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Enhancing Concrete Performance With GGBFS: An Analysis of Strength Characteristics at Various Replacement Levels

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Abstract

This study investigates the effect of ground-granulated blast furnace slag (GGBFS) as a partial replacement for cement on the mechanical properties of concrete. The primary objective was to assess the compressive, flexural, and split tensile strengths, along with the modulus of elasticity, at different replacement levels of cement with GGBFS and at distinct curing ages of 7, 28, and 56 days. Concrete mixes were prepared by replacing cement with GGBFS at levels of 40%, 50%, 60%, and 70%, and their performance was compared to that of a control mix with no GGBFS.The results indicate that increasing the GGBFS content generally leads to a reduction in compressive strength, particularly at higher replacement levels such as 60% and 70%. However, the mix with 40% GGBFS demonstrated a marginal improvement in compressive strength compared to the control mix, particularly at the later ages of 28 and 56 days. Among all the replacement levels, the mix with 50% GGBFS exhibited superior performance. It achieved the highest split tensile strength across all curing periods and the maximum flexural strength at 28 and 56 days, indicating its effectiveness in enhancing tensile and flexural properties. Additionally, the modulus of elasticity also showed a slight increase for the 50% GGBFS mix when compared to the control mix, further confirming its enhanced stiffness and durability. These findings suggest that replacing up to 50% of cement with GGBFS not only reduces the dependence on traditional cement but also improves key mechanical properties of concrete. This makes it a sustainable and effective alternative for various construction applications. The research underscores the potential of GGBFS as a supplementary cementitious material, striking a balance between strength and sustainability in modern concrete production.

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Keywords: GGBFS, cement replacement, concrete strength, durability, pozzolanic materials

INTRODUCTION

The most common type of concrete is largely used construction material, valued to be able to be engineering it for developing enhanced strength, improved flexural properties, better workability, and improved durability. It is assembled from dried cement paste and aggregates of different sizes; hence, it is often subject to a number of inherent problems, such as micro-cracks and porosity. However, these can be mitigated by incorporating GGBS into the mix. Historically, the trend was to consume as much cement as possible in the concrete, but the trend is now changing towards reducing the cement content in concrete using mineral admixtures. More important is that, in developing nations, energy resources are always scarce and production of materials like cement requires huge energy that produces huge CO2 emissions of the order of around 0.82 tons per ton of cement. In the world, the cement industry alone is accountable for more than 10% of greenhouse gas emissions. Most of these gases can be reduced by minimizing the use of cement through replacement with suitable pozzolanic materials like GGBS. [1,2,5].

Melting iron slag in steam or water, then drying and grinding it into a fine powder, is the process used to make GGBS. The fineness and amount of reactive glass in GGBS determine the cementitious or pozzolanic effectiveness in concrete composites. GGBS is latent hydraulic substance that combines with water to create a C-S-H gel, which is accelerated by calcium hydroxide CaOH produced from the primary hydration of ordinary Portland cement. Concrete composites that use GGBS as single cementitious material are generally termed GGBS concrete, GGBSC. GGBS combines with OPC and other pozzolanic materials to form durable concrete structures. [3,4,6].

Its benefits are well-established realized in Europe and are now being realized in the United States and Asia for its capability to increase the life span of concrete structures from fifty to a hundred years. The use of blended cement, containing GGBS, has grown larger because of the resultant economies in cost, energy savings, environmental, and resource conservation benefits. GGBS is now acknowledged as a substitute for cement that is prized for its special qualities that it imparts to concrete; hence, it is an essential constituent of producing quality slag cement and durable ready-mixed or site-batched concretes. Apart from the technical advantages, GGBS is more economical than OPC, hence lowering the total cost of concrete. [7,10,12].

It is often specified in concrete for offering resistance to sulphate and chloride attacks, and it has virtually replaced SRPC in the marketplace in that it performs better and is cheaper. Roughly 8.2 million tons of blast furnace slag are produced annually in India; its chemical makeup is quite similar to that of cement clinker. GGBS cement has near-white colour, unlike OPC concrete, which is stone grey in colour, thus enabling architects to achieve lighter-coloured, exposed fair-faced concrete finishes without incurring extra cost. [9,11,13].

In addition, the concretes made from GGBS are very much smoother, with less defective surface, and hence the maintenance cost will be less because the fineness of GGBS is less readily adhered to by dirt than OPC concrete. Moreover, it prevents efflorescence, which is composed of calcium carbonate deposits and stains the concrete surface, so this shouldn't happen with GGBS cement. In high-volume GGBS concrete, the varying hydration characteristics of OPC and GGBS cement regulate the strength development, ultimately yielding a higher strength in comparison to OPC concrete. Research shows that GGBS gets stronger over time, reaching twice the strength it had after 28 days after 10 to 12 years. [14,15,16].

GGBFS

Additionally, to lower the cost and increase viscosity of SCC, additional cementitious or inert ingredients such as GGBS, natural pozzolans, and limestone powder are utilized. The most common of these materials is called GGBS, which is made by quenching molten iron slag—a byproduct of making iron and steel—in a blast furnace with water or steam to create a granular product. The material is then dried and ground into a fine powder, which is subsequently used as a cement substitute in concrete. This substitution enhances the concrete's performance, durability, and longevity, contributing to improved structural strength and sustainability. [8,17,20].

Def of GGBFS

As a by-product of iron and steel manufacture, GGBFS stands for "Ground Granulated Blast Furnace Slag" according to the Cement and Concrete Terminology. [18,19].

Scope of The Present Study

Concrete is the costlier and more energy-tier part of concrete. The unit cost of concrete can be reduced by partially replacing cement with Ground Granulated Blast Furnace Slag (GGBS). This substitution not only lowers material costs but also enhances the concrete's durability and sustainability, making it a cost-effective solution for construction projects. The major problems associated with GGBS, from the point of view of an environmentalist, are its disposal, as dumping it as waste material could result in several environmental issues and hazards. The application of GGBS instead of dumping as waste material can be partly practiced on economic grounds as a pozzolana for due to its advantageous properties, which include better sulfate resistance and a decreased need for comparable workability for the same concrete mix, partial replacement of cement is recommended.

Need for Present Study

To investigate the endurance and mechanical characteristics of GGBS concrete with varying mix ratios in terms of its

- Compressive Strength
- Split tensile test
- Flexural test
- Modulus of elasticity

Replacement levels of GGBFS Investigated

The study investigated 40%, 50%, 60%, and 70% replacement levels of Ground Granulated Blast Furnace Slag (GGBFS) in place of cement in concrete mixes.

Concrete Mix Designs Used and Proportions

The abstract does not provide explicit details about the concrete mix designs or how the proportions of the other materials (like aggregates and water) were adjusted when GGBFS was introduced. Typically, when GGBFS replaces cement, the water-to-binder ratio and aggregate quantities may be adjusted, but this information would need to be sourced from the full study.

Durability Assessments

The abstract does not mention any assessments related to the durability of GGBFS-enhanced concrete, such as resistance to sulfate attack or permeability. The focus of the study appears to be on the mechanical strengths (compressive, tensile, flexural) and modulus of elasticity.

Microstructural Analysis

The abstract does not indicate whether any microstructural analysis, such as Scanning Electron Microscopy (SEM) or X-Ray Diffraction (XRD), was conducted to understand the effects of GGBFS on the concrete at a microscopic level.

LITERATURE REVIEW

GGBS has gained significant attention as an additional cementitious substance (SCM) in concrete production due to its potential to enhance both Concrete's durability and mechanical qualities. This review discusses the findings of numerous investigations into the application of GGBS in concrete.

There is a lot of study on the use of GGBS in concrete for its impact on durability. Bouikni et al. [3] investigated concrete's long-lasting qualities containing 50% and 65% slag, concluding that the inclusion of GGBS significantly improves the resistance to aggressive environments, such as those involving sulfate attack. Similarly, Osborne [14] highlighted the enhanced durability of Portland blast-furnace slag cement concrete, particularly in terms of resistance to chloride ion penetration, which is critical for preventing steel reinforcement corrosion.

The effect of GGBS on concrete's strength under compression has also been thoroughly investigated. An experimental study was carried out by Oner and Akyuz [10] to find the ideal GGBS content for optimum compressive strength. According to their research, the right amount of replacement GGBS varies based on the particular mix design and curing circumstances. Lübeck et al.'s [12] investigation of the electrical characteristics and compressive strength of concrete containing GGBS and white Portland cement revealed that the addition of GGBS not only increases strength but also improves electrical properties, indicating improved durability.

The result of GGBS on the bleeding characteristics of concrete was studied by Wainwright and Rey [6]. They discovered that the inclusion of GGBS reduces the bleeding of concrete, especially when Delays occur in the addition of GGBS during mixing. This discovery holds significant relevance in exceptionally well concrete applications where stability and workability are paramount.

Research has increasingly focused on the role of Ground Granulated Blast Furnace Slag (GGBS) in creating sustainable concrete, particularly in its ability to reduce the environmental impact of concrete production. By partially replacing traditional cement with GGBS, the carbon footprint of concrete is significantly lowered, as GGBS is a byproduct of the steel industry and requires less energy-intensive processing compared to cement. This not only conserves natural resources but also reduces CO_2 emissions, aligning with global sustainability goals while enhancing the long-term durability and performance of concrete. Berndt [8] looked into the features of environmentally friendly concrete that contains fly ash, slag, and recycled concrete material. He found that adding GGBS enhances the qualities of the concrete and lowers the need for Portland cement, which promotes sustainability. The circular economy and sustainable construction concepts are in line with the use of industrial by-products like GGBS.

The pozzolanic activity of GGBS and its contribution to the long-term strength development of concrete has been examined by numerous researchers. Hwang and Lin [19] investigated the strength development of mortars made with blended blast furnace slag and cement, revealing that the pozzolanic reactions between GGBS and calcium hydroxide contribute significantly to the evolution of long-term strength. The pozzolans' effectiveness in cement composites was further explored by Babu et al. [20], who demonstrated that the incorporation of pozzolanic materials such as GGBS leads to enhanced strength and durability properties.

The adoption of GGBS within concrete is supported by various standards and guidelines. The Indian Standards Bureau (BIS) has provided detailed specifications and testing methods for concrete containing GGBS [15,16,21,22,23]. These standards ensure that GGBS is utilized effectively to achieve the desired properties in concrete, such as improved strength, durability, and resistance to chemical attacks. By adhering to established guidelines, the appropriate proportion of GGBS can be incorporated into the concrete mix, optimizing its performance while ensuring consistency, quality, and compliance with environmental and structural requirements. This careful regulation also helps in maximizing the sustainability benefits of GGBS, contributing to the production of high-performance concrete. Additionally, the American Concrete Institute (ACI) has published guidelines on the addition of GGBS to concrete as a cementitious ingredient [4], which serve as a valuable resource for engineers and researchers.

TESTING OF MATERIALS USED

This section deals with the testing of materials to identify the physical properties of fine aggregate, coarse aggregate, and cement and GGBFS.

Testing For Cement

1. Initial setting time
2. Final setting time
3. Specific gravity of cement

Initial setting time

To establish a time trial, the initial setting time test is conducted using the Vicat apparatus, as shown in Figure. Begin by measuring out 500g of a cement sample and mix it with 0.85 times the amount of water required for standard consistency cement paste. The paste should be prepared and placed into the

Vicat mold within 3 to 5 minutes, following the device's instructions. Start the stopwatch immediately when water is added to the cement. The test and water temperatures should be maintained within 27ºC ± 2ºC. Gradually lower the needle until it contacts the surface of the paste in the Vicat mold, then release it quickly. Allow the needle to penetrate the paste. Over time, as the paste begins to lose its plasticity, the needle will penetrate less deeply, reaching only 33-35 mm from the top of the Mold. The initial setting time is recorded as the time elapsed from the moment water is added to the cement until the needle penetrates to a depth of 33-35 mm from the surface of the test block.

Final setting time

Change the Vicat apparatus's needle with a circular one attachment. The cement will be considered ultimately set when the circular cutting edge of the attachment fails to leave an impression on the test block's surface, but the centre needle does once the attachment is gradually lowered to cover it. Stated differently, the paste should not exceed 0.5 mm.

Specific gravity of cement

Aseptically dry the flask and fill it with kerosene or naphtha up to a point on the stem between the zero- and 1-ml marks. Record the amount of liquid in the flask as the initial reading (V1). Next, add a measured amount of cement to the flask, ensuring that the level of kerosene rises to the 22 ml mark. Care should be taken to prevent splashing and to ensure that no cement adheres to the exterior of the flask above the liquid.

After all the cement has been added, gently roll the flask in an inclined position to release any trapped air bubbles. Continue until no further air bubbles appear on the surface of the liquid. Record the new liquid level as the final reading (V2).

The following calculations can then be made:

- Weight of cement used = W g
- Initial reading of flask = V1 ml
- Final reading of flask = V2 ml
- Volume of cement particles = V2 - V1 ml
- Weight of equal volume of water = (V2 - V1) × specific weight of water
- Specific gravity of cement = Weight of cement / Weight of an equal volume of water
- = $W / (V_2 - V_1)$

Coarse Aggregate Tests

1. Specific gravity
2. Fineness modulus

Coarse aggregate's specific gravity

The Indian standard specification IS: 386 (part III) - 1963 gives the various procedures to find out the particular seriousness of different sizes of aggregates. The subsequent process is used to find the specific gravity of sizes larger than 10 mm.

An aggregate sample weighing no less than 2 kg is taken and thoroughly washed to remove any finer particles and dust adhering to the aggregates. This cleaning process ensures the removal of impurities that may affect the accuracy of subsequent tests or the quality of the concrete mix. After washing, the sample is typically dried or used as required for further analysis. After that, it is put in a wire basket and submerged in distilled water that is between less than 22º to 33ºc. Immediately after immersion, by raising the basket holding the sample, the trapped air is released to a point only 25 mm above the tank's base and allowing it to descend 25 times at the practical pace of roughly one drops every second. During the operation, it is ensured that the basket and aggregate should remain fully submerged in water. They are, on average, immersed in water for 24 ± 1/2 hours after which. The bucket and aggregates is vibrated and weighed (weight A1) in water that's been heated to 22ºc. to 33ºc. After being taken out of the water, the basket and the aggregate drained for some minutes, and after being removed from the basket, the aggregates are placed on dry cloth. diffusely surface-dried with the cloth. Finally, after being gently moved to the second dry cloth, the aggregate is dried even more. The water is submerged in the empty basket again and shaken 25 times, after which the basket is weighed in water again (A2 weight). Next, the aggregate is spread out in an even layer and exposed to the atmosphere, out of the direct sunlight, for not less than 10 min until it appears completely surface dry. Then, the aggregate is weighed separately in air and then water; that is, the weight is determined in water by soaking the dry saturated surface-dry sample in water for a time until all visible bubbles escape and then weighing the aggregate while in water. The aggregate is then maintained at a temperature of 100°C to 110°C for a period of 24 ± 0.5 hours to ensure complete drying. After this, the aggregate is allowed to cool in an airtight container to prevent moisture absorption from the surrounding air. Once cooled, the aggregate is weighed again to obtain its dry weight.

The specific gravity of the aggregate is calculated using the following formula:

Specific Gravity=$C/B-A$

Where:

A = Weight (in grams) of the water-saturated aggregate (A1 - A2)

B = Weight (in grams) of the saturated surface-dry aggregate in air

C = Weight (in grams) of the oven-dried aggregate in air

Fineness modulus of coarse aggregate

Aggregate grading is typically arranged so that the consecutive sieve openings are progressively doubled, such as 10 mm, 20 mm, 40 mm, and so on. The aggregates used in concrete production are typically of maximum sizes of 80 mm, 40 mm, 20 mm, 10 mm, and 4.75 mm.

The combined aggregate fraction ranging from 80 mm to 4.75 mm is classified as coarse aggregate.

The grading of a coarse aggregate sample is determined by sieving it through a series of sieves arranged in descending order of size, with the largest sieve placed at the top.

The material retained on each sieve after shaking represents the fraction of aggregate that is coarser than the specific sieve and finer than the sieve immediately above it.

Sieving can be performed either mechanically or manually, depending on the requirements of the test.

Calculation

Fineness modulus = (cumulative % retained) / 100

Testing For Fine Aggregate

1. Specific gravity
2. Fineness modulus

Fine aggregate's specific gravity

Take a sample weighing approximately 500g and place it in a pycnometer. Fill the pycnometer with distilled water until it is completely full. To release any trapped air, gently rotate the pycnometer while covering the small hole at the apex of the cone with your finger. Once all air is removed, carefully wipe the outer surface of the pycnometer and record its weight (W).

Next, empty the contents of the pycnometer into a tray, ensuring all aggregate is transferred. Refill the pycnometer with fresh distilled water to the same level as before and measure its weight again (W1).

To remove excess water from the sample, use suction through filter paper. Place the sample in an oven on a tray at a temperature of 100°C to 110°C for 24 ± 0.5 hours, stirring occasionally to ensure even drying. After the drying period, allow the sample to cool and record its final weight (W2).

Calculation

Apparent specific gravity = (weight of dry sample/weight of equal volume of water)

$= W_2 / (W_2 - (W - W_2))$

Fineness modulus of fine aggregate

- *Aggregate grading*: The grading of aggregates is typically arranged so that consecutive sieve openings are progressively doubled, such as 10 mm, 20 mm, 40 mm, etc. In concrete production, aggregates are commonly available in maximum sizes of 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 600 microns, 300 microns, and 150 microns.
- *Coarse aggregate*: This refers to the aggregate fraction with particle sizes ranging from 4.75 mm to 150 microns.
- *Grading pattern:* The grading pattern of a coarse aggregate sample is determined by sieving the sample through a series of sieves, arranged in descending order of size with the largest sieve on top. The materials retained on each sieve after shaking represent the fraction of the aggregate that is coarser than the sieve in question and finer than the sieve above it. Sieving can be carried out either mechanically or manually.

Calculation

Fineness modulus = (cumulative % retained) / 10

MATERIAL PROPERTIES AND MIX PROPORTIONS

The numerous components utilized in the project work and their characteristics are listed in the information that follows.

Cement

OPC 53 grade) in line with IS: 12269-1987 reaffirmed in 2004 was used. The first setting time complies with IS: 65 minutes and the last time to set is 255 minutes

In the current investigation, a specific gravity of 3.18 and a fineness of 2800 cm^2/g were used. These parameters provide key information about the density and particle size distribution of the material, which are crucial for assessing its suitability and performance in concrete applications.

Coarse Aggregate

In the current investigation, angular granite of 20 mm size with a specific gravity of 2.66 and a fineness modulus of 7.66 was used.

Fine Aggregate

Well-graded river sand conforming to zone-III with specific gravity 2.61 and fineness modulus 2.57 was used. The examination was conducted in accordance with IS:383-1970 reaffirmed in 1997.

GGBS

GGBFS is a mineral admixture having pozzolanic property. The GGBFS used in Vizag Steel plant Visakhapatnam (Andhra Pradesh) and conformed to BS: 6699–1992 as shown in Table-1and Figure1.

Concrete Mix design

ACI mix design

The fine aggregate's specific gravity = 2.61 coarse aggregate's specific gravity = 2.66

(a) $f_m = f_{min} + ks$
= 40 + 1.65×5.7
= 49.4 N/mm^2
(b) Since OPC is used, the estimated w/c ratio is 0.40
(c) For a slump of 50 mm, 12.5 max size of aggregate

The mixing water content is 200 kg/m^3

Approximate entrapped air content = 2 %
(d) Required Cement content = 200/0.40
= 500 kg/m^3
(e) Weight of coarse aggregate = 1600×0.565
= 904 kg/m^3
(f) Weight of fine aggregate = 2400-500-200-904
= 796 kg/m^3

Table 1. Chemical properties of GGBS.

S N.	Chemical characteristics	% of Composition
1.	Magnesium Oxide	8.78
2.	Sulphur Content	0.41
3.	Sulphide Sulphur	0.48
4.	Loss on Ignition	0.68
5.	Insoluble Residue	0.48
6.	Chloride	0.014
7.	Moisture Content	0.40
8.	Manganese Content	0.20
9.	Glass content	93.00
10.	Chemical Moduli	
	a) $CaO + Mgo + SiO_2$	77.84
	b) $(CaO + Mgo)/ SiO_2$	1.31
	c) CaO / SiO_2	1.10


Figure 1. Pictorial representation of GGBS

Table 2 Mix proportion.

W/C	Binder (cement + GGBS)	Fine aggregate	Coarse aggregate
0.40	1.00	1.59	1.80

Table 3. Details of different mixes.

Mix ID	OPC content	GGBS content
G0	100%	-
G1	60%	40%
G2	50%	50%
G3	40%	60%
G4	30%	70%

Table 4. Dimensions of the specimens (mm).

Cubes	150×150×150
Cylinders	150×300
Prisms	500×100×100

Below Table 2 and Table 3 shows the mix proportions and details of mixes

Mixing, Compacting and Curing

A tilting-type rotary drum mixer is used for mixing concrete ingredients. Begin by switching on the rotary drum mixer. Add all the ingredients, including coarse aggregate, fine aggregate, binder materials such as cement and fly ash, into the mixer. Then, during the rotation, add water mixed with a superplasticizer solution. For the first minute of mixing, add 80% of the total water. After one minute, add the remaining water along with any fibers, and continue mixing for an additional two minutes. Each specimen is then placed in standard molds conforming to IS: 10086-1982 and vibrated on a standard vibrating table to ensure uniform compaction and consistency. Immediately after completion of mixing process After pouring concrete into the tightened moulds to a depth of five centimetre's, they were left to vibrate. After a few seconds, the concrete in the mould compacts, forming a second layer of five centimeters. Concrete was poured into the mould to allow for compaction on the vibrating table. After the uppermost layer was compacted, the concrete was smoothed out using a trowel, and the cast specimens were taken out by de-moulding and kept in the curing tank until testing. This procedure was carried out a day later as shown below Table 4.

EXPERIMENTAL PROCEDURE

Compressive strength Test

In order to calculate compressive strength over the course of 7, 28, and 56 days, three cubes are tested on average for each mix. After 28 days in the curing tank, the cubes are taken out and placed on the compressive testing machine's bearing surface. The centre of thrust of the spherically seated platen was precisely aligned with the specimen's axis. The spherically seated block was applied to the specimen, and the movable portion was carefully adjusted by hand to ensure uniform seating.

Weight was then applied gradually and without shock, increasing at a rate of approximately 140 kg/cm² per minute. The load was continuously increased until the specimen could no longer withstand the rising pressure and failed to support any additional load.[22] as shown in Figure 2

Calculation

The closest N/mm2 can be used to express the specimen's equivalent cube strength by dividing the greatest load by the area of contact with the bearing plates and results shown in Table 5and Figure 6 and 7.

Figure 2. Compression strength test

Split tensile strength Test

Shims and/or loaders should be carefully placed along the top and bottom of the specimen loading plane when the specimen is placed in a centering fixture. With the specimen in the center, place the fixture in the machine. For cubic specimens, apply the load to the formed surface so that the fracture plane intersects the smooth surface. For cylindrical specimens, it is crucial to ensure that the top plate is perfectly parallel to the bottom plate. This alignment is essential for accurate and consistent testing results, as any misalignment can affect the load distribution and overall performance of the specimen during testing. Apply the load without impact and increase continuously at a nominal rate of 1.2 N/mm2/min to 2.4 N/mm2/min. Once set, the rate is held constant until failure. Record the maximum applied load.[23] as shown in Figure 3

Calculation

The measured splitting tensile strength (fc) of the specimen will be calculated using the following formula, to the nearest 0.05 N/mm2. And results shown in Table 6 and Figure 8 and 9.

$F_c = 2P/ (\pi \times L \times D)$

Where,

P = max load in Newton's applied to the specimen
L = he specimen's length (in mm) and
D = measurement of the specimen's cross section (in mm).

Figure 3. Split tensile strength test.

Flexural strength Test

There is a 100 x 100 x 500 mm beam used. Before testing the beam, the running surfaces of the loading and supporting rollers must be completely cleaned, and any loose sand or other debris that comes into contact with the rollers on the specimen's surface must be removed. The specimen needs to be placed inside the machine so that the force applied to the mould's top surface is distributed between two lines that are 20.0 and 13.3 cm apart, respectively. The axes of the specimen and the loading device are exactly lined up. Filler material cannot be inserted between the specimen's running surface and the rollers. At a pace that increases the load steadily, the ultimate fiber tension is raised as shown in Figure 4.

Calculation

The modulus of rupture (fbf_bfb), representing the flexural strength of the specimen, can be calculated to the nearest 0.5 kg/cm² using the following formula: When '*a*' it's more than 13.3 cm for a sample that is 10.0 cm in size and results show in Table 7 and Figure 10

$f_b = PL/bd^2$

When 'a' is larger than 11.0 cm but less than 13.3 cm for a specimen that measures 10.0 cm.

,$f_b = 3Pa/bd^2$

where

b = measured specimen width in centimetres,
d = measured the specimen's depth in centimetres at the failure point,
L = length in centimetres of the span that supported the specimen, and
P = maximum weight applied to the specimen in kilograms.

Test for Elasticity Modulus

The three test specimens were tested, and the average compressive strengths were recorded. Soon after the cylinder was removed from the water and while it was still wet, extensometers were fastened to its ends, or on opposing sides and parallel to its axis. This made guaranteed that the gauge points were always halfway between the specimen's diameter and width and that they were symmetrical around its centre. Each end of the extensometer was used to set the recording points. Immediately after being carefully centered, the specimen was placed inside the testing deviceA stress of (C + 5) kg/sq. cm was regularly reached by applying weight without causing any shocks, with C representing one-third of the cubes' average compressive strength, measured to the nearest 5 kg/sq. cm. Up to 140 kg/sq. cm/min of shock is administered. A stress of (C + 1.5) kg/sq. cm was the average stress that was attained after applying the load once again at the same pace as the extensometer measurements were taken. After maintaining the stress at a certain level for at least one minute, it is then reduced to an average of 1.5 kg/cm². While maintaining this constant load, obtain extensometer readings to monitor any deformation or strain. Next, take readings at 1.5 kg/cm² while gradually reducing the load. Extensometer values should also be recorded approximately ten minutes after the load is reapplied. Continue taking readings as the stress is increased in equal steps up to an average stress of C+1.5C + 1.5C+1.5 kg/cm². Ensure that readings are taken as promptly as possible at each loading stage to accurately capture the material's response to changing stresses. The loading cycle will continue until the variation in strain between successive readings, at, does not surpass 5%, provided that the overall strains, which are measured on the second and third readings at different, are maintained [21].

Calculation

For each extensometer, the elongations at the different loads for the previous two cycles were computed, and the values were shown on a stress scale. For each extensometer, the plotted values of the two cycles were divided into straight lines. The average value was calculated by taking the slope of these two lines. If there was a discrepancy between the individual measurements, it was rounded to the nearest 1000 kg/sq cm and the average value was used as the concrete's modulus of elasticity.

Otherwise, the difference was higher than 15% of the average value. If the difference is more than 15%, the specimen needs to be repositioned in the testing device and the test needs to be redone. If after re-centering and testing the discrepancy persisted to be greater than 15% of the average value, the test results were ignored as shown in figure 5 and results shown in Table 8 and Figure 11.

Figure 4. Flexural strength test.

Figure 5. Test for elasticity modulus.

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RESULTS AND DISCUSSION

Discussion on Test Results

Test of strength during compression

Referring to Table 6, the compressive strength of the concrete mix after seven days when GGBS was utilized, G1 with 40% of GGBS and 50% of GGBS in mix G2, was lower than the degree of citation strength concrete mix—G0—by up to 19.14% and 8.67%, respectively. The compressive strength mixtures of the material include the increases range from 2% to 6% when comparing the G3 and G4 concrete mixes to the G0 control mix. It is evident that the compressive strength of concrete mix G3 is nearly identical to that of the control mix, concrete mix G0. Figure 6 illustrates the compressive strength of concrete mixtures G1 at 28 days. It is only slightly greater than the control group mix G0, and lower than the reference concrete mix for the other mixes, G2, G3, and G4. It implies that, in comparison to the other mixtures, there is a slight enhancement with 40% GGBS mix at ages 7 and 28 days. The results are shown in Table 7 and indicate that, at 56 days of age, the concrete mix G1 has risen by 6% in comparison to the reference concrete mix G0.

Table 5. Test results strength of compression (MPa).

Mix designation	7 Days	28 Days	56 Days
G0	28.5	51.0	58.2
G1	24	53.50	59.3
G2	26.2	48.66	51.3
G3	29.0	45.91	49.8
G4	30	43.2	47.4

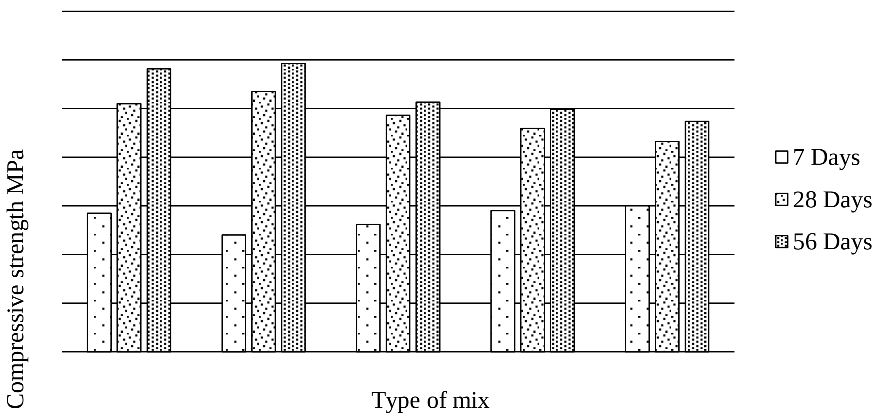

Figure. 6. Results of strength of compression.

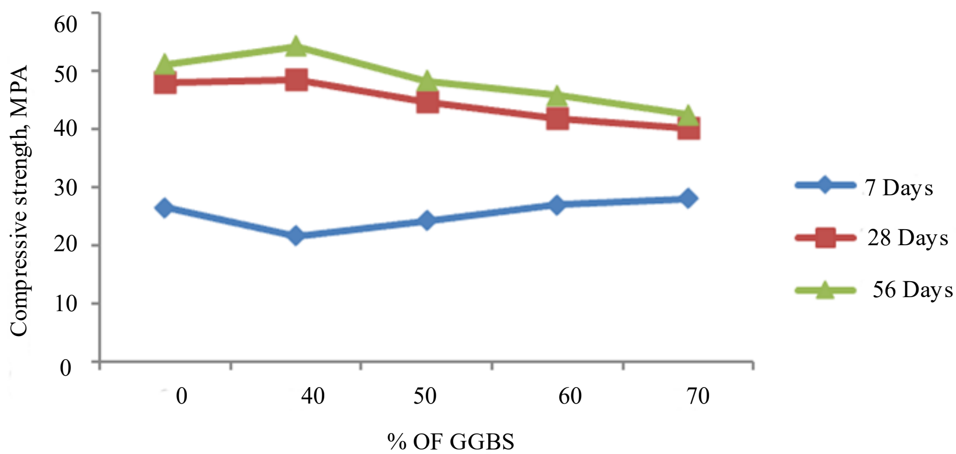

Figure 7. Results strength of compression.

Table 6. Test for Split Tensile Strength results (MPa).

Mix designation	7 Days	28 Days	56 Days
G0	3.56	5.1	5.24
G1	4.45	5.5	5.64
G2	4.69	5.85	5.91
G3	3.52	5.6	5.75
G4	2.89	5.2	5.31

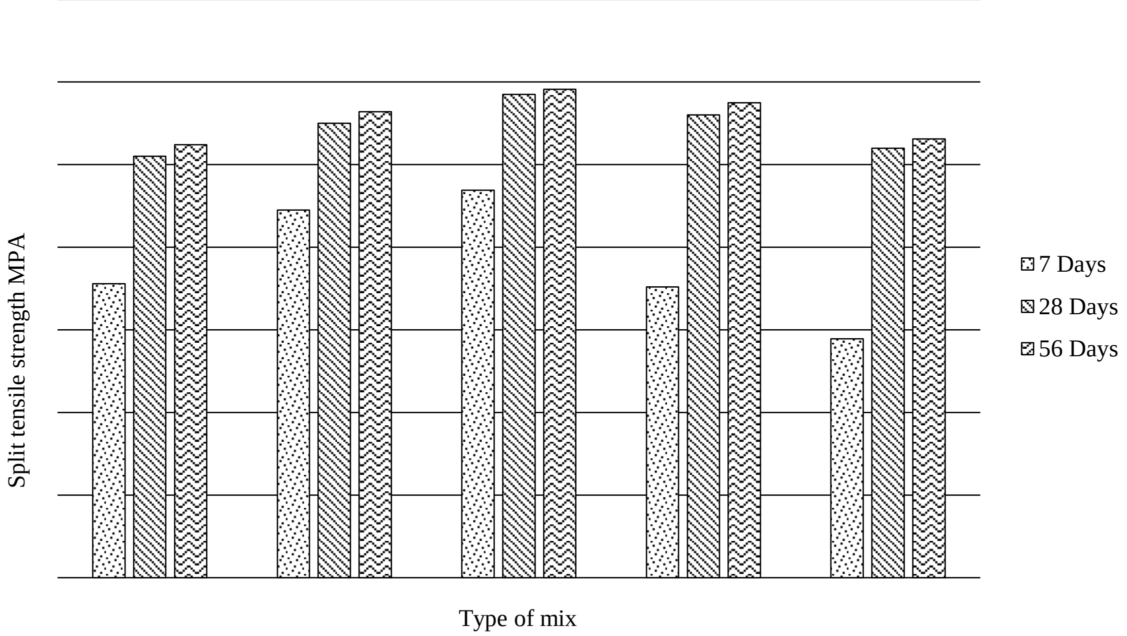

Figure 8. Results of tensile strength split.

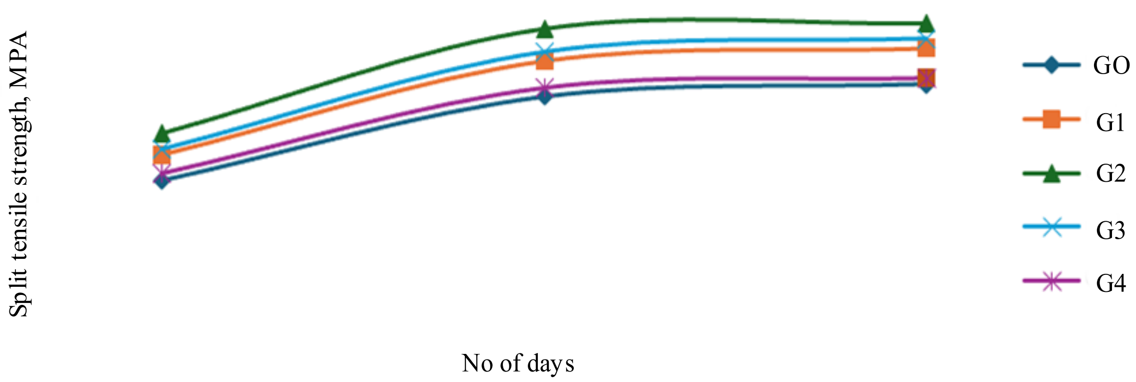

Figure 9. Results of tensile strength split.

Table 7. Flexural strength test results (MPa).

Mix designation	28 Days	56 Days
G0	6.21	6.24
G1	6.42	6.53
G2	6.80	6.91
G3	6.91	6.98
G4	6.62	6.71

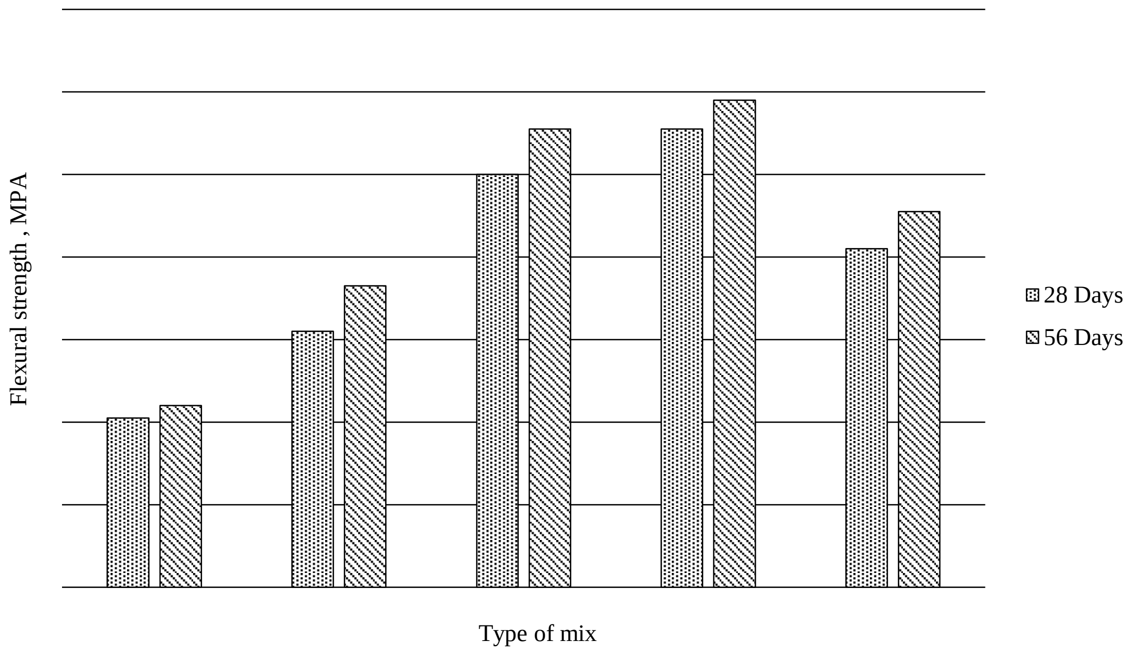

Figure 10. Flexural strength for 28 days and 56 days.

Table 8. Test results for Modulus of Elasticity (GPa).

Mix designation	28 Days	56 Days
G0	43.6	45.1
G1	44.2	45.7
G2	47.1	48.2
G3	46.3	47.3
G4	44.4	45.4

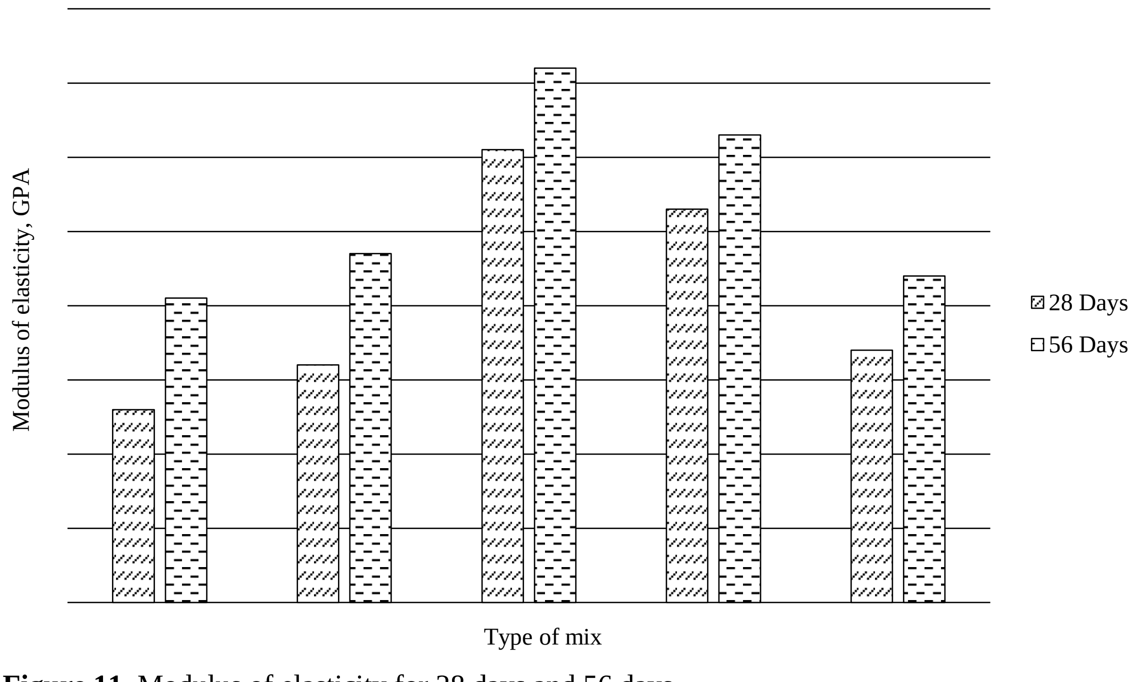

Figure.11. Modulus of elasticity for 28 days and 56 days.

Figure 12. Tested specimens

Tested Specimen's Figures Shown Below at Figure12.

The compressive strengths of the concrete mixes were as follows:

- Mix G2 exhibited a compressive strength that was 5.6% lower than that of the control mix G0.
- Mix G3 had a compressive strength that was 10.5% lower than G0.
- Mix G4 showed a compressive strength that was 17.2% lower than G0.

The data show that a 40% GGBS mix in the reference mix can only marginally improve the problem at 7 and 28 days of age.

Test for split tensile strength

Table 7, the spilt tensile strengths between the concrete mixtures at days 7, 28, and 56 are presented. From Table 7, it is revealed that the concrete's split tensile strength mixes G1 and G2, to reference concrete mix G0, which contains 40% and 50% of GGBS, respectively, increased to 10% and 24%. For concrete mixes:

- G3 exhibited a 16% increase in split tensile strength compared to the control mix G0.
- G4 showed a 3.5% increase in split tensile strength relative to G0.

After seven days, the results of all mixes incorporating GGBS are better than those of the conventional reference concrete. For concrete mixes G1, G2, G3, and G4, the gains in breaking strength at 28 days were 13%, 24.2%, 17%, and 3.5%, respectively, in contrast with the reference concrete mix G0. This suggests that concrete mixes containing GGBS are outperforming regular concrete at 28 days. The tensile strength of the split concrete mixtures after 56 days is shown in Table 6. According to Table 7, the G1 and G2 concrete mixes, which had GGBS contents of 40% and 50%, respectively, increased in split tensile strength by 12.5% and 21% when compared to the G0 reference mix. Comparing concrete mixes: G3 showed a 16% increase in split tensile strength compared to the control mix G0.G4 exhibited a 2.5% increase in split tensile strength relative to G0. After 56 days, all the mixes including GGBS were stronger than ordinary concrete.

Flexural strength test

The bending strengths of the concrete mixes after 28 and 56 days are shown in Table 7. According to Table 8, after 28 days, the flexural strength of the concrete has risen by 5% and 14%, respectively, compared to the reference concrete mix G0 mixes, which comprise 40% and 50% GGBS, G1 and G2, respectively. Mixes G3 and G4 showed a 17% and 10% increase in split tensile strength when compared to control mix G0. After 28 days, all GGBS mixtures outperform conventional concrete in terms of performance. Table 8 In comparison to the control concrete mix, it is noted that the flexural strength of concrete mixes G1, G2, G3, and G4 has grown by 7%, 16%, 17.5%, and 11%, respectively, at 56 days. When the behavior of the GGBS mixtures at 56 days is compared to that of the control concrete, more favorable results are observed.

Modulus of Elasticity test

Table 8 Modulus of elasticity for concrete mixes, 28 and 56 days From Table 8, it is shown that the concretes G1 and G2, with 40% and 50% GGBS, respectively, showed at 28 days an increase of modulus of elasticity, of 2.6% and 15% higher with respect to the G0 reference concrete mix. In comparison to the plain concrete mix G0, mixtures of concrete G3 and G4 showed an increase in the elasticity modulus by 12% and 4%, respectively. At the 28-day period, all the GGBS mixes are showing improving results in contrast to traditional concrete. In comparison to Table 8, the modulus of elasticity of the G1, G2, G3, and G4 concrete mixtures increases by 2%, 12.5%, 9%, and 3%, respectively, after 56 days. G0 can be interpreted as controlling the mixing of concrete. More favorable outcomes are attained when the performance of GGBS mixtures at 56 days of age differs from that of regular concrete.

CONCLUSIONS

- *Compressive strength*: After 28 days, the compressive strength of GGBFS-based concrete mixes generally decreases as the GGBFS content increases. However, the concrete mix with a 40% GGBFS replacement level shows a slight increase in compressive strength compared to the control mix at both 28 and 56 days.
- *Split tensile strength*: The concrete mix with a 50% GGBFS replacement level exhibits improved split tensile strength at all ages (7, 28, and 56 days) compared to the control mix and other GGBFS mixes.
- *Flexural strength*: Mix G3 demonstrates higher flexural strength compared to other mixes after 28 and 56 days.
- *Modulus of Elasticity*: The modulus of elasticity increases marginally in the G2 mix compared to the control mix.
- *Overall strength:* The concrete mix with 50% GGBFS replacement shows superior strength compared to other mixes, indicating that up to 50% GGBFS can be effectively used to achieve desirable strength properties.

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