Study On the Effect of Partially Replacing Cement Textile Waste and Ggbs in Concrete

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***Abstract*—This research focuses on the experimental evaluation of concrete in which a portion of ordinary Portland cement (OPC) is partially replaced with textile waste and Ground Granulated Blast Furnace Slag (GGBS), aiming to assess the feasibility of developing sustainable and environmentally friendly construction materials. The study explores the combined effects of these two supplementary materials on the fresh and hardened properties of concrete, particularly focusing on workability, setting time, compressive strength, and durability characteristics. Textile waste, a major environmental concern due to its non-biodegradable nature, is utilized in shredded or powdered form, while GGBS, an industrial byproduct from the steel manufacturing process, is known for its pozzolanic properties and cementitious behavior. The results of the study indicate that an optimal combination of textile waste and GGBS can lead to improved compressive strength, better workability, and enhanced durability, depending on the replacement level. Moreover, the utilization of these waste materials contributes significantly to reducing the environmental footprint of concrete production by lowering cement consumption and promoting waste recycling. The findings demonstrate that with proper mix design, textile waste and GGBS can serve as effective partial replacements for cement in concrete, offering both structural efficiency and environmental sustainability.**

***Index Terms*—GGBS, Textile Sludge.**

I. INTRODUCTION

1.1 General

Concrete is the most widely used construction material, with Ordinary Portland Cement (OPC) as its primary binder. However, the production of OPC is energy-intensive and contributes significantly to environmental degradation, emitting about one ton of CO_2 for every ton of cement produced. This process also depletes natural resources. As a result, there is growing interest in finding alternative materials to reduce the environmental impact of concrete production.

This study explores the potential of partially replacing cement with textile waste and Ground Granulated Blast Furnace Slag (GGBS) in concrete. Both materials offer a sustainable solution by promoting waste recycling and reducing carbon emissions. The research aims to assess the impact of these alternatives on the mechanical properties of concrete, contributing to the development of more eco-friendly construction materials.

1.2 Cement Replacement Materials

The textile industry generates significant amounts of sludge as a by- product, which, if improperly disposed of, can lead to environmental issues such as silting in water bodies, harming aquatic life, and contributing to pollution. Given the rising demand for potable water and the increasing population, the disposal of textile sludge has become a pressing environmental concern. This project explores the use of textile sludge as a partial replacement for cement in concrete, specifically at replacement levels of 2%, 4%, 6%, and 8%. This approach provides an eco-friendly solution for waste disposal while potentially reducing the cost of concrete production.

Textile sludge, when incorporated into concrete, does not require additional resources and could help reduce the environmental footprint of concrete production. Through the densification process, the sludge is compacted, making it easier to store and transport for use in concrete. While previous studies have shown that wet sludge can decrease concrete's

compressive strength, the use of controlled amounts of textile sludge (2%,4%, 6%, and 8%) may offer a balance, improve durability while maintain concrete's structural integrity. Replacing textile sludge in concrete also helps reduce the need for landfilling, which otherwise generates harmful greenhouse gas emissions.
This research investigates how these specific replacement levels of textile sludge affect the mechanical and durability properties of concrete, including its compressive strength and resistance to environmental factors such as sulfate attack and chloride penetration. The findings aim to establish optimal replacement percentages that balance performance with sustainability.

1.3 Textile Sludge

Textile sludge is a by-product generated during various stages of the textile manufacturing process, primarily during the dyeing, washing, and finishing of fabrics. The textile industry is a major consumer of water, particularly in processes like dyeing, bleaching, and fabric treatment, where large volumes of water are used to rinse, clean, and treat fabrics. During these stages, various chemicals, dyes, detergents, and other additives are applied to the materials, which, along with suspended fibers and organic matter, dissolve or disperse into the wastewater. The effluent produced from these processes contains a mixture of these chemicals, fibers, and other contaminants, and requires proper treatment to avoid environmental pollution.
To treat this effluent, processes like coagulation, flocculation, and sedimentation are used, which help in separating the contaminants from the water. As a result, textile sludge is formed, a semi-solid material that consists of fibers, dyes, chemical residues, and organic matter. This sludge, containing a mixture of both biological and non-biological components, can vary in composition based on the type of textile processing and the chemicals used. The next step typically involves the densification or drying of the sludge to reduce its water content, making it more compact and easier to handle, transport, and store.
Improper disposal of textile sludge can have significant environmental impacts, such as water pollution, silting, and harm to aquatic life when released into water bodies. Additionally, when landfilled, textile sludge can contribute to environmental degradation and the uncontrolled production of greenhouse gases. As such, the use of textile sludge in concrete production as a partial replacement for cement provides a sustainable solution by reducing its environmental impact while offering a potential way to recycle this waste material. This project explores the use of textile sludge as an alternative material in concrete, helping to mitigate both waste disposal challenges and the environmental footprint of concrete production.

1.4 GGBS

Ground Granulated Blast Furnace Slag (GGBFS) is a highly efficient supplementary cementitious material obtained as a by-product during the extraction of iron in a blast furnace. When molten slag is rapidly cooled with water, it forms a glassy granulated material, which is then dried and ground into a fine powder. Chemically, GGBFS primarily contains calcium oxide (35–40%), silicon dioxide (30–40%), aluminum oxide (10–15%), and magnesium oxide (5–10%). It is a latent hydraulic material, meaning it reacts with calcium hydroxide in the presence of water, forming additional calcium silicate hydrate (C-S-H), which enhances the strength and durability of concrete. Partial replacement of Ordinary Portland Cement (OPC) with GGBFS in the range of 40% to 60% has been shown to significantly improve concrete performance, including a 15–25% increase in long-term compressive strength, reduced heat of hydration, and enhanced resistance to sulfate and chloride attacks. It also improves workability and reduces porosity, leading to better impermeability and durability, especially in aggressive environments. In terms of sustainability, the use of GGBFS greatly reduces the carbon footprint of concrete production, as it emits minimal additional CO_2 compared to OPC, which releases approximately 0.9 to 1.0 tons of CO_2 per ton of cement produced. Therefore, the inclusion of GGBFS in concrete not only improves structural properties but also supports eco-friendly construction by conserving natural resources and minimizing environmental impact.

1.5 Research Significance

The increasing environmental impact of cement production and the growing volume of industrial waste have driven researchers to explore sustainable alternatives in concrete technology. Studies on

Ground Granulated Blast Furnace Slag (GGBFS) have consistently demonstrated its effectiveness as a partial replacement for Ordinary Portland Cement, showing improvements in both mechanical and durability properties of concrete. Research has indicated that incorporating GGBFS enhances long-term compressive strength by up to 25%, reduces porosity, and significantly improves resistance to chemical attacks such as sulfates and chlorides. Additionally, GGBFS contributes to sustainability by lowering the carbon footprint of concrete production, making it a practical option for green construction.

In parallel, recent studies on the use of textile sludge in concrete have opened up new possibilities for reusing industrial waste. Textile sludge, when used in controlled proportions, has been found to improve certain properties of concrete, including shrinkage resistance and durability in fiber- reinforced systems. However, excessive sludge content can adversely affect compressive strength, underscoring the need for careful optimization. Research combining textile sludge with other supplementary materials like GGBFS has shown promise in balancing mechanical performance with environmental benefits.

This research builds upon these findings by examining the combined effect of textile sludge and GGBFS on the performance of concrete. By evaluating specific replacement levels (2%, 4%, 6%, and 8% textile sludge with GGBFS), the study aims to determine an optimal mix that supports structural integrity while promoting sustainable construction practices. The integration of these two materials not only addresses waste management issues but also contributes to the development of eco-efficient, low-emission concrete solutions for the future.

1.6 Objective

1. Evaluate the feasibility of using textile sludge as a supplementary cementitious material in concrete.
2. Assess the impact of GGBFS in enhancing the performance of concrete when used alongside textile sludge.
3. Examine the compressive strength, load-bearing capacity, and deflection behavior of concrete with varying replacement levels (2%, 4%, 6%, and 8%) of textile sludge.
4. Identify the optimal percentage of cement replacement that balances structural performance with environmental sustainability.

1.7 Scope

1. Preparation of concrete mix designs incorporating varying percentages of textile sludge and GGBFS.
2. Casting and curing of concrete specimens including cubes and beams for mechanical testing.
3. Conducting tests such as compressive strength and flexural load- deflection analysis.
4. Comparing results with conventional concrete to assess improvements or reductions in performance.
5. Determining the optimal mix ratio that balances strength, durability, and sustainability.
6. Encouraging the reuse of industrial by-products in construction to reduce environmental impacts and promote resource efficiency.

II. LITERATURE REVIEW

The study by Shweta Goyal, Rafat Siddique, and Sujant Jha explores the use of textile effluent treatment plant (ETP) sludge as a partial replacement for cement in mortar and paste. It found that replacing cement with up to 5% textile sludge does not significantly affect setting time, strength, or durability, while helping reduce industrial waste (1). However, higher replacement levels led to reduced compressive strength, increased porosity, and greater drying shrinkage due to poorer hydration. The research concludes that using textile sludge up to 5% is viable for sustainable construction, but further addition compromises performance (2). The study titled "Technical Feasibility Study on Utilization of Textile Sludge as a Cement Substitute in Rubber Mould investigates the potential of using textile effluent treatment plant (ETP) sludge as a partial replacement for cement in M30 grade rubber mould paver blocks. The researchers experimented with replacing cement with textile sludge in varying proportions: 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, and 40% by weight (3). The study found that while compressive strength and abrasion resistance gradually decreased with increasing sludge content, the paver blocks met the desired standards up to a

20% replacement level. Beyond this threshold, the performance fell below acceptable values (4). The study by Md Shoaib Hussain S, Adithya V, and Chandan P focuses on evaluating the mechanical and durability properties of M20 grade concrete when cement is partially replaced with Ground Granulated Blast Furnace Slag (GGBS) and reinforced with polypropylene fibers. GGBS was used in proportions of 25%, 50%, and 75%, with a constant 2% addition of polypropylene fibers. The results indicated that compressive strength improved with higher GGBS content, reaching a maximum at 75% replacement, while the inclusion of fibers slightly reduced workability (5). However, the overall durability and sustainability of the concrete improved due to reduced cement usage and better resistance to environmental impacts. The study concludes that this combination is effective for producing eco- friendly and high-performance concrete (6). The use of textile waste and Ground Granulated Blast Furnace Slag (GGBFS) in concrete has been explored as an innovative approach to improve both sustainability and mechanical properties (7). GGBFS, which is a by-product of steel production, has been shown to replace 20-50% of Ordinary Portland Cement (OPC) in concrete. Studies have demonstrated that this substitution enhances concrete's long-term strength, durability, and resistance to chemical attacks, including sulfate and chloride corrosion, while also improving freeze-thaw resistance (8). The use of 30% GGBFS in place of OPC, for example, has been found to reduce CO_2 emissions by around 40-50% compared to traditional concrete (9). On the other hand, textile waste such as cotton or polyester fibers has been evaluated for partial cement replacement, typically in the range of 5-10% by weight. Incorporating textile waste in concrete has shown positive results in terms of ductility, flexural strength, and crack resistance (10). The fibers help in controlling micro-crack propagation, providing internal reinforcement, and improving the impact resistance of concrete. However, increasing the percentage of textile waste beyond 10% can lead to a decrease in compressive strength up to 10-20% lower than conventional concrete due to the weaker bonding between the textile fibers and the cement matrix (11). Furthermore, textile fibers can increase water absorption, which may slightly reduce the durability of concrete over time. When combined, the use of 10% textile waste and 30-50% GGBFS creates a balance between enhanced workability, reduced cracking, and improved environmental sustainability, offering a promising solution for more sustainable concrete production (13). Despite the benefits, further optimization of the mix design is required to balance strength, durability, and environmental impact effectively (14).

III. MATERIALS AND THEIR PROPERTY

In our experiment investigation, we use the following material to cast the specimen to study the mechanical properties of concrete beams.

3.1 Cement

OPC 53 grade cement is a high-strength Ordinary Portland Cement that achieves a minimum compressive strength of 53 MPa after 28 days. It sets and hardens quickly, making it ideal for fast-track and heavy-duty construction like high- rise buildings, bridges, and industrial floors. Its durability and strength allow for reduced cement usage, but proper curing is essential to avoid cracks due to heat generated during setting as shown figure 1.

Figure 1 Cement

3.2 Fine Aggregate

River sand is a natural fine aggregate sourced from river beds, known for its smooth, rounded particles that provide excellent workability and ease of mixing in construction. It is widely used in concrete, plastering, and bricklaying due to its good gradation, cohesiveness, and load-bearing capacity. River sand contributes to higher compressive strength and durability of concrete, making it suitable for foundations, roads, and buildings. However, it may contain impurities like silt and organic matter, and excessive mining has environmental impacts. Despite this, river sand remains a preferred material for precise construction work because of its natural texture and stability as shown figure 2.

Figure 2 Fine aggregate

3.3 Coarse Aggregate

Coarse aggregate refers to granular construction materials like crushed stone, gravel, or recycled concrete with particle sizes typically retained on a 4.75 mm sieve, ranging up to about 63 mm in diameter. These aggregates provide bulk, strength, and stability to concrete and are essential for structural integrity in construction projects such as buildings, roads, and railway ballast. The quality, hardness, and shape of coarse aggregates significantly influence the strength and durability of concrete, making their selection and cleanliness crucial for optimal performance as shown figure 3.

Figure 3 Water absorption of Coarse aggregate

3.4 Textile Waste

Textile waste in construction is used to create sustainable materials like insulation, soundproofing, eco-friendly bricks, roofing, and geotextiles for soil stabilization. Incorporating textile fibers into concrete and composites improves durability, reduces landfill waste, conserves natural resources, and lowers the environmental impact of building projects. These recycled textile-based products offer benefits such as better thermal and acoustic insulation, lightweight structures, and enhanced crack resistance, supporting eco-friendly and circular economy goals in construction as shown figure4.

Figure 4 Specific gravity of Textile Sludge

3.5 GGBS

GGBS (Ground Granulated Blast Furnace Slag) is a finely ground material obtained by rapidly cooling molten slag from iron and steel production, then grinding it into a powder. When used as a partial replacement for cement in concrete, GGBS enhances the concrete's strength, durability, and resistance to chemical attacks like sulfate and chloride ingress. It also reduces the heat generated during hydration, which minimizes the risk of thermal cracking in large structures. Additionally, GGBS lowers permeability and helps prevent alkali-silica reactions, improving the longevity of concrete. Using GGBFS contributes to sustainability by recycling industrial waste, reducing cement consumption, and lowering carbon dioxide emissions associated with cement production. It is widely used in infrastructure projects such as bridges, marine structures, pavements, and precast concrete, making it a valuable material for high-performance and eco-friendly construction.

3.6 Percentage of Materials

In this research, textile sludge and Ground Granulated Blast Furnace Slag (GGBFS) are partially used to replace cement in the concrete mix. The replacement is carried out at three different levels: 2%, 4%, and 6% of the total mass of cement. For each replacement level, six concrete cubes of dimensions 100 mm × 100 mm × 100 mm are cast to evaluate the effect of these materials on the strength and performance of the concrete. This section presents the exact proportions used in each mix to assess the impact of incremental replacement on the concrete's properties.

3.7 Workability of slump cone test

The slump test is a means of assessing the consistency of fresh concrete for the calculated mix ratio, the slump test was conducted. The slump value for ordinary concrete without superplasticizer is 25 mm. The figure 5 shows the slump test carried for concrete.

Figure 5 Slump Cone Test

Table 1 Preliminary test result

SI.no	Material	Parameter	Reference
1.	Cement	Specific Gravity = 3.1815 Fineness of Cement = 9 % Consistency of Cement = 32%	Is 4031 (Part-11)
2.	Coarse Aggregate	Sieve Analysis = 20 mm Specific Gravity = 2.66 Water Absorption = 1.06 %	Is 2386 (Part -1,3)
3.	Fine Aggregate	Sieve Analysis = Zone-II Specific Gravity = 2.66	Is 383 (Table.No.9) Is 2720 (Part-3)
4.	Textile Sludge	Specific Gravity = 2.80 Percentage of Fineness = 1 %	IS 3812 (Part-1)
5.	GGBS	Percentage of Fineness = 5 % Specific Gravity = 3.12	IS 12089
8.	Fresh concrete test	Slump value = 25 mm	IS 1199

IV. EXPERIMENTAL INVESTIGATION

The experimental investigation for this project focuses on evaluating the compressive strength of concrete in which cement is partially replaced with textile sludge and ground granulated blast furnace slag (GGBFS) at varying levels of 2%, 4%, 6%, and 8% by mass. Concrete cubes are prepared using weight batching for all materials, including cement, aggregates, textile sludge, GGBFS, and water, to ensure consistency across all mixes. These specimens are then cured and tested for compressive strength at 7, 14, and 28 days using a standard compression testing machine in accordance with relevant codes. The results are compared with those of conventional concrete specimens without any replacement.

Based on existing literature and preliminary observations, it is expected that the compressive strength will decrease as the percentage of textile sludge and GGBFS increases, with the reduction becoming more pronounced at higher replacement levels. This study aims to systematically analyze the effect of these alternative materials on the compressive strength of concrete, thereby assessing the feasibility of utilizing textile sludge and GGBFS as sustainable partial replacements for cement.

4.1 Specimen Details

Table 2 Specimen details

Si.no	Specimen Details	No.of Specimen	Specimen tested for
1.	Conventional Cube	9	Compressive Strength
2.	2% of Textile sludge and GGBFS	9	Compressive Strength
3.	4% of Textile sludge and GGBFS	9	Compressive Strength
4.	6% of Textile sludge and GGBFS	9	Compressive Strength
5.	8% of Textile sludge and GGBFS	9	Compressive Strength

4.2 Casting of Specimen Cube

The casting of 100 mm concrete cubes involves preparing a concrete mix with the specified proportions of cement, textile sludge, and GGBFS. The mix is poured into 100 mm x 100 mm x 100 mm molds in layers. After each layer is added, a vibrator is used to compact the concrete and remove air voids, ensuring a uniform and dense mix. The molds are then covered to prevent moisture loss during the initial setting phase, typically for 24 to 48 hours, before the specimens are demolded. The cubes are then ready for the curing process, which is essential for developing the desired strength and properties as shown figure 6.

Figure 6 Compaction of Conventional concrete

4.3 Curing Of Concrete

Curing should be carried out for a minimum of 7 days to allow adequate hydration, particularly since GGBFS hydrates slowly. Extended curing, up to 14 days, is recommended to ensure optimal strength development, especially when using textile sludge and GGBFS. To fully assess the long-term performance and durability of the concrete, curing up to 28 days may be necessary. This timeline ensures the hydration processes are completed, allowing for accurate evaluation of the concrete's strength and durability as shown figure 7.

Figure 7 Curing of Conventional Cubes

V. RESULT AND DISCUSSION

5.1 General

The compressive strength of concrete is one of the key indicators of its quality. This test is performed by applying a compressive load on 100 mm x 100 mm x 100 mm cube specimens, which are prepared, cured, and tested according to the standards outlined in IS 516:1959.

5.2 Compressive Strength Test

The Cube Compression Test, following IS 516:1959, involves casting concrete into 100 mm x 100 mm x 100 mm molds, compacting it in layers with a vibrator, and curing the cubes in water for 7, 14, or 28 days. After curing, the cubes are measured and placed in a compression testing machine, where a gradual load is applied at 140 kg/cm² per minute until failure occurs.

5.3 Procedure

The concrete cubes of size 100 mm x 100 mm x 100 mm are cast by filling the molds in three layers, each layer being compacted with a tamping bar 35 times to ensure proper consolidation and the elimination of air pockets. After the cubes are cast, they are left to set for 24 hours before being demolded and cured in water at a temperature of 27 ± 2°C for the required curing period After curing, the cubes are removed from the water while still wet, and their dimensions are measured to ensure they meet the required specifications. The specimen is then placed centrally on the lower platen of the compression testing machine, with its longitudinal axis at right angles to the supporting rollers. The load is applied gradually at a rate of 180 kg/min for 100 mm cubes. The load is increased until the cube fails, and the maximum load at failure is recorded. The results are typically reported as the average compressive strength of at least three specimens.

5.4 Formula for Compressive Strength

The compressive strength is calculated using the formula:

$$Compressive\ Strength\ (MPa) = \frac{Maximum\ Load\ (N)}{Cross\ sectional\ Area\ (mm^2)}$$

For 100 mm cubes, the cross-sectional area is:

$$Area = 100 \times 100 = 10{,}000\ mm^2$$

Figure 8 Partially Replaced Cement Cubes

5.5 Cubes

Conventional Concrete (Cc)

Table:3 The Compressive Strength of CC Cubes

SI.no	No.of days curing	Compressive strength N/mm^2			Average Value N/mm^2
		Trial I	Trial II	Trial III	
1.	7	19	20	20	19.67
2.	14	24	26	25	25
3.	28	32	30	30	30.67

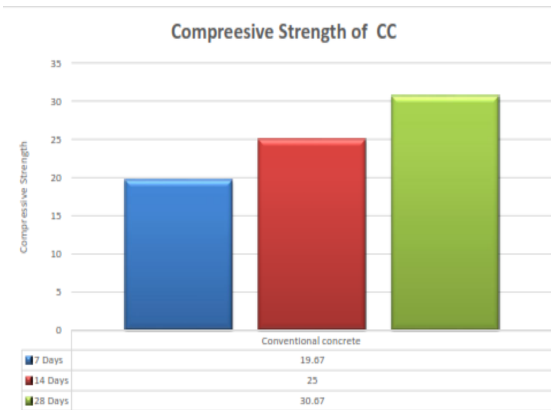

Figure 9 Compressive Strength of CC

5.6 Concrete Cube 2% With Textile Waste And GGBFS

Table 4 The Compressive Strength of Cubes

SI.no	No.of days curing	Compressive strength N/mm^2			Average Value N/mm^2
		Trial I	Trial II	Trial III	
1.	7	15	18	16	16.34
2.	14	25	24	25	24.67
3.	28	29.00	29.50	29.33	29.82

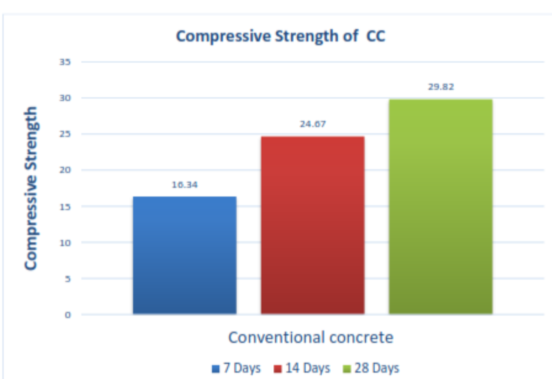

Figure 10 Compressive Strength of CC

5.7 Concrete Cube 4% With Textile and GGBFS Waste

Table 5 The Compressive strength of Cubes

SI.no	No.of days curing	Compressive strength N/mm^2			Average Value N/mm^2
		Trial I	Trial II	Trial III	
1.	7	13.0	13.4	13.8	13.4
2.	14	15.0	16.1	15.3	15.4
3.	28	28.80	28.10	28.0	28.97

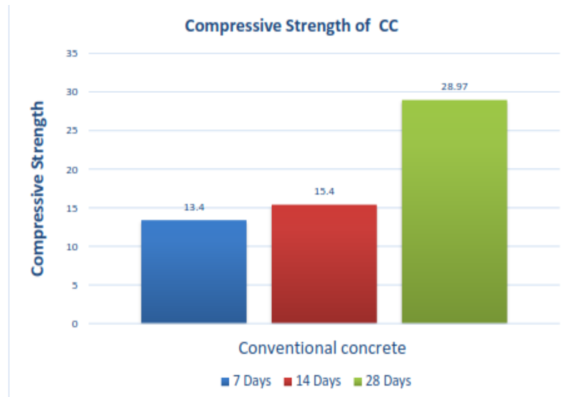

Figure 11 Compressive Strength of CC

5.8 Concrete Cube 6% With Textile and GGBFS Waste

Table 6 The Compressive strength of CC Cubes

SI.no	No.of days curing	Compressive strength N/mm^2			Average Value N/mm^2
		I	II	III	
1.	7	11.0	11.2	11.15	11.12
2.	14	14.2	14.3	14.4	14.3
3.	28	24.6	24.5	24.3	24.46

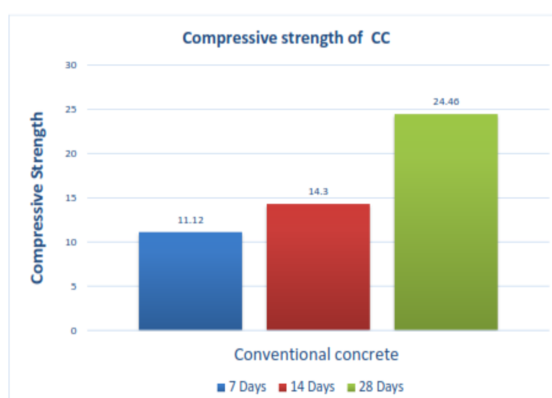

Figure 12 Compressive Strength of CC

5.9 Concrete Cube 8% With Textile And GGBFS Waste

Table 7 The Compressive strength of CC Cubes

SI.no	No.of days curing	Compressive strength N/mm²			Average Value N/mm²
		I	II	III	
1.	7	9.1	10.5	9.4	9.67
2.	14	12.3	12.6	13.1	12.67
3.	28	19.3	19.4	19.1	19.26

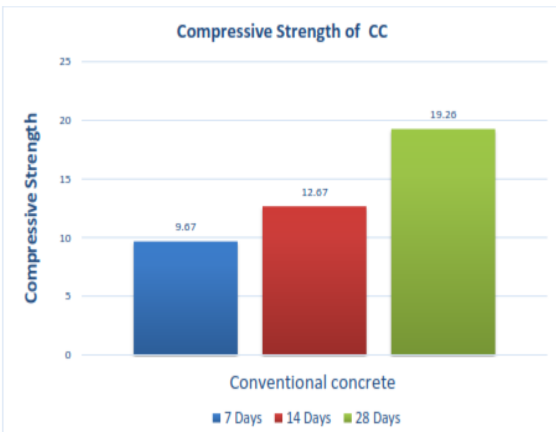

Figure 13 Compressive Strength of CC

5.10 Comparison Of Result

Table 8 The compression Compressive Strength of CC

No. of days Curing	7 Day Strength N/mm²	14 Day Strength N/mm²	28 Day Strength N/mm²
Conventional Cube	19.67	25	30.67
2% of Textile Sludge and GGBFS	16.34	24.67	29.82
4% of Textile Sludge and GGBFS	13.4	15.4	28.97
6% of Textile Sludge and GGBFS	11.12	14.3	24.46
8% of Textile Sludge and GGBFS	9.67	12.67	19.26

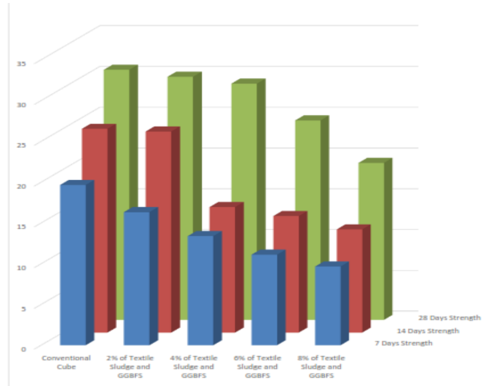

Figure 14 Compression Compressive Strength of CC

VI. CONCLUSION

This study investigated the effect of partial replacement of cement with textile waste and Ground Granulated Blast Furnace Slag (GGBFS) at replacement levels of 2%, 4%, 6%, and 8% on the properties of concrete.

1. The use of sludge waste combined with Ground Granulated Blast Furnace Slag (GGBFS) as partial replacements for cement in concrete offers a sustainable alternative that reduces the environmental impact of conventional cement production by lowering CO_2 emissions.
2. Incorporating sludge waste and GGBFS improves the mechanical properties of concrete. Experimental results indicate that adding sludge waste up to 2% along with GGBFS enhances concrete's strength and durability compared to conventional mixes.
3. GGBFS contributes significantly to strength gain through its pozzolanic reaction, while sludge waste helps in improving workability and crack resistance when properly done.
4. The optimal strength development depends on careful mix design and curing conditions. Proper curing, such as maintaining moisture and temperature, ensures better hydration and pozzolanic activity, leading to improved long-term performance.
5. Overall, concrete with sludge waste and GGBFS shows potential for achieving strength and durability comparable to or better than conventional concrete, making it a viable and eco-friendly construction material.

6. Using textile waste and GGBFS reduces cement consumption, lowering carbon footprint and promoting recycling of industrial and textile wastes.
7. The use of textile waste and GGBFS as partial replacements for cement in concrete is both technically feasible and environmentally beneficial.

Future work is recommended on:
1. Long-term durability testing
2. Field performance
3. Life-cycle assessment for sustainability benchmarking.

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