International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 4, Jul-Aug 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Effect on Properties of Concrete by Replacement of GGIFS (Ground Granulated Induction Furnace Slag)

Ravi Kumar[1], Er. Janardan Tiwari[2]

[1]M Tech Scholar, [2]Guide,
[1,2]Jan Nayak Chaudhary Devi Lal Memorial College of Engineering, Sirsa, Haryana, India

ABSTRACT
Concrete is a very common building material, but when excessive cement is used, there are high CO_2 emissions and degradation of the environment. This research examines the impact of Ground Granulated Induction Furnace Slag (GGIFS) as an incomplete cement standby to produce eco-friendly and high-performance concrete. Six mixtures were designed by 0%, 10%, 20%, 30%, 40%, and 50% GGIFS using Okamura-Ouchi SSC method with a fixed water-binder ratio of 0.36 and 2% super plasticizer. Compression split tensile strength, flexural strength, and surface hardness tests were performed at 7, 14, and 28 days. Results indicated that a 20% GGIFS replacement (M2) resulted in maximum performance, with a compressive strength of 52.5 MPa, 3.85 MPa split tensile strength, 7.60 MPa flexural strength, and rebound hammer value of 44 at 28 days. But for replacement more than 30%, there was a decrease in strength because of less cementitious material. The research concludes that the most suitable substitution level is 20% GGIFS, providing enhanced strength, toughness, and environmental sustainability, and thus proving to be a good substitute for contemporary concrete manufacture.

KEYWORDS: GGIFS, sustainable concrete, cement replacement.

How to cite this paper: Ravi Kumar | Er. Janardan Tiwari "Effect on Properties of Concrete by Replacement of GGIFS (Ground Granulated Induction Furnace Slag)" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-4, August 2025, pp.1245-1253, URL: www.ijtsrd.com/papers/ijtsrd97420.pdf

IJTSRD97420

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1. INTRODUCTION

Concrete is among the most common building materials used across the globe because it possesses great compressive strength, long lifespan, and versatility. Concrete has typically been produced by combining cement, sand, coarse aggregate, and water in definite ratios [1]. Cement is the main binding material among all the above ingredients that binds the concrete mixture and gives it strength. Large-scale cement production has, however, emerged as a significant environmental issue [2]. Production of cement emits large quantities of CO_2 into the environment, causing climate change and global warming. Moreover, raw material extraction for cement production contributes to natural resource depletion and presents sustainability issues for the construction sector [3, 4].

Over the past few years, researchers and engineers have been actively working on the creation of environmentally friendly, economical, and sustainable partial replacements for cement in concrete. Using industrial by-products as supplemental cementitious materials is one example of a replacement [5] . Of these by-products, “Ground Granulated Induction Furnace Slag (GGIFS)” has been a material that is highly sought after for improving the efficiency of concrete while reducing its negative effects on the environment.

GGIFS is a fine powder that is derived as a by-product from induction furnaces employed during the manufacturing of steel. In the process of steel production, plenty of molten slag is produced, which is immediately cooled, dried, and powdered to achieve GGIFS. Chemically, GGIFS is composed of large levels of calcium, silica, alumina, and other substances, which confer to it characteristics akin to those of Portland cement. Due to these pozzolanic and cementitious properties, GGIFS can be efficiently utilized as partial substitute for cement in concrete mixtures without affecting performance [6] .

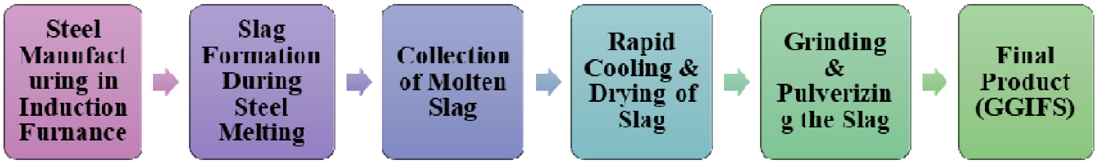

Figure 1: Process of GGIFS Production

Utilization of GGIFS in concrete has various benefits. Due to its tiny size and smooth exterior, it increases the ability to work of fresh concrete, allowing the combination simpler to deal with and put in place. Secondly, GGIFS contributes to concrete's long-term strength by means of a gradual pozzolanic reaction that produces additional “Calcium Silicate Hydrate (C-S-H)” gel [7] . Third, it greatly enhances the chemical resistance of concrete to attacks by chemicals like sulfate and chloride penetration and is hence very applicable in marine and aggressive environments [8] . In addition, GGIFS utilization reduces heat of hydration, which is a great advantage for large-sized concrete structures where excessive heat is likely to induce cracking.

Besides the technical advantages, GGIFS also has a significant role to play in sustainable construction. Being an industrial waste material, GGIFS uses waste materials otherwise destined for landfills, thus cutting down on environmental pollution [9] . Meanwhile, partial cement replacement decreases total energy consumption and carbon-based emissions of cement production. Thus, GGIFS-based concrete is an eco-friendly and cost-effective option for new age infrastructure developments [10] .

In spite of these benefits, the influence of GGIFS on mechanical and durability characteristics of concrete is highly dependent on the level of replacement. At lower levels of replacement (10%–30%), GGIFS has been reported to enhance compressive strength, durability, and overall performance [11] . But at elevated levels of replacement (>50%), there is a possibility of a decrease in early-age strength with reduced availability of cementing compounds. Hence, the critical issue is to find the optimal ratio of GGIFS in the mix of concrete to obtain the optimal performance-cost-sustainability balance [12] .

In the present research work, emphasis has been laid upon the investigation of the replacement of cement with GGIFS on a variety of concrete characteristics, including hydration heat, workability, durability, and compressive strength. From the investigation of these effects, engineers as well as researchers can design concrete mixes that are not only durable and strong but also eco-friendly. It helps in moving towards the circular economy using industrial waste efficiently and supporting the increasing requirement of green building materials. Therefore, the application of GGIFS as a incomplete standby for cement in concrete offers a valuable chance to upgrade the performance of concrete, lower construction costs, and promote environmental sustainability. With an enhanced global focus on sustainable development, incorporating innovative materials such as GGIFS can play an significant role in determining the future of the building industry.

2. Literature Review

Sherfenaz et al., (2025) [13] suggested utilizing “Induction Furnace Slag (IFS)” as an alternative for coarse aggregate in “Pervious Concrete (PC)” to solve the problem of sustainable pavement construction. Eighteen PC mixtures were manufactured by changing aggregate gradation, fine aggregate fraction, and water-cement ratios. The outcomes revealed compressive strength up to 22.5 MPa, porosity between 6.2%–31.3%, and permeability up to 4.84 cm/s, establishing that IFS-based PC was better compared to traditional stone aggregate PC.

Panda et al., (2025) [14] proposed the employment of “Induction Furnace Steel Slag (IFSS)” as a total replacement of river sand in M25 grade concrete in order to curb the issue of high sand utilization. Concrete specimens were prepared with the practice of “Portland Slag Cement (PSC)” and “Portland Pozzolana Cement (PPC)”. At 100% replacement, the compressive strength was 34.83 MPa (PSC) and 38.10 MPa (PPC) with tensile strength up to 3.32 MPa, establishing IFSS to be a sustainable substitute.

Herki et al., (2025) [15] suggested the utilization of IFSS, such as “Steel Slag Powder (SSP)”, “Low-Density Steel Slag (LDSS)”, and “High-Density Steel Slag (HDSS)”, for partial replacement of cement and coarse aggregates to mitigate environmental risks from slag disposal. Different proportion mixes were analyzed, and findings indicated 40% HDSS substitution produced the optimum performance with a 5.2% increase in compressive strength and 2.1% reduction in water absorption, contributing to increased durability overall.

Birgonda e al., (2024) [16] suggested utilizing IFS for the first time as both fine and coarse aggregates in “Quaternary Blended Self-Compacting Concrete (QBSCC)” in order to overcome insufficient research in the area of sustainable aggregates. Eighteen mixes were also tested for durability properties. Findings indicated that

IF-slag mixes recorded slightly poor durability compared to natural aggregates but QBSCC surpassed traditional SCC, recording up to 48% lower absorption coefficient, 46% lower sorptivity, and better chloride resistance and electrical resistivity, which boost energy efficiency.

Adegoke et al., (2024) [17] suggested using cement replaced with different percentages of IFS to enhance concrete performance with lower cement consumption. Concrete specimens containing 0–60% IFS were evaluated for compressive strength, water absorption, and chloride ion penetration after varying curing times. Findings indicated that 25% replacement of IFS attained the best performance. Microstructural analysis (SEM, XRD, and XRF) confirmed the results, and mathematical models were formulated to predict compressive strength as a function of IFS content, chloride penetration, and void ratio.

Mohammed et al., (2024) [18] suggested utilizing other fine aggregates such as BFA, SFA, LFS, RBFA, WWF, and IFS in place of natural river sand in order to produce sustainable concrete. Tests on specimens of concrete and mortar were conducted for strength, workability, and durability. Results indicated best compressive strength at 30% BFA, 30% SFA, 20% LFS, and 20% WWF, while the strength was attained by RBFA even at 100% replacement. IFS-based ECC was found to possess enhanced heat resistance and best performed at 50% sand replacement.

Mark et al., (2024) [19] developed empirical models for predicting the filling ability and compressive strength of "High-Performance Self-Compacting Concrete (HPSCC)" by incorporating IFS as a supplementary cementitious material. The problem of utilizing eco-friendly alternatives in concrete production was addressed by partially replacing cement with IFS (0–50%). Experimental tests, including slump flow and compressive strength, validated the models, achieving high accuracy ($R^2 > 94\%$ for filling ability and $R^2 > 86\%$ for strength), proving IFS's sustainability and effectiveness.

van Engelenburg et al., (2024) [20] established a parameterized linkage between the "Stock-Flow-Service (SFS)" nexus and circularity strategies to quantify reductions in primary material use. Addressing the problem of increasing resource demands due to population growth and rising wealth, the study analyzed material flows for shelter, mobility, comfort, and infrastructure. Results showed that maintaining 77 tons of material stock per person required 1.3 tons/year of primary materials, and circularity strategies could reduce primary material flows by nearly two-thirds without rebound effects.

ANAMICA et al., (2023) [21] utilized IFS with alkali activators as a cement replacement to address the problem of high cement usage and environmental concerns. Mortar cubes were prepared using sodium hydroxide solutions of 6M, 9M, and 12M under room and elevated curing conditions. The results showed that 9M achieved optimal strength, and high-temperature curing yielded 80–82% strength within three days, demonstrating an eco-friendly alternative to conventional cement.

3. Materials and Method

This research examines the effect of GGIFS on fresh and hardened concrete properties using partially replaced cement. The experimental program includes the selection of quality materials, the planning of the concrete mixtures, and the testing of their performance.

3.1. Material selection

The selected materials are given below.

- **Cement**

Standard Portland cement (OPC, Grade 42.5R) was employed as the main binder in this research work. Its specific gravity was 3.06, and its fineness was 6%. It met the requirements of IS: 12269 for high-strength concrete. Its uniform particle size ensured efficient hydration that helped the strong point and robustness of the concrete.

- **Fine Aggregates**

The fine aggregate used was clean, genuine river sand having a sieve size of less than 4.75 mm IS. Its water absorption capacity was 0.85%, its specific gravity was 2.64, and its bulk density was 1.52 g/cm³. The sand was well-graded, silt and clay free, and organic matter free, providing improved workability along with good bonding in the concrete matrix.

- **Coarse Aggregates**

Coarse aggregates used were crushed granite of maximum size 12.5 mm. They possessed specific gravity as 2.66, bulk density of 1.55 g/cm³, and water absorption of 0.75%. The aggregates were angular, well-graded, and were within the standards of IS: 383, lending strength and stability to the concrete.

- **Ground Granulated Induction Furnace Slag (GGIFS)**

GGIFS is a by-product of the induction furnace process of steel production. The slag was air-cooled and ground, and then sieved to obtain a particle size of approximately 90 µm. It possessed a specific gravity of 2.95 and contained silica (44.6%), alumina (11.1%), and ferric oxide (23.0%). It is a good supplementary cementitious material. GGIFS was applied to replace cement partially in various proportions to make concrete stronger and last longer.

- **Water**

Potable, clean water with no organic impurities, no salts that are harmful, and no suspended particles was employed for mixing and curing. The water conformed to the quality specifications of IS: 456-2000. Its low chloride ion content and neutral pH ensured no harmful influence on hydration or corrosion of reinforcement, leading to uniform development of strength.

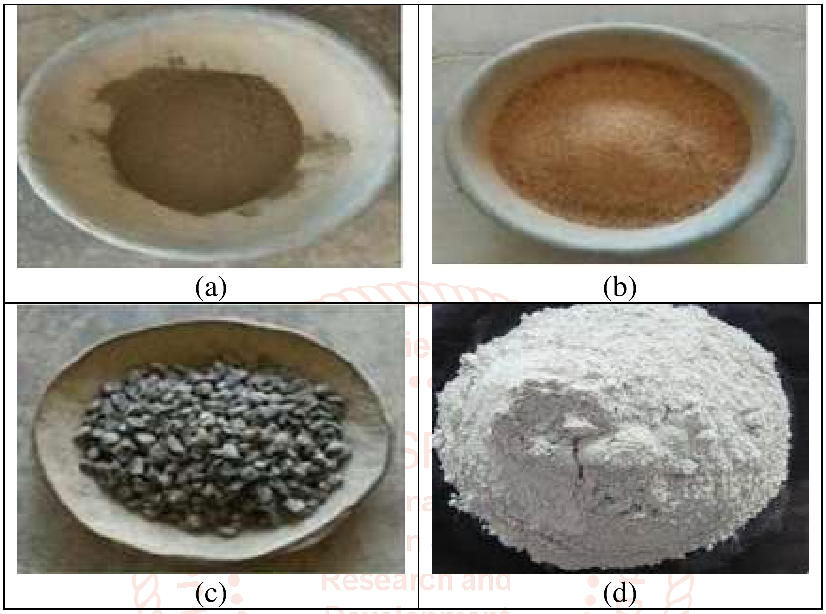

Figure 2: Materials (a) Cement (b) Fine Aggregate (c) Coarse Aggregate (d) GGIFS

3.2. Mix Design and Replacement Level

Six concrete mixes were developed in which "Ordinary Portland Cement (OPC)" used GGIFS as a partial substitute at 0, 10, 20, 30, 40, and 50% by binder weight. The proportions were derived following the Okamura-Ouchi "Self-Compacting concrete (SCC)" mix design method with an approximate binder**:** sand**:** coarse aggregate ratio of 1.00:1.02:0.95. The "water-to-binder (w/b)" ratio was set at 0.36, and the super plasticizer was the poly carboxylate-based type, added at 2% of the mass of the binder to obtain sufficient workability. Only the proportions of GGIFS and cement were changed. The proportions of aggregates, water, and super plasticizer were held constant in all mixes.

Table 1: Concrete Mix Proportions for Different GGIFS Replacement Levels (per m³)

Mix ID	GGIFS Replacement (%)	Cement (kg)	GGIFS (kg)	Fine Aggregate (Sand) (kg)	Coarse Aggregate (Granite) (kg)	Water (kg)	Super plasticizer (kg)
M0	0%	733.0	0.0	747.66	696.35	263.88	14.66
M1	10%	659.7	73.3	747.66	696.35	263.88	14.66
M2	20%	586.4	146.6	747.66	696.35	263.88	14.66
M3	30%	513.1	219.9	747.66	696.35	263.88	14.66
M4	40%	439.8	293.2	747.66	696.35	263.88	14.66
M5	50%	366.5	366.5	747.66	696.35	263.88	14.66

Table illustrates the mix proportions of the concrete for various levels of replacement by GGIFS from 0% to 50% by weight of binder. There are six designed mixes (M0 to M5) where the cement content reduces progressively along with the increase in the percentage of GGIFS, and the amounts of the fine aggregate (747.66 kg), coarse aggregate (696.35 kg), water (263.88 kg), and super plasticizer (14.66 kg) remain the same for all the mixes. The effect on concrete's workability, strength, and durability of partially replacing cement with GGIFS can be evaluated with the help of this method.

3.3. Specimen Casting and Curing

The specimens used for testing were created in iron moulds with no external vibration to keep their self-compacting properties after the concrete mixtures were prepared. To prevent excessive drying out, plastic sheets were placed over the moulds immediately upon casting and removed after 24 hours. The specimens were taken out of the moulds and put in a water-curing tank where they remained until the day of testing, in an environment maintained at 23 ± 2 °C and 65 ± 5% relative humidity.

Table 2: Specimen Details and Testing Schedule

Test Type	Specimen Size (mm)	Curing Ages (Days)	Specimens per Mix (n)	Total Specimens
Compressive Strength	150 × 150 × 150	7, 14, 28	3 per age per mix	54
Split Tensile Strength	100 × 200 (Cylinder)	7, 14, 28	3 per age per mix	36
Flexural Strength	100 × 100 × 500	7, 14, 28	3 per age per mix	36
Rebound Hammer Test	On Cube Surface	7, 14, 28	3 per mix; 10 readings/face	36

The table presents the testing schedule and specimen details used to assess the replacement of GGIFS and its effect on selected, concrete properties. There were a total of four test types completed: "Compressive Strength (CS)", "Split Tensile Strength (STS)", "Flexural Strength (FS)", and "Rebound Hammer Test (RHT)". All specimens were of the standard size, which meant 150 × 150 × 150 mm cubes fo rCS, 100 × 200 mm cylinders for tensile strength, and 100 × 100 × 500 mm prisms for FS. The testing schedule included testing at 7, 14, and 28 days, with three specimens per mix per age to ensure accurate and precise results. In total, there were 162 specimens tested for all mixtures, which allowed for thorough analysis of the data.

3.4. Curing Conditions

After 24 hours of casting, the pieces of concrete were removed from their moulds and placed in a curing tank to allow them to remain hydrated for the whole length of the experiment. To guarantee that the curing media was free of contaminants that could impact hydration rates, the specimens were submerged in potable water. Curing was done in controlled environmental conditions to maintain consistency and reliability of the test results.

- **Curing Medium:** Clean potable water
- **Temperature Maintained:** 23 ± 2 °C
- **Relative Humidity:** 65 ± 5%
- **Curing Duration:** Until the respective testing ages (7, 14, and 28 days)

Ensuring that the concrete specimens developed correctly in terms of strength and durability necessitated keeping controlled curing conditions to produce homogeneous hydration of cementitious ingredients. It was crucial to use this regulated curing period to precisely evaluate how GGIFS substitution affected the mechanical properties and durability attributes of concrete.

4. Result and Analysis

The experimental study on the impact of GGIFS on concrete characteristics is the source of the results given here. Six mixes were assessed where GGIFS was replaced at different levels (M0 to M5) in terms of CS, STS, FS and RHT values at 7, 14, and 28 days.

4.1. Compressive Strength Results

The CS of concrete was tested on 150 × 150 × 150 mm cubes after curing periods of 7, 14, and 28 days.

Table 3: CS Results of Concrete at Different Ages

Mix ID	GGIFS (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0	0%	29.5	35.2	45.6
M1	10%	33.2	37.5	47.8
M2	20%	35.4	40.3	**52.5**
M3	30%	29.8	37.0	42.1
M4	40%	24.5	33.5	39.6
M5	50%	20.8	28.7	32.2

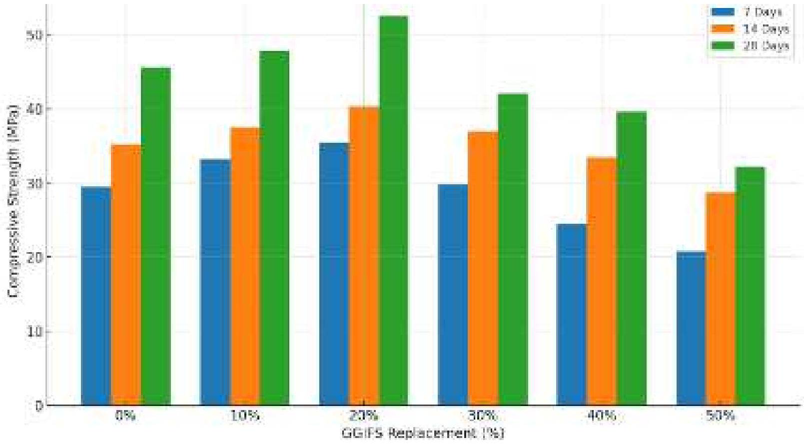

Figure 3: Compressive Strength vs. GGIFS Replacement (%)

The compressive strength results for multiple replacement levels of GGIFS demonstrate a meaningful impact on the performance of the concrete at ages of 7, 14, and 28 days. At 20% replacement with GGIFS (M2), the concrete had the highest CS (52.5 MPa) at 28 days of age, suggesting that using GGIFS at that level effectively utilized the material to improve the strength. A 10% replacement with GGIFS (M1) provides a marginally improved compressive strength when compared to the control mix (M0, 45.6 MPa). Any amount of GGIFS replacement greater than 30% (M3, M4, M5) resulted in dropping compressive strength due to having a lower amount of cementitious material and a slower rate of hydration. The greatest amount of GGIFS in the concrete was present in the M5 mix (50% GGIFS), which resulted in the lowest compressive strength (32.2 MPa) and was not operational in improving the CS at higher replacement levels.

4.2. Split Tensile Strength Results

The STS was tested on 100 × 200 mm cylinders after 7, 14, and 28 days of curing.

Table 4.4: STS Results of Concrete at Different Ages

Mix ID	GGIFS (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0	0%	2.45	2.90	3.30
M1	10%	2.60	3.15	3.55
M2	20%	2.80	3.35	**3.85**
M3	30%	2.55	3.05	3.40
M4	40%	2.30	2.75	3.05
M5	50%	2.05	2.40	2.75

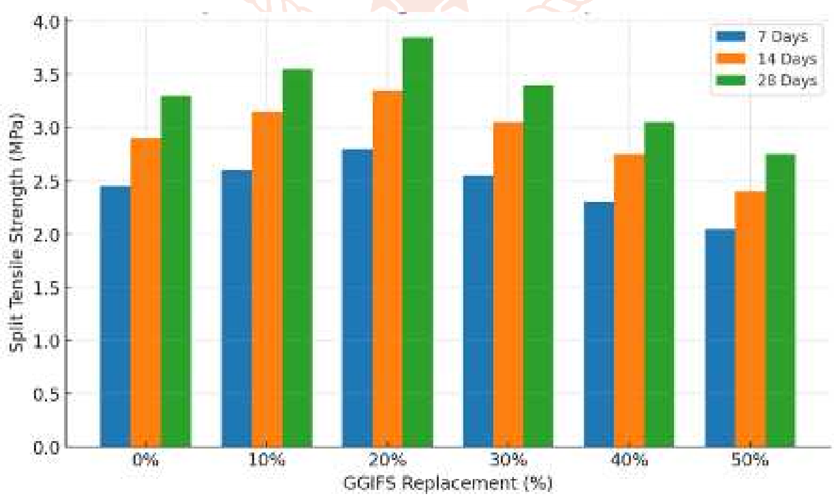

Figure 4: Split Tensile Strength vs. GGIFS Replacement (%)

The split tensile strength values at varying GGIFS replacement levels signify a significant impact on concrete performance in 7, 14, and 28 days. Maximum TS of 3.85 MPa was observed at 20% GGIFS replacement (M2), significantly improving over the control mix (M0, 3.30 MPa). Strength was also increased by 10% replacement (M1) to 3.55 MPa at 28 days. But for replacement over 30% (M3, M4, M5), the tensile strength decreased slowly because of lower cement content and poorer bonding. The lowest reading (2.75 MPa) occurred at 50% GGIFS, reflecting that too much replacement has a detrimental effect on performance.

4.3. Flexural Strength Results

The FS of beams (100 × 100 × 500 mm) was measured after 7, 14, and 28 days of curing.

Table 4.5: FS Results of Concrete at Different Ages

Mix ID	GGIFS (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0	0%	4.55	5.80	6.70
M1	10%	4.80	6.05	7.10
M2	20%	5.10	6.45	**7.60**
M3	30%	4.75	6.00	6.85
M4	40%	4.40	5.55	6.25
M5	50%	4.05	5.15	5.80

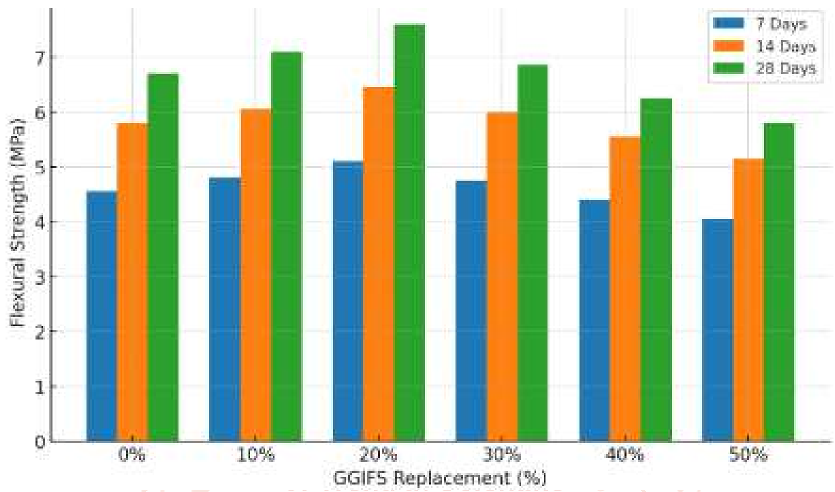

Figure 5: Flexural Strength vs. GGIFS Replacement (%)

The flexural strength data show that 20% replacement of GGIFS (M2) recorded the highest strength of 7.60 MPa at 28 days with a very substantial improvement compared to the control mix (M0, 6.70 MPa). 10% replacement (M1) also improved flexural strength to 7.10 MPa. But for more than 30% replacement (M3, M4, M5), the strength reduced progressively because of decreasing cementitious content and lower adhesive capacity. The minimum value (5.80 MPa) was recorded at 50% GGIFS, which suggests that 20% replacement is the best, while higher substitution adversely affects flexural strength.

4.4. Rebound Hammer Test Results

The RHT was achieved on cube surfaces to estimate surface hardness after 7, 14, and 28 days.

Table 4.6: RHT Results

Mix ID	GGIFS (%)	7 Days	14 Days	28 Days
M0	0%	25	32	38
M1	10%	27	34	41
M2	20%	29	37	**44**
M3	30%	26	33	39
M4	40%	24	31	36
M5	50%	22	28	33

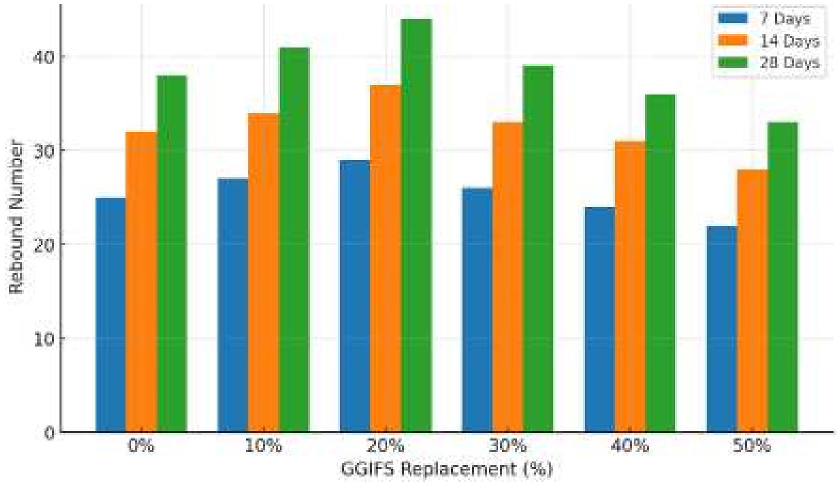

Figure 6: Rebound Hammer Test vs. GGIFS Replacement (%)

The results of the RHT indicated that the surface hardness of concrete improved with the inclusion of GGIFS until 20% was replaced (M2), achieving the best rebound value of 44 at 28 days compared to the control mix (M0, 38). A 10% replacement (M1) also increased hardness to 41 rebound value. However, after 30% GGIFS (M3, M4, M5), the values decreased incrementally due to the decrease in cement content, and reduction in strength. The prone value of 33 was established at 50% replacement indicating that up to 20% GGIFS is the most effective in increasing surface hardness.

5. Conclusion

The purpose of this experimental study to determine how using GGIFS in place of some of the cement in concrete affected the material's mechanical and durability characteristics. Using GGIFS cement as a binder weight replacement at 0%, 10%, 20%, 30%, 40%, and 50% yielded six distinct concrete mixtures. Up to an ideal replacement level of at least 20%, the results reveal that GGI enhanced the mechanical properties of concrete, specifically its CS and surface hardness. With a rebound hammer value of 44 after 28 days, a CS of 52.5 MPa, a STS of 3.85 MPa, and a FS of 7.60 MPa, the M2 mix (20% GGIFS) performed the best. The mechanical property improvements in concrete are ascribed to the pozzolanic activity and smaller particle size of GGIFS that formed a denser micro structure and increased bonding in the concrete. However, after 30% replacement there was a progressive decrease in mechanical properties due to dilution of the cement and subsequent drop in strength and durability.

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