Journal of Engineering, Mechanics and Modern Architecture
Vol. 3, No. 11, 2024 ISSN: 2181-4384
Innova Science

SUSTAINABLE CONCRETE: A STUDY ON SEWAGE DERIVATIVES AND RECYCLED WATER

Abstract:

The study examines the effects of incorporating sewage sludge ash (SSA) and treated sewage water on the strength and durability of concrete, aiming to evaluate their viability as sustainable alternatives in construction materials. Sewage sludge is burned at a high temperature of 800°C to produce SSA, which is analyzed for its chemical, physical, and morphological properties. The high-temperature burning process imparts pozzolanic properties to the ash, enhancing the compressive and tensile strengths of concrete when used as a partial cement replacement. Various SSA replacement levels (5%, 10%, 15%, 20%, and 25%) are tested, with 15% SSA achieving the highest strength improvements. While SSA influences setting time and workability, treated sewage water shows no significant impact on concrete properties. Concrete incorporating SSA demonstrates superior strength compared to conventional mixes prepared with both fresh and treated water.

Durability tests indicate that SSA concrete resists acid attacks better than conventional concrete and exhibits minor efflorescence in saltwater, highlighting its enhanced durability.

Keywords: *Sewage Sludge, Sewage Sludge Ash, Treated Sewage Water, High Temperature.*

Information about the authors

Amar Nath Kumar, Brajesh Kumar
Lecturer, Department of Civil Engineering, Sandip Foundation's Shri Ram Polytechnic, Madhubani, Bihar, India

1. INTRODUCTION

Sewage sludge, a byproduct of sewage treatment plants, consists of suspended solids containing organic and inorganic compounds derived from human waste, food particles, and other organic materials mixed with water. The separation of these particles forms a slurry known as sewage sludge, which is challenging to manage due to its high moisture content (80–85%) and complex composition (Chin-Wei Hsu, 2020). Various treatment methods, such as pyrolysis and anaerobic digestion, are employed to address these issues by reducing the sludge's volume, odor, and pathogen content while recovering methane for energy use (Mahutjane, 2023). Additionally, supercritical water gasification has been explored as a method to produce hydrogen gas, further mitigating sludge-related problems (Abebaw, 2020).

Despite these advancements, improper disposal of sewage sludge remains prevalent, leading to environmental issues such as soil and water contamination and the spread of harmful pathogens. Many countries have prohibited its disposal on land or in water bodies to safeguard public health (Lynn, 2015). Incineration is another widely used approach, capable of reducing sludge volume by 70–90%. While it mitigates certain risks, it can contribute to air and soil pollution. Interestingly, studies indicate that incineration may help curb the spread of diseases like foot-and-mouth disease (Donatello, 2013).

Globally, the volume of sewage sludge produced is immense. For instance, Karnataka generates approximately 2,647.5 MLD of sewage, far surpassing its treatment capacity. In 2014, Hong Kong produced about 1,000 tonnes of sludge daily (Zen Chen, 2017), while Romania generated 520 tonnes annually in 2018 (Rusănescu, 2022). In China, sludge production reached 240 million tonnes of wet sludge in 2010. Other countries, such as England and Germany, produced 1.03 million tonnes and 1.85 million tonnes respectively, contributing to a global production of 45 million tonnes in 2017 (Yan Xia, 2023). With population growth driving increased sewage generation, traditional disposal methods such as landfilling and incineration are proving insufficient, necessitating alternative solutions.

In construction, sewage sludge shows promise as a sustainable material. However, its high moisture content and organic matter pose challenges when used directly in cementitious materials, leading to increased porosity and weakened bonding strength (Ashwini L. K., 2024). Research highlights innovative applications, such as in geopolymer concrete, where the use of NaOH and water glass addresses these drawbacks by improving strength and reducing water demand (Thukkaram, 2024; Zhao, 2023). Other studies demonstrate its effectiveness as a fine aggregate in concrete (Baeza-Brotons, 2014), as an additive in construction blocks (Arooj, 2021), and in mortar production (Haustein, 2022; Coutand, 2006). Sewage sludge has also been successfully incorporated into brick manufacturing (Lin, 2001), showcasing its versatility in sustainable construction practices. Water, an essential resource for life, faces significant challenges. Although water covers 70% of the Earth's surface, only 3% is freshwater, suitable for drinking. Countries such as India, the United States, and China are experiencing large-scale groundwater extraction, leading to concerns about sustainability. Groundwater contamination through leaching further degrades water quality, resulting in health issues such as bone and dental diseases. By 2030, industrial water demand is expected to reach 1,500 billion m^3, with concrete production alone requiring approximately 500 liters per cubic meter (Harshit Varshney, 2021).

The construction industry also contributes to water pollution, with activities like washing Ready-Mix Concrete trucks contaminating water and soil. Despite the potential for wastewater reuse in construction, it remains underexplored. For instance, studies have demonstrated the feasibility of using car wash water in high-strength concrete (Al-Jabri, 2011) and treated domestic wastewater for curing and concrete production (G. Asadollahfardi, 2016). Research suggests that treated wastewater can effectively sustain concrete strength, making it a promising alternative.

Standards such as IS 456 recommend that non-fresh water used in construction should not reduce the strength of concrete by more than 10% compared to a nominal mix, emphasizing the viability of alternative water sources in sustainable construction practices.

2. GAPS AND GOALS

Several studies on the use of sewage sludge in concrete have yielded varied outcomes. While some report enhanced strength and pozzolanic activity, they also note an increased water demand, whereas others observe a decline in strength. Similarly, research on treated wastewater shows that concrete performance varies based on the water's properties. However, there is limited research combining sewage sludge ash (SSA) as a partial cement replacement with treated wastewater.

This study focuses on assessing the compressive, split tensile, and flexural strengths of concrete incorporating SSA and treated wastewater. It also evaluates the durability of the concrete against acid (H_2SO_4) and saltwater exposure. Additionally, the morphological and compositional characteristics of SSA are analyzed using SEM and XRF techniques to better understand its impact on concrete properties.

3. EVALUATION OF MATERIALS

3.1. MATERIALS

The materials utilized in this study include:

3.1.1. Cement

Ordinary Portland Cement (OPC) of Grade 53 is used for conducting tests and casting specimens. The chemical composition of the cement is detailed in Table 5, and other tests, such as specific gravity, are performed in accordance with Indian Standard codes and summarized in Table 2.

3.1.2. Fine Aggregate

The fine aggregate used in this study is locally sourced M-sand, commonly used in nearby construction projects. Basic tests on the fine aggregate, as per Indian Standard codes, are listed in Table 2.

3.1.3. Coarse Aggregate

The coarse aggregate used comprises 20 mm and smaller-sized materials, which are locally available and widely used in construction. Relevant tests conducted on the coarse aggregate, in line with standard codes, are summarized in Table 2.

3.1.4. Sewage Sludge Ash (SSA)

Sewage sludge ash is a byproduct of incinerating sewage sludge at a furnace temperature of 800°C. Research indicates that temperatures between 750°C and 800°C are optimal for achieving good pozzolanic properties (Sara Naamane, 2016). The sewage sludge, collected from a local sewage treatment plant, was semi-solid with a moisture content of 80–85%, as shown in Figure 1.a). The sludge was sun-dried, with the resulting appearance depicted in Figure 1.b). After drying, the weight reduction was approximately 350–400 grams per kilogram of sludge.

The dried sludge was incinerated to produce a clinker-like material, shown in Figure 1.c). These clinkers were ground to a fine powder capable of passing through a 90-micron sieve. This processed ash was used as a partial replacement for cement in the concrete specimens prepared for compressive and tensile strength tests. The basic properties of the obtained SSA were determined through standard tests, the results of which are provided in Table 2.

3.1.5. Treated Sewage Water

Treated sewage water, also referred to as effluent, undergoes a multi-stage treatment process to eliminate harmful contaminants such as bacteria and organic matter. While this water is not typically potable, it is considered safe for uses like irrigation and industrial applications. Recognizing the growing demand for fresh water, this study explores the use of treated sewage water in concrete.

The treated water, sourced from the same sewage treatment plant, has a specific gravity of 1.01. For water other than freshwater to be used in concrete, it must comply with the limits specified by relevant codes. A series of tests were conducted to evaluate its suitability, and the results, along with the permissible limits, are detailed in Table 1. The findings confirm that the properties of the treated water fall within the acceptable range.

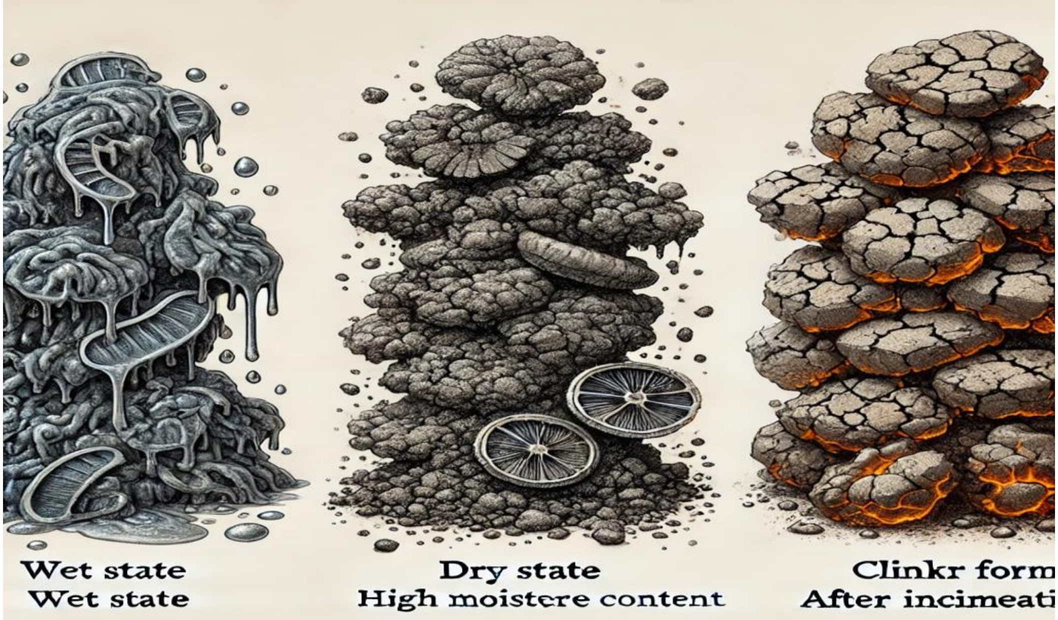

Figure 1: Sewage Sludge in Various Forms

A. Wet State (Semi Solid), B. Dry State C. Clinkers Form

Parameters	Tested value	Provision of Code
Temperature	15-25 ºC	-
pH	9.5 mg/l	>6
Turbidity	13 mg/l	-
Sulfate (SO_4)	187 mg/l	400mg/l
Nitrate (NO_3)	11 mg/l	-
Nitrite (NO_2)	2.7 mg/l	-
Chloride	67 mg/l	-
Total Solid (TS)	587 mg/l	2000mg/l
Total suspended solid (TSS)	327 mg/l	-
Chemical Oxygen Demand (COD)	83 g/l	-

Table 1: Analysis Results of Treated Sewage Water

3.2. Analytical Methods

3.2.1. SEM and EDX Analyses

Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) are employed to examine the microstructure and elemental composition of materials. SEM provides high-resolution images that reveal details such as porosity and cracks, offering insights into the material's quality and texture. When coupled with EDX, SEM enables the identification of specific elements in the material, such as calcium, silicon, aluminum, and iron, based on the elemental composition of different regions.

3.2.2. XRF Analysis

X-ray Fluorescence (XRF) analysis is a non-destructive method used to determine the elemental composition of materials, including any admixtures. During XRF analysis, a sample is exposed to X-rays, which cause the elements within the sample to emit secondary (fluorescent) X-rays. These emitted X-rays are characteristic of specific elements, allowing for the identification and quantification of major oxides such as SiO_2, Al_2O_3, Fe_2O_3, CaO, as well as trace elements. This technique is essential for assessing the purity and composition of the materials.

3.3. Pozzolanic Evaluation

A pozzolanic check is necessary for replacement materials, and several methods exist for this purpose, including the Strength Activity Index (SAI), Frattini test, Chapelle test, and analytical techniques like XRF and Thermogravimetric Analysis (TGA). In this study, the Strength Activity Index and Chapelle test were used.

For the Strength Activity Index, mortar tests were conducted with varying percentages of sewage sludge ash (SSA) replacing cement. Mortar samples, including a control mix, were prepared and cured for 7 and 28 days. The compressive strength of the SSA-mixed mortars was found to be 78-80% of that of the control mix, indicating good pozzolanic activity.

The Chapelle test was also employed to determine the pozzolanic content of SSA. In this test, a solution containing SSA and calcium hydroxide was boiled under reflux for 16 hours. Titration with hydrochloric acid (HCl) revealed that the SSA consumed approximately 75-80% of the calcium hydroxide, demonstrating significant pozzolanic properties.

3.4. Density

The density of sewage sludge ash (SSA) is approximately 455 kg/m³, which may contribute to its porous nature. The specific gravity of SSA is relatively low, around 2.27, which is lower than that of cement. This lower specific gravity affects the weight of the specimens, with the weight decreasing as the percentage of SSA increases. However, despite its lower specific gravity, the SSA exhibits strong bonding after hydration with cement, resulting in high strength in the concrete specimens.

Physical Properties					
Sl no	**Properties**	**Materials**			
		Cement	**Fine aggregate**	**Coarse aggregate**	**Sewage sludge ash**
1	Specific Gravity	3.20	2.57	2.60	2.47
2	Fineness Module	-	2.6	7.1	-
3	Water Absorption	-	0.38%	0.7%	1.5%
4	Impact value	-	-	26.95%	-
5	Crushing value	-	-	24.73%	-
6	Abrasion	-	-	8.93%	-
7	Bulk density	-	15.73%	-	-
8	LOI	1.98	-	-	2.74

Table 2: Material Physical Properties

4. EXPERIMENTAL STUDIES

4.1. Mixes and Methods

The specimen mix proportions were determined based on the guidelines provided in IS 10262:2019, using data from material tests. To distinguish between different percentages additions, specific mix labels were assigned. These include M0 and M1, which represent nominal concrete mixes using normal water and sewage-treated water, respectively. Mixes M2, M3, M4, M5, and M6 correspond to concrete with cement replaced by 5%, 10%, 15%, 20%, and 25% sewage sludge ash, respectively, with all mixes using 100% sewage-treated water. Table 3 outlines the mix proportions for each combination. The required number of specimens were cast according to these mix designs.

MIXES	**Cement (kg/m3)**	**SSA (kg/m3)**	**Fine Aggregate (kg/m3)**	**Coarse Aggregate (kg/m3)**	**Water (kg/m3)**
M0	457	---	541	1157	199
M1	454	---	585	1145	191
M2	444	23.7	578	1137	191
M3	428	54.4	524	1039	191
M4	364	79.6	529	1015	191
M5	357	101.7	519	998	191
M6	340	134	507	974	191

Table 3: Mix Proportions for Different Concrete Combinations

4.2. Setting Time

The initial and final setting times were determined for mixes M0, M1, M2, M3, M4, M5, and M6 to evaluate the effect of sewage sludge ash and sewage-treated water on the setting time. To further assess the impact of treated water, mixes with sewage sludge ash were also tested using normal water, labeled as N1, N2, N3, N4, and N5, where the cement was replaced with 5%, 10%, 15%, 20%, and 25% sewage sludge ash, respectively, and normal water was used in the mixes. The results are shown in Figure 2.

It was observed that treated water had minimal effect on the setting time. However, the replacement of cement with sewage sludge ash did influence the setting time. Specifically, M1 showed only a slight difference in final setting time compared to M0, while mixes M2-M6 exhibited an increase in both initial and final setting times, with initial setting times reaching 70 minutes and final setting times reaching 285 minutes.

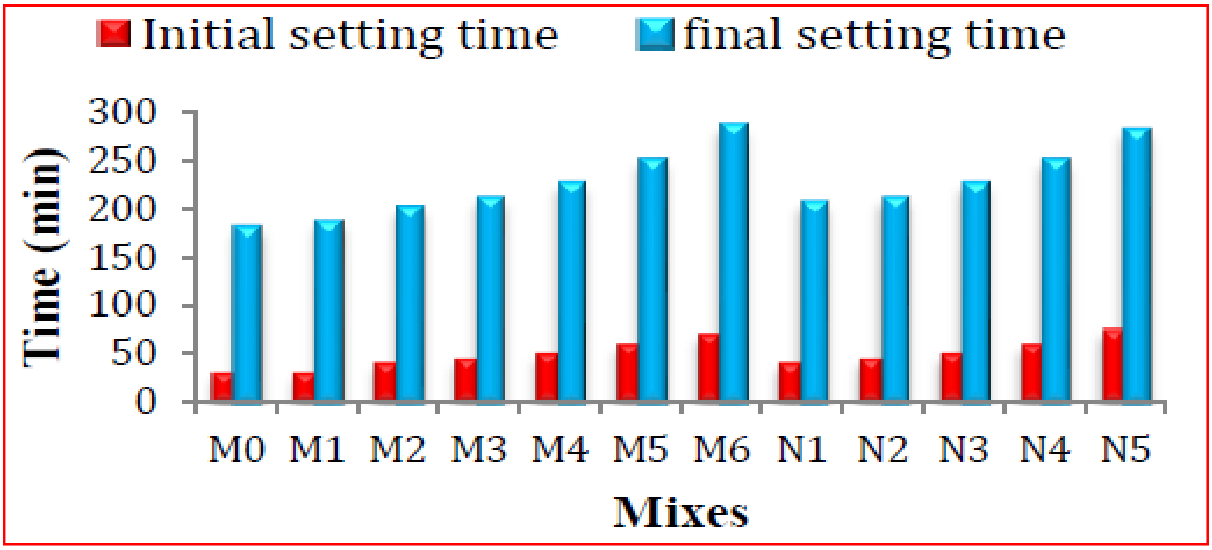

Figure 2: Initial and Final Setting Times of the Mixes

4.3. Consistency and Specific Gravity of the Mixes

The consistency of the mixes was evaluated to assess their water demand. The addition of sewage sludge ash as a replacement material notably affected the consistency, with higher replacement percentages showing more significant changes, especially compared to mixes with treated water. The specific gravity of the mixes decreased as the percentage of sewage sludge ash increased, likely due to the low density of the sludge ash, which is around 455 kg/m³. Table 4 presents the consistency and specific gravity values for the different mixes.

Mixes	Specific gravity (g/cm3)	Consistency (%)
M0	3.14	28
M1	3.18	28
M2	2.65	31
M3	2.77	36
M4	2.51	39
M5	2.43	41
M6	2.37	43

Table 4: Consistency and Specific Gravity of Different Mixes

4.4. Workability

Workability is a crucial factor in concrete, as high workability can lead to segregation and bleeding, while low workability may result in improper compaction and affect strength due to the presence of voids. The slump values of the mixes are shown in Figure 3. The nominal concrete mix with sewage-treated water exhibited a slight reduction in slump compared to the mix with normal water, suggesting that sewage-treated water has an impact on slump, as noted by Harshit Varshney (2021). Although the setting times were similar, a noticeable difference was observed in the slump values. Additionally, the slump values decreased as the percentage of sewage sludge ash in the concrete mix increased.

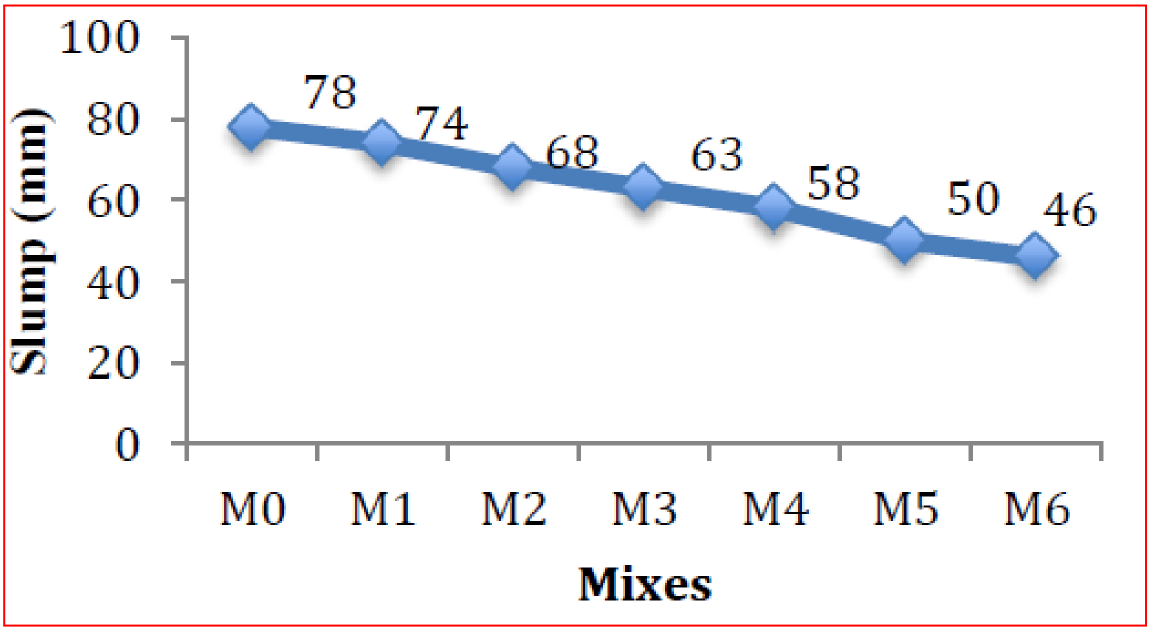

Figure 3 Slump Values of Different Mixes

4.5. Analytical Methods

4.5.1. SEM & EDX Analysis

the sample consists of irregular, angular particles of varying sizes and shapes. The rough and textured surface of the particles suggests the presence of surface irregularities. The overall morphology indicates a crystalline or polycrystalline structure. The Energy Dispersive X-ray (EDX) spectrum of the material highlights its elemental composition, with peaks corresponding to silicon (Si), oxygen (O), aluminum (Al), calcium (Ca), and smaller amounts of iron (Fe), potassium (K), and magnesium (Mg). These elements suggest the presence of pozzolanic compounds, which could influence both the strength and durability of concrete when used as a replacement.

4.5.2. XRF Analysis

The significant amounts of SiO_2, Al_2O_3, Fe_2O_3, and CaO present in the materials contribute to strength development. SiO_2 plays a key role in forming calcium silicate hydrate (C-S-H), the primary compound responsible for strength. Al_2O_3 enhances the pozzolanic properties, improving both long-term strength and durability. Additionally, CaO aids in the formation of C-S-H, further promoting strength enhancement.

5. BEHAVIOR OF MATURED CONCRETE

5.1. Compressive Strength

Compressive strength, a critical property for concrete design, was measured using 150mm^3 cube specimens containing varying percentages of sewage sludge ash (SSA) and treated water. The concrete samples were tested at 7, 14, 28, and 56 days of curing. The results indicated that the concrete mix with 15% SSA replacement achieved the highest strength at all curing stages, while mixes with 5%, 10%, 20%, and 25% SSA replacements showed varying degrees of strength development. The use of treated water did not significantly affect the compressive strength. The superior strength of the 15% SSA mix is attributed to its pozzolanic properties, which enhance the bonding by increasing the Al_2O_3 content.

5.2. Split Tensile Strength

Split tensile strength is a key indicator of a concrete's capacity to withstand tensile forces, particularly in structures subjected to bending or lateral stresses. This test involves applying a compressive load diametrically to cylindrical specimens (15 cm diameter, 30 cm height) until failure occurs. The tensile strengths of M0 and M1 were similar, while M2 and M3 performed comparably. The M4 mix, containing 15% SSA, exhibited the highest tensile strength, likely due to the increased iron content in the SSA compared to cement. However, M5 and M6, with higher SSA content, showed a reduction in tensile strength.

5.3. Flexural Strength

Flexural strength, which measures a concrete's ability to resist bending failure, was assessed through a Modulus of Rupture test conducted on unreinforced concrete beams. The test followed a two-point loading method, and beams of 100mm × 100mm × 500mm dimensions were cast. The flexural strength, expressed as the Modulus of Rupture. The results suggest that the addition of sewage sludge ash may improve tensile strength. M0 and M1 exhibited similar flexural strength, indicating that the use of treated water did not impact the tensile performance. M2 and M3 also showed comparable results to M0 and M1. The M4 mix, with a 20% SSA replacement, achieved the highest flexural strength of 5.18 MPa, likely due to the higher iron content in SSA. However, M5 and M6, with higher SSA percentages, demonstrated reduced flexural strength, indicating a negative effect of increased SSA content on the concrete’s bending resistance.

5.4. Durability

Durability in concrete refers to its capacity to withstand various environmental conditions while maintaining its strength and structural integrity over time. It is affected by factors such as water permeability, freeze-thaw cycles, chemical exposure, and the overall quality of the materials used. Durable concrete resists degradation caused by physical, chemical, or biological processes, ensuring long-term performance in constructions. Proper curing, optimal mix design, and protective measures can enhance the durability of concrete. High durability is crucial for reducing maintenance costs and extending the lifespan of infrastructure, especially in challenging environments like coastal areas or regions exposed to heavy chemical or industrial pollutants.

5.4.1. Water Absorption

The immersion test is commonly employed to evaluate the water resistance of concrete. In this test, concrete specimens are submerged in water to measure the amount of water that penetrates the material. A lower water absorption rate signifies better durability, indicating the concrete’s greater resistance to moisture ingress. The water absorption percentages for the different mixes at various immersion intervals. Specimens of nominal concrete, with either normal or treated water, showed higher water absorption compared to those with SSA. This difference can be attributed to the permeability of the mixes. The SSA replaces voids in the concrete matrix, leading to reduced water absorption. Among the SSA-containing mixes, the 15% replacement exhibited the lowest absorption, followed by 10% and 5%. The 20% SSA mix showed absorption similar to the 15% mix. At later curing stages, all mixes demonstrated reduced absorption, with the 25% SSA mix showing the least absorption overall. This pattern suggests that initial water absorption was mainly due to the hydration process, and as the concrete matured and reached target strength, it developed fewer pores, resulting in lower permeability and water absorption.

5.4.2. Salt Attack

Concrete's resistance to salt is particularly important in coastal and marine environments, where salts can cause efflorescence, expansion, and deterioration of the material. To evaluate this property, cube specimens were immersed in a 5% salt solution, and their compressive strength was measured. The results, which mix M0 to M3 experienced slight reductions in strength over time, suggesting moderate resistance to salt attack. In contrast, M4 maintained the highest strength throughout the exposure, demonstrating excellent durability despite some surface efflorescence formation. However, mixes M5 and M6 showed a significant decline in strength, failing to reach the target strength that was achieved under normal curing conditions.

5.4.3. Acid Attack

Chemical resistance is vital for ensuring the durability of concrete, especially in industries where concrete may be exposed to acids, alkalis, and industrial salts that can lead to considerable degradation. To assess acid resistance, cube specimens were immersed in a 5% H_2SO_4 solution, and both their compressive strength and weight were monitored over time. A decrease in strength as the immersion period increased. Mixes M0 to M3 exhibited moderate resistance to acid attack, with M4 demonstrating the highest strength and durability. Conversely, mixes M5 and M6, which initially had lower strengths, showed stability in their performance. However, their weight loss followed a similar trend, with M0, M1, M5, and M6 experiencing greater deterioration compared to the other mixes.

6. CONCLUSION

This study examined the impact of using sewage sludge ash (SSA) as a partial replacement for cement after incinerating sewage sludge at 800°C, and the potential use of sewage-treated water in place of fresh water for concrete production. The findings demonstrated that incorporating sewage sludge ash into concrete resulted in improved strength compared to the control mix. The enhanced strength can be attributed to the fine particles generated by grinding the incinerated sludge, its pozzolanic properties, and its surface texture. The high ferric content in the ash likely contributed to the improved tensile strength, as indicated by higher modulus of rupture and split tensile strength values compared to the control mix. The finer grinding of the ash helped fill voids in the concrete, enhancing its binding properties. Despite the lower weight of the SSA concrete specimens, their strength exceeded that of the nominal mix. Additionally, permeability decreased over time and with higher SSA content.

The use of sewage-treated water in the nominal mix and in mixes with SSA as a replacement did not negatively impact strength or other properties, suggesting that treated water, when meeting code specifications, does not compromise concrete quality. Increasing the percentage of SSA in concrete affected workability, but the strength was notably higher for 15% SSA replacement, surpassing the nominal mix. The 10% replacement showed strength similar to the nominal mix, while the 20% replacement reached target strength at 56 days of curing, compared to 28 days for other mixes.

Durability tests revealed that concrete with SSA and treated water showed minimal strength loss when exposed to salt solution, despite slight efflorescence formation. In contrast, the nominal mix with both normal and treated water exhibited a more significant strength reduction. In acid attack testing, a 10% SSA replacement showed a slight strength loss, but higher percentages of SSA did not exhibit substantial strength reduction, while the nominal mix experienced a significant drop in strength. Further research is needed to explore the effects of SSA in reinforced concrete and to identify methods for enhancing strength with higher SSA replacement levels.

REFERENCES

1. Thukkaram, Sathya, and Arun A. Kumar. "Data-driven approach for sustainable geopolymer mortar production with treated sewage sludge." Australian Journal of Civil Engineering (2024): 1-17.
2. Kumar, N., Kumar, P., Kumar, A. and Kumar, R., 2023. An Investigation of Asphalt Mixtures Using a Naturally Occurring Fibre. AMERICAN JOURNAL OF SCIENCE AND LEARNING FOR DEVELOPMENT, 2(6), pp.80-87.
3. Abebaw, Dereje. Effect of sewage sludge as partial replacement of fine aggregate in concrete at elevated temperature: compressive and tensile strength characterstics. Diss. 2020.
4. Chen, Zhen, and Chi Sun Poon. "Comparative studies on the effects of sewage sludge ash and fly ash on cement hydration and properties of cement mortars." Construction and Build ing Materials 154 (2017): 791-803.
5. Kumar, A., Yadav, O. and Shukla, R., 2023. A COMPREHENSIVE REVIEW PAPER ON PARTIAL CEMENT SUBSTITUTION IN CEMENT MORTAR WITH WOOD ASH. Research in Multidisciplinary Subjects, 1, p.26.

6. Xia, Yan, et al. "Value-added recycling of sludge and sludge ash into low-carbon con struction materials: current status and perspectives." Low-carbon Materials and Green Con struction 1.1 (2023): 23
7. Kumar, A., Yadav, O. and Kumar, A.N., 2023. A review paper on production of environment friendly concrete by using sewage water. International Journal of Creative Research Thoughts (IJCRT), ISSN, pp.2320-2882.
8. Haustein, Elżbieta, et al. "Influence of cement replacement with sewage sludge ash (SSA) on the heat of hydration of cement mortar." Materials 15.4 (2022): 1547.
9. Kumar, A., Yadav, O. and Kumar, S., AN OVERVIEW ARTICLE ON INCORPORATING HUMAN HAIR AS FIBRE REINFORCEMENT IN CONCRETE. International Journal of Creative Research Thoughts (IJCRT), ISSN, pp.2320-2882.
10. Sara Naamane, Zakia Rais, and Mustapha Taleb. "The effectiveness of the incineration of sewage sludge on the evolution of physicochemical and mechanical properties of Portland cement." Construction and Building Materials 112 (2016): 783-789.
11. Alam, F., Kumar, A. and Kumar, R., 2023. Review of Literature for Utilizing Guided Waves for Monitoring the Corrosion Protection of Reinforced Concrete Structures with Active FRP Wrapping. American Journal of Engineering, Mechanics and Architecture (2993-2637), 1(6), pp.18-26.
12. Kumar, A. and Yadav, O., 2023. Effect of Fiber Reinforcement on the Tensile Strength and Ductility of Fly Ash Based Composites. Web of Synergy: International Interdisciplinary Research Journal, 2(6), pp.137-143.
13. Kumar, R., Kumar, P. and Yadav, O., 2023. Experimental Study on Hot Bituminous Mix. World of Science: Journal on Modern Research Methodologies, 2(5), pp.48-53.
14. Jha, A.K. and Yadav, O., kumar, A..(2023). Evaluation of Binding Properties of Bituminous Pavement Layers. American journal of science and learning for development, 2(5), pp.3-8.
15. Lin, Deng-Fong, and Chih-Huang Weng. "Use of sewage sludge ash as brick material." Journal of environmental engineering 127.10 (2001): 922-927.
16. IS 456: 2000, “Indian Standard Code of Practice for Plain and Reinforced Concrete”, Bureau of Indian Standard, New Delhi.
17. IS 10262: 1982, “Recommended Guidelines for Concrete Mix design”, Bureau of Indian Standard, New Delhi.
18. IS 383: 1970, “Specification for Coarse aggregate and Fine aggregate from Natural Sources for Concrete”, Bureau of Indian Standard, New Delhi.
19. IS 9103: 1999, “Indian Standard Concrete Admixture Specification”, Bureau of Indian Standard, New Delhi.
20. IS 9399: 1959, “Specification for Apparatus for Flexural Testing of Concrete”, Bureau of Indian Standard, New Delhi.
21. IS 516: 1959, “Flexural Strength of Concrete”, Bureau of Indian Standard, New Delhi.