onto unhydrated Alite (C_3S) clinker grains, forming a passivating barrier that slows calcium ion (Ca^{2+}) dissolution and C-S-H gel nucleation. Le-Chatelier expansion increased slightly (1.5 mm to 2.6 mm) due to trace sulfates forming minor secondary ettringite, but remained safely below the 10.0 mm safety limit specified in IS 269:2015.

4.2. Fresh Concrete Workability

A monotonic decline in slump workability was observed with increasing sludge substitution under a constant water-to-binder ratio ($w/b = 0.50$). Slump values dropped from 112 mm (Control) to 94 mm (CS5), 78 mm (CS10), and 52 mm (CS15). Because the specific gravity of Jetpur sludge (1.95) is lower than OPC 53 (3.15), replacing cement on an equivalent mass basis increases the absolute volume of fine particles in the mix. This increases internal surface area and particle friction, raising yield stress and stiffening the fresh concrete.

Table 5: Fresh Slump Characteristics of Cement-Replaced Concrete Mixes

Concrete Mix ID	Cement Replacement Level (%)	Measured Slump Value (mm)	Relative Workability Classification
CC (Control)	0% Reference Control	112 mm	Medium-to-High Workability
CS5	5% Cement Replacement	94 mm	Medium Workability
CS10	10% Cement Replacement	78 mm	Medium Workability
CS15	15% Cement Replacement	52 mm	Low-to-Medium Workability

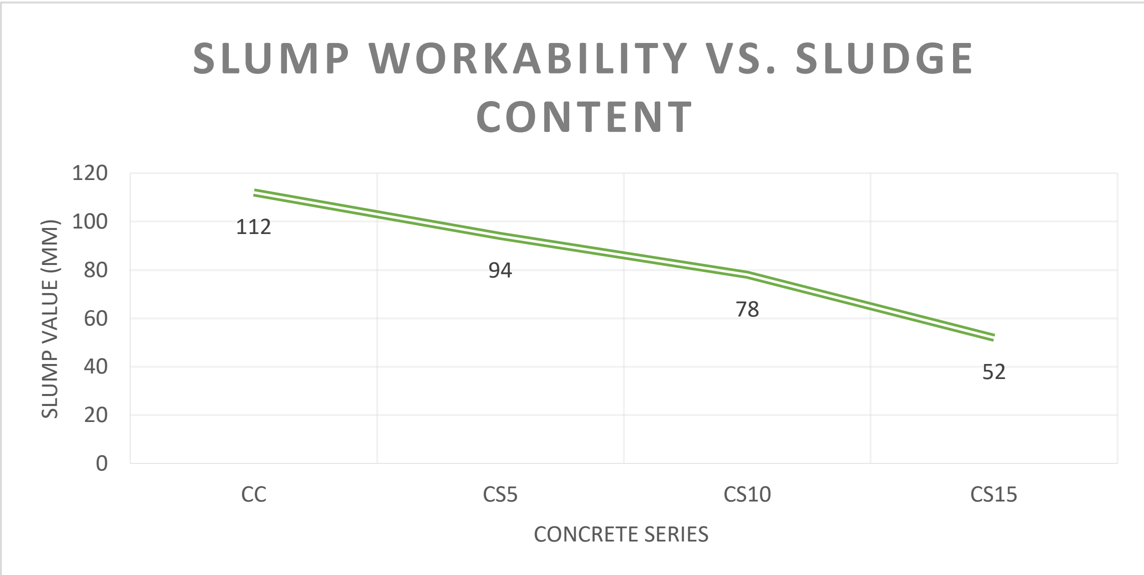

Fig.1 Effect of Sludge Content on Concrete Workability

4.3. Mortar and Concrete Compressive Strength Development

Compressive strength results across mortar and concrete series are presented in Table 6.

Table 6: Compressive strength performance of mortar (MS) and concrete (CS) series.

Mortar Mix ID	Cement Replacement (%)	7-Day Compressive Strength (MPa)	14-Day Compressive Strength (MPa)	28-Day Compressive Strength (MPa)	Net 28-Day Variance vs. Control (%)
MS-Control	0% Reference Control	34.20	44.80	57.00	*Baseline Reference*
MS5	5% Cement Replacement	29.50	38.60	49.50	-13.16%
MS10	10% Cement Replacement	25.10	32.40	42.10	-26.14%

MS15	15% Cement Replacement	21.00	27.20	36.00	-36.84%
CC (Control)	0% Reference Control	21.30	26.80	**32.40**	*Baseline Reference*
CS5	5% Cement Replacement	20.80	26.20	**32.00**	-1.23%
CS10	10% Cement Replacement	23.40	29.10	**34.90**	**+7.72%**
CS15	15% Cement Replacement	16.50	20.40	**24.20**	-25.31%

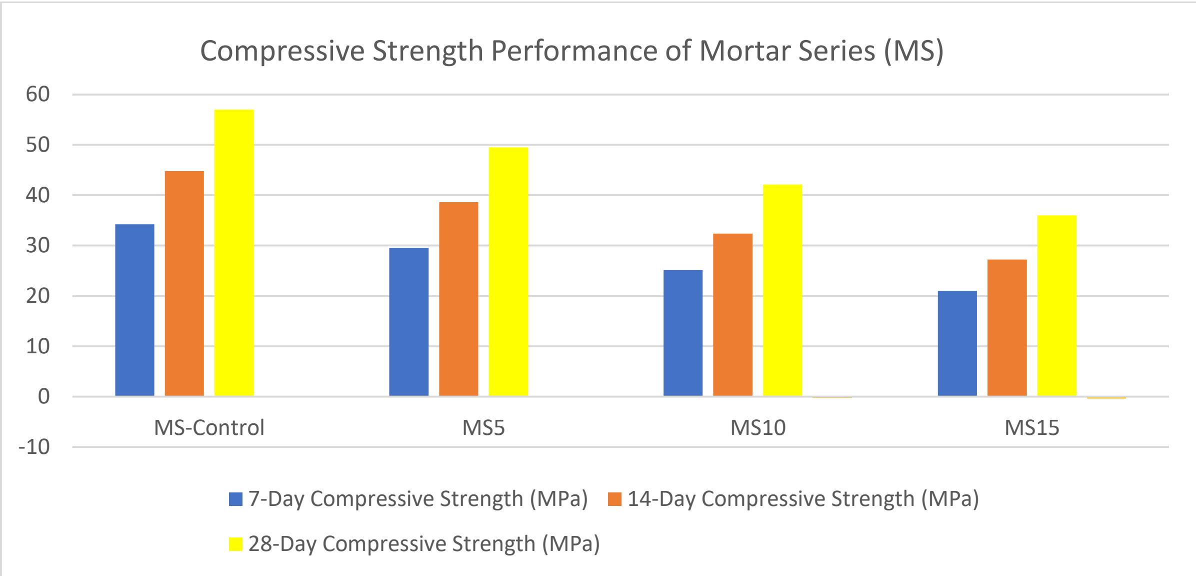

Fig. 2 Compressive strength performance of mortar series

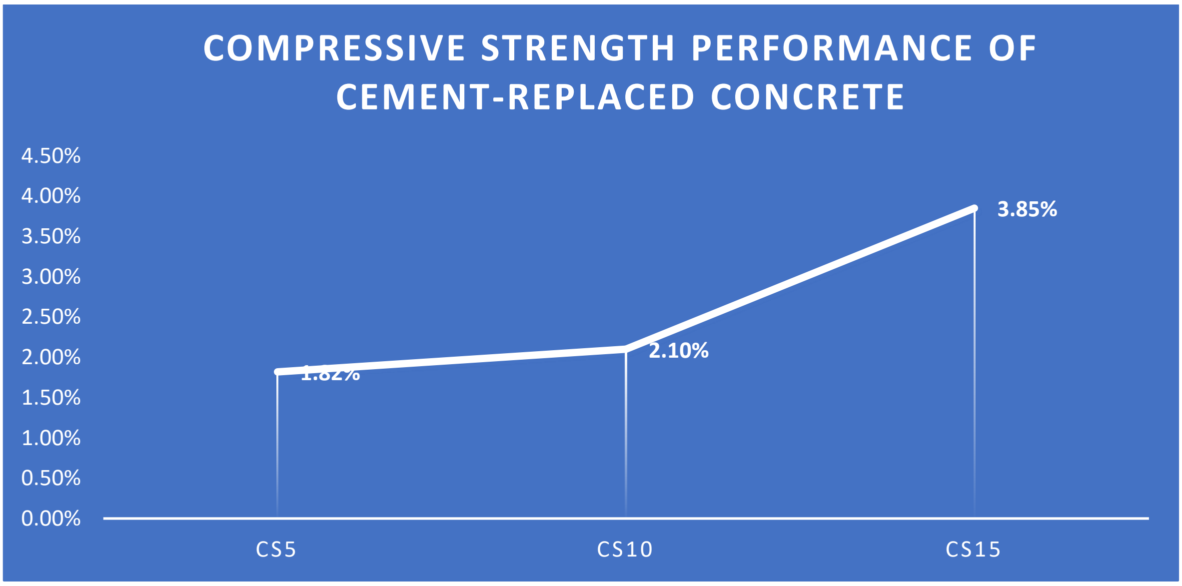

Fig. 3 Compressive strength performance of cement-replaced concrete

In pure mortar systems, direct cement substitution causes a linear drop in strength due to clinker dilution, as the non-reactive sludge lowers the concentration of hydraulic Alite and Belite phases. Conversely, in full aggregate concrete, a distinct non-linear optimization window occurs at a 10% cement replacement level (Mix CS10), achieving a 28-day compressive strength of 34.90 MPa (+7.72% over control). This localized enhancement is driven by two physical mechanisms:

1. **Heterogeneous Nucleation Catalysis:** Fine sludge particulates (<150 μm) act as active nucleation nodes, accelerating clinker hydration product precipitation.

2. **Microfiller Void Packing:** Ultra-fine particulates physically pack interstitial voids between sand and aggregate faces, refining pore structure.

Increasing replacement to 15% (CS15) causes a severe strength drop (-25.31% to 24.20 MPa) due to excessive clinker dilution and sludge particle agglomeration.

4.4. Flexural, Split-Tensile, and ITZ Mechanics

Flexural and split-tensile strengths evaluated at 28 days are detailed in Table 7.

Table 7: 28-day mechanical strength and durability transport properties.

Concrete Mix ID	Cement Replacement (%)	28-Day Compressive Strength (MPa)	28-Day Flexural Strength (MPa)	28-Day Split-Tensile Strength (MPa)	Flexural Strength Variance (%)	Split-Tensile Variance (%)
CC (Control)	0% Control	32.40	5.83	3.42	Reference	Reference
CS5	5% Replacement	32.00	5.45	3.18	-6.52%	-7.02%
CS10	10% Replacement	34.90	5.03	2.85	-13.72%	-16.67%
CS15	15% Replacement	24.20	3.64	1.92	-37.56%	-43.86%

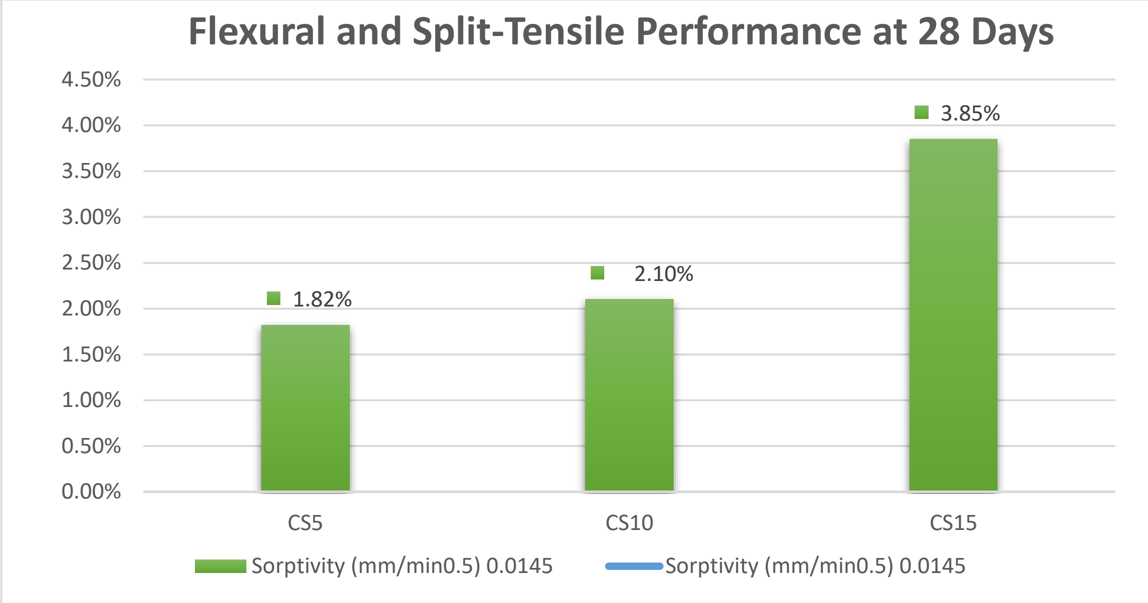

Fig. 4 Flexural and split-tensile performance

Despite achieving peak compressive strength, the CS10 mix exhibits a 13.72% reduction in flexural strength (5.03 MPa) and a 16.67% drop in split-tensile strength (2.85 MPa). Flexural and tensile resistances depend heavily on the Interfacial Transition Zone (ITZ) the 10–15 μm boundary layer surrounding coarse aggregates. During placement, volatile organic residues and heavy metals migrate with bleeding water to aggregate boundaries, inhibiting dense C-S-H gel crystallization and creating a weakened ITZ prone to tensile debonding.

4.5. Durability Kinetics and Heavy Metal Containment (TCLP)

Saturated water absorption and sorptivity increased with sludge content due to the open internal cellular porosity of organic sludge particles. However, the 5.45% absorption recorded for CS10 remains well below the 10.0% standard limit for durable structural concrete.

TCLP leaching results (US EPA Method 1311) via ICP-MS for pulverized 28-day cured CS10 concrete are presented in Table 7.

Table 8: Heavy metal leachate concentrations and fixation efficiencies for CS10 concrete.

Heavy Metal Species Evaluated	Concentration in Raw Sludge (mg/L)	Leachate Concentration from CS10 Concrete (mg/L)	US EPA Permissible Regulatory Limit (mg/L)	Calculated Net Fixation Efficiency
Zinc (Zn)	1019.60 mg/L	0.48 mg/L	5.00 mg/L	99.95%
Lead (Pb)	45.60 mg/L	0.02 mg/L	5.00 mg/L	99.96%
Total Chromium (Cr)	18.20 mg/L	0.03 mg/L	5.00 mg/L	99.83%

Heavy metal fixation efficiencies exceeded 99.8%. This containment is governed by alkaline precipitation (converting cations to insoluble hydroxides like $Zn(OH)_2$ under matrix pH > 12.5) and isomorphic substitution (locking metallic ions within C-S-H and ettringite lattices). Final leachate concentrations rest orders of magnitude below US EPA safety thresholds, fully validating environmental safety.

5. Conclusion

Based on this experimental study, the following primary conclusions are drawn:

1. **Optimal Design Threshold:** Substituting 10% Ordinary Portland Cement with processed Jetpur ETP sludge (Mix CS10) represents the optimum design formulation, balancing waste utilization with structural performance.

2. **Compressive Strength Enhancement:** Mix CS10 achieves a 7.72% enhancement in 28-day compressive strength (34.90 MPa vs. 32.40 MPa control), driven by microfiller void packing and heterogeneous nucleation catalysis.

3. **Tensile ITZ Defect:** Cement replacement causes flexural (-13.72%) and split-tensile (-16.67%) strength deficits due to organic matter migration weakening aggregate-paste interfacial bonding.

4. **Environmental Safety:** Hydrated cement matrices act as exceptional solidification/stabilization systems. TCLP testing confirmed heavy metal fixation efficiencies exceeding 99.8%, maintaining Zn, Pb, and Cr leachate concentrations well within US EPA safety limits.

5. **Practical Application:** Utilizing a 10% pre-stabilized sludge replacement in concrete provides a structurally viable, environmentally safe, and sustainable route for repurposing hazardous industrial waste.

References

- IS 456 : 2000, "Plain and Reinforced Concrete Code of Practice," Bureau of Indian Standards, New Delhi, India, 2000.
- IS 10262 : 2019, "Concrete Mix Proportioning Guidelines," Bureau of Indian Standards, New Delhi, India, 2019.
- IS 383 : 2016, "Coarse and Fine Aggregates for Concrete Specification," Bureau of Indian Standards, New Delhi, India, 2016.
- IS 2386 (Parts 1 to 8), "Methods of Test for Aggregates for Concrete," Bureau of Indian Standards, New Delhi, India.
- IS 12269 : 2013, "Ordinary Portland Cement, 53 Grade Specification," Bureau of Indian Standards, New Delhi, India, 2013.
- IS 516 (Part 1 : Section 1) : 2021, "Hardened Concrete Methods of Test: Testing of Strength of Hardened Concrete (Compressive, Flexural and Split Tensile Strength)," Bureau of Indian Standards, New Delhi, India, 2021.
- IS 1199 (Parts 1 to 3) : 2018, "Fresh Concrete Methods of Sampling, Testing and Analysis," Bureau of Indian Standards, New Delhi, India, 2018.
- IS 15658 : 2006, "Precast Concrete Blocks for Paving Specification," Bureau of Indian Standards, New Delhi, India, 2006.
- IS 1077 : 1992, "Common Burnt Clay Building Bricks Specification," Bureau of Indian Standards, New Delhi, India, 1992.
- IS 3495 (Parts 1 to 4) : 1992, "Methods of Testing of Burnt Clay Building Bricks," Bureau of Indian Standards, New Delhi, India, 1992.

- M. S. Shetty and A. K. Jain, *Concrete Technology: Theory and Practice*, 8th ed. New Delhi, India: S. Chand Publishing, 2019.
- A. K. Tiwari and A. Richariya, "Study on Utilization of Textile ETP Sludge as Partial Replacement of Cement," *MTech Dissertation*, Gujarat Technological University, Gujarat, India, 2023.
- V. Palanisamy, "Utilization of Textile Effluent Waste Sludge in Brick Production," *International Journal of Sciences: Basic and Applied Research*, vol. 4, no. 1, pp. 1–10, 2011.
- M. Rahman, M. M. Rahman, M. T. Uddin, and M. A. Islam, "Textile Effluent Treatment Plant Sludge: Characterization and Utilization in Building Materials," *Journal of Environmental Engineering and Science*, 2017.
- A. Dhinesh, R. Karthikeyan, S. Dinesh, and S. Karthik, "Preliminary studies of common effluent treatment waste sludge in manufacturing of solid block," *International Journal of Innovative Research in Science, Engineering and Technology*, 2014.
- A. D. Mandlik and S. A. Karale, "Sludge Use in Concrete as a Replacement of Cement," *International Research Journal of Engineering and Technology (IRJET)*, 2018.
- K. Patel, R. L. Patel, and J. Pitroda, "Technical Feasibility Study on Utilization of Textile Sludge as a Cement Substitute in Rubber Mould Paver Block," *International Journal of Advanced Technology in Engineering and Science*, vol. 2, no. 5, 2014.
- J. Balasubramanian, P. C. Sabumon, J. U. Lazar, and R. Ilangovan, "Reuse of textile effluent treatment plant sludge in building materials," *Waste Management*, vol. 26, no. 1, pp. 22–28, 2006.
- M. Garg, L. P. Singh, S. Maiti, and A. Pundir, "Characterization of automobile effluent treatment plant sludge: its utilization in construction materials," *Construction and Building Materials*, vol. 73, pp. 603–609, 2014.
- P. Sengupta, N. Saikia, and P. C. Borthakur, "Bricks from petroleum treatment plant sludge: properties and environmental characteristics," *Journal of Environmental Engineering*, vol. 128, no. 11, pp. 1090–1094, 2002.
- M. Alqam and A. Jamrah, "Utilization of Cement Incorporated with Water Treatment Sludge," *Journal of Environmental Sciences and Technology*, pp. 354–365, 2011.
- K. Thaniya, "Reuse Water Treatment Sludge for Hollow Concrete Block Manufacture," *Energy Research Journal*, vol. 1, no. 2, pp. 131–134, 2010.
- M. M. Swamy, P. Navaneetham, and D. S. Bhargava, "Potential of municipal wastewater sludge as a cementing material," *Journal of Environment and Pollution*, vol. 7, no. 1, pp. 51–57, 2000.
- N. U. Sandesh, K. Varun, and V. P. Prashanth, "A study on engineering properties of textile ETP sludge-based cement concrete," *International Journal of Innovations in Engineering and Technology*, pp. 324–330, 2014.
- R. Siddique and M. I. Khan, *Supplementary Cementing Materials*, Berlin, Germany: Springer Science & Business Media, 2011.
- S. S. Shrikant, S. Shrihari, and B. Manu, "Reuse Of Textile Mill Sludge In Burnt Clay Bricks," *International Journal of Advanced Technology in Civil Engineering*, vol. 2, no. 1, pp. 96–99, 2013.
- I. H. Jayasinghe, B. F. A. Basnayake, K. S. P. Amarathunga, and P. B. R. Dissanayake, "Environmental Conservation Efforts in Developing Textile Waste Incorporated Cement Blocks," *Tropical Agricultural Research*, vol. 21, no. 2, pp. 126–133, 2010.
- V. Sahu, P. Sohoni, N. Dave, and V. Isha, "Utilization of industrial by product as raw material in construction industry - a review," *International Journal of Engineering Science and Technology*, vol. 5, no. 2, pp. 242–246, 2013.
- S. Pirouz and S. M. Khezri, "Using Urban Sewage Filtration Sludge for Producing Construction Material," *Global Journal of Science Frontier Research*, vol. 15, 2015.

- S. M. Ghannam, "Use of Waste Water Sludge in Concrete Mixes with Treated Water," *Journal of Civil Engineering*, 2016.
- K. Ahmed, "Hybrid composites prepared from Industrial waste: Mechanical and swelling behaviour," *Journal of Advanced Research*, pp. 225–232, 2015.
- Y. W. Choi, Y. J. Kim, O. Choi, and K. M. Lee, "Utilization of tailings from tungsten mine waste as a substitution material for cement," *Construction and Building Materials*, vol. 23, no. 7, pp. 2481–2486, 2006.
- M. O. Ramadan, H. A. Fouad, and A. M. Hassanain, "Reuse of water treatment plant sludge in brick manufacturing," *Journal of Applied Sciences Research*, vol. 4, pp. 4–9, 2008.
- S. R. Zeedan, Z. S. El Den Houssien, and A. M. Kandeel, "Utilization of sewage sludge ash as fine aggregate with local pozzolanic materials," *HBRC Journal*, vol. 3, no. 1, pp. 254–258, 2007.