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Strength Properties of Concrete with Ground Granulated Blast Furnace Slag (GGBS) as Partial Cement Replacement

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Abstract: *Construction industry consumes a huge volume of concrete every year, and it is expected that it demand may increase soon. Concrete is one of the most widely used construction materials; main ingredient of concrete is cement. The demand for concrete as a construction material is on the increase. However, the production and utilization of cement causes pollution to the environment and reduction of raw material (limestone). The production of Portland cement worldwide is increasing annually. The current contribution of greenhouse gas emission from Portland cement production signifies the need for supplementary cementitious material as a supplementary pozzolanic material for concrete. This leads to the intensification of interest towards the utilization of wastes and industrial by products in order to minimize the Portland cement consumption. This paper reviews on the use of GGBS as a partial pozzolanic replacement of cement in concrete. The literature shows that GGBS was found to enhance the properties of concrete at later age subject to replacement level.*

In this report, GGBS will chemically and physically characterized and will be used as partial replacement in the ratio of 0%, 5%, 10%, 15% and 20% by weight of cement in concrete. Fresh concrete tests like Compressive strength, at the age of 7, 14 and 28 days will have been done for M25 grade of concrete. Test results will compared with conventional concrete and Ultimate Concrete for GGBS with different percentages used as partial replacement.

Keywords: Cement, GGBS, Replacement ratio (0–20%), Partial cement replacement, Industrial by-products utilization

I. INTRODUCTION

Concrete remains the most widely used construction material globally, primarily due to its exceptional versatility, strength, durability, and cost-effectiveness. Simplicity in production, and low maintenance compared to timber and steel. It consists of a combination of four major ingredients: fine aggregate, coarse aggregate, binding material and water. Cement has become expensive as the traditional binding material and produces a lot of carbon dioxide (CO_2), which is not favorable for the environment. Likewise, river sand, which is widely utilized as fine aggregate, has become scarce. Its excessive use causes riverbed destruction and decreases the natural recharge of groundwater. To overcome these two issues, there have been attempts to produce concrete with alternative and supplementary materials. Ground Granulated Blast Furnace Slag (GGBS), which is a steel manufacturing by-product, has been utilized to replace a portion of cement. Various mix proportions were proportioned with different amounts of cement, GGBS, coarse aggregate, and water. The fresh and hardened properties of the concrete were examined for all the mixes. From these tests, inferences were made regarding the behavior of the concrete.

Concrete is inherently weak in tension and brittle by nature. The concept of utilizing materials such as Ground Granulated Blast Furnace Slag (GGBS) and quarry stone dust to enhance building materials has been in existence for centuries. Some of the earliest examples are mixing clay bricks, horsehair in plaster, and asbestos in ceramics to add

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strength. Since the development and refinement of reinforced concrete, strength and flexibility (ductility) have both improved. However, achieving these benefits requires careful and skilled placement of the concrete.

Traditionally, the binding material for concrete is cement, but it is now costly and environmentally damaging when it comes to producing it. Therefore, there is an increased necessity for alternative and complementing cementing materials based on cement. Ground Granulated Blast Furnace Slag (GGBS), for example, is one of the materials produced as a by-product of the iron industry. Another potential development is the incorporation of fibres both for reinforced and unreinforced concrete applications. The contemporary fibre-reinforced concrete development commenced the early 1960s.

The incorporation of fibres into concrete can render it more homogenous, uniform, and isotropic. When cracks initiate, the fibres, which are randomly disposed, become active and assist in arresting the formation and extension of cracks. This enhances the material overall strength and ductility of the concrete material. The two principal failure modes are either the degradation of the bond of the fibres within the concrete matrix or the fracture of the fibres themselves. This report provides a state-of-the-art summary of fibre- reinforced concrete and the outcome of experimental tests carried out utilizing available materials within the locality. Ground Granulated Blast Furnace Slag (GGBS) is one of the supplementary cementitious materials that replaces cement partly in concrete. Its price is actually close to half the cost of ordinary cement and thus offers a cheaper alternative. Substitution of cement with GGBS provides great advantages for the quality of concrete both when it is fresh and hardened. An experimental study is required for the assessment of the joint action of GGBS and quarry stone dust on the quality of concrete both under fresh and hardened states.

Need of study

After reviewing extensive literature, it is clear that research is ongoing with incorporate concrete mixes with GGBS.

- It concerns solely the use of GGBS with the goal of sustainable and environmentally friendly production of concrete economically.
- The work studies variable quantities of GGBS for the replacement of cement for an examination of the strength behavior of the concrete

II. EXPERIMENTAL WORK

Concrete Mix Proportioning According to IS 10262:2009

A concrete grade mix design of M25 was conducted following the standards outlined in IS 10262:2009 and IS 456:2000.

Target Mean Compressive Strength (fck')

To ensure that the concrete meets the required characteristic compressive strength (fck) with a high degree of reliability (typically 95%), the target mean strength is calculated using the equation:

$fck = fck + 1.6 \times S$

fck = Characteristic compressive strength = 25 N/mm² (for M25)- S = S.D = 4.00 N/mm² 1.65 = Statistical factor for a 95% confidence level.

Thus, the target mean compressive strength is calculated as:

$fck = 25 + (1.6 \times 4.0) = 31.61$ N/mm²

Water-Cement Ratio (W/C Ratio)

According to IS 456:2000, Table 5, for reinforced concrete in moderate environmental conditions, the maximum water-cement ratio is set at:

Max. W/C Ratio = 0.45

Min. Cement Content = 320 kg/m³

Maximum Cement Content = 450 kg/m³

The selected wc ratio should be equal to or less than 0.45, depending on the required workability, strength, and durability.

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Parameter	Value
Maximum Aggregate Size	20 mm
Maximum Water Content	190 l/m³
Water-Cement Ratio (w/c)	0.450
Cement Content	171 ÷ 0.450 = 380 kg/m³

Step	Description	Calculation	Result
i	Total Concrete	Given	1.000 m³
ii	Cement Volume	(380 ÷ 3.12) × (1 ÷ 1000)	0.121 m³
iii	Water Volume	(190 ÷ 1.0) × (1 ÷ 1000)	0.190 m³
iv	Aggregates Volume	1 – (0.121 + 0.190)	0.689 m³
v	Fine Aggregates (38%)	0.689 × 0.38	0.261 m³
vi	Coarse Aggregates (62%)	0.689 × 0.62	0.427 m³
vii	Fine Aggregates (Sp. Gr. = 2.74)	0.261 × 2.74 × 1000	717 kg
viii	Coarse Aggregates (Sp. Gr. = 2.74)	0.427 × 2.74 × 1000	1171 kg

Concrete Mix Ratio(by Weight)

Cement: Fine Aggregates: Course Aggregates: Water

Material	Quantity (kg/m³)	Normalized Ratio
Cement	380	1.00
Fine Aggregates	717	1.67
Coarse Aggregates	1171	2.60
Water	190	0.45

Mix proportions for cube Casting

Explanation:
To prepare a concrete mix for casting cubes, we first calculate the volume of one mold and then scale it using a correction factor (typically 1.52) to account for dry volume (which includes voids and losses).

Volume Calculation

Parameter	Calculation	Result(m³)
Volume of Cube Mold	0.15×0.15×0.15	**0.003375m³**
Dry Volume Correction Factor	1.52	—
Design Volume for Mix	**1.52×0.003375**	**0.00513m³**

Concrete Mix Design Calculation (100% Cement, 0% GGBS) Assumptions:

- Total concrete volume = 1 m³
- Content Cement = 380 kg/m³
- Content Water = 190 kg/m³
- Specific gravity (S.G) of Cement = 3.15
- Spec.G of Water = 1.0
- S.G of Aggregates = 2.74
- Coarse Aggregate ratio = 62%
- Fine Aggregate ratio = 38%

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Step	Description	Formula /Calculation	Result
A	Concrete	Given	**1.000m³**
B	Cement	380/(3.15×1000)	**.121m³**
C	Water	190/(1×1000)	**.190m³**
D	GGBS	0%GGBSused	**0.000m³**
E	Aggregates Required	1–(B+C+D)=1–(0.121+0.190+0.000)	**0.689m³**
F	Coarse Aggregates(62%)	0.689×0.62×2.74×1000	**1171kg**
G	Fine Aggregates(38%)	0.689×0.38×2.74×1000	**717kg**
H	**GGBS Content**	**Not used**	**0kg**

95% Cement and 5% GGBS Assumptions:

- Content Cement = 361 kg/m³
- Content GGBS = 19 kg/m³
- Content Water = 190 kg/m³
- Specific gravity (S.G.) of Cement = 3.15
- Water Specific gravity = 1.00
- Aggregates Specific gravity = 2.74
- Coarse Aggregate ratio = 62%
- Fine Aggregate ratio = 38%
- Volume of concrete = 1.000 m³

Step	Description	Formula / Calculation	Result
A	Concrete Volume	Given	1.000 m³
B	Cement Volume	361 ÷ (3.15 × 1000)	0.1146 m³
C	Water Volume	190 ÷ (1.00 × 1000)	0.1900 m³
D	GGBS Volume (S.G. = 2.90)	19 ÷ (2.90 × 1000)	0.0066 m³
E	Total Binder Volume (B + D)	0.1146 + 0.0066	0.1212 m³
F	Volume of Aggregates Required	1 – (E + C) = 1 – (0.1212 + 0.1900)	0.6888 m³
G	Coarse Aggregates Mass (62%)	0.6888 × 0.62 × 2.74 × 1000	1171.0 kg
H	Fine Aggregates Mass (38%)	0.6888 × 0.38 × 2.74 × 1000	717.0 kg

Final Mix Proportion

Material	Quantity(kg)
Cement	**361.0**
GGBS	**19.0**
Water	**190.0**
Fine Aggregates	**717.0**
Coarse Aggregates	**1171.0**

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Concrete Mix Design–90% Cement and 10% GGBS Replacement

Assumptions:

- Total concrete volume=1.000m³
- Content Cement=342kg/m³(90%)
- Content GGBS=38kg/m³(10%)
- Content Water=190kg/m³
- Specific Gravity(S.G.)of:
- Cement=3.15
- GGBS=2.90
- Water=1
- Aggregates=2.74
- Fine Aggregate Ratio=38%
- Coarse Aggregate Ratio=62%

Step	Description	Formula/Calculation	Result
A	Concrete Volume	Given	**1.000m³**
B	Cement Volume	342/(3.15×1000)	**0.1086m³**
C	GGBS Volume	38/(2.90×1000)	**0.0131m³**
D	Total of Binders Volume(B+C)	0.1086+0.0131	**0.1217m³**
E	Water Volume	190/(1.00×1000)	**0.1900m³**
F	Aggregates Volume of Required	1.000–(D+E)=1–(0.1217+0.1900)	**0.6883m³**
G	Coarse Aggregates Mass of(62%)	0.6883×0.62×2.74×1000	**1171.0kg**
H	**Fine Aggregates Mass of (38%)**	**0.6883×0.38×2.74×1000**	**717.0kg**

Material	Quantity (kg)
Cement	342.0
GGBS	38.0
Water	190.0
Fine Aggregates	717.0
Coarse Aggregates	1171.0

Concrete Mix Design – 85% Cement and 15% GGBS Assumptions:

- Total concrete volume = 1.000 m³
- Content Cement = 323 kg/m³ (85%)
- Content GGBS = 57 kg/m³ (15%)
- Content Water = 190 kg/m³
- Specific Gravity (S.G.) of:
- Cement = 3.15
- GGBS = 2.90
- Water = 1.00
- Aggregates = 2.74
- Coarse Aggregate Ratio = 62%
- Fine Aggregate Ratio = 38%

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Step	Description	Formula/Calculation	Result
A	Concrete Volume	Given	**1.0000m³**
B	Cement Volume	323/(3.15×1000)	**0.1025m³**
C	GGBS Volume	57/(2.90×1000)	**0.0197m³**
D	Total of Binders Volume(B+C)	0.1025+0.0197	**0.1222m³**
E	Water Volume	190/(1.00×1000)	**0.1900m³**
F	Aggregates Required Volume	1.000–(D+E)=1–(0.1222+0.1900)	**0.6878m³**
G	Coarse Aggregates Mass of(62%)	0.6878×0.62×2.74×1000	**1170.3kg**
H	**Fine Aggregates Mass of(38%)**	**0.6878×0.38×2.74×1000**	**717.1kg**

Material	Quantity (kg)
Cement	323.0
GGBS	57.0
Water	190.0
Fine Aggregates	717.1
Coarse Aggregates	1170.3

Concrete Mix Design – 76 kg GGBS (Cement 80%, GGBS 20%) Assumptions:

- Total concrete volume = 1.000 m³
- Content Cement = 304 kg/m³ (80%)
- Content GGBS = 76 kg/m³ (20%)
- Content Water = 190 kg/m³
- Specific Gravity (S.G.) of:
- Cement = 3.15
- GGBS = 2.90
- Water = 1.00
- Aggregates = 2.74
- Coarse Aggregate Ratio = 62%
- Fine Aggregate Ratio = 38%

Step	Description	Formula/Calculation	Result
A	Concrete Volume	Given	**1.0000m³**
B	Cement Volume	304/(3.15×1000)	**0.0965m³**
C	GGBS Volume	76/(2.90×1000)	**0.0262m³**
D	Total Binders Volume of(B+C)	0.0965+0.0262	**0.1227m³**
E	Water Volume	190/(1.00×1000)	**0.1900m³**
F	Aggregates Volume Required	1.000–(D+E)=1–(0.1227+0.1900)	**0.6873m³**
G	Coarse Aggregates Mass of(62%)	0.6873×0.62×2.74×1000	**1170.4kg**
H	**Fine Aggregates Mass of(38%)**	**0.6873×0.38×2.74×1000**	**717.0kg**

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Material	Quantity (kg)
Cement	304.0
GGBS	76.0
Water	190.0
Fine Aggregates	717.0
Coarse Aggregates	1170.4

Tests on hardened concrete specimens

Slump Test

For each mix Slump test carried and results were examined. Below:-

Mix ID	GGBS Replacement (%)	Slump Value (mm)	Workability Classification
M1	0% (Control mix)	85	Medium workability
M2	5%	90	Medium workability
M3	10%	95	Medium–high workability
M4	15%	100	High workability
M5	20%	105	High workability

Calculation of Compressive Strength:

The **compressive strength (f_{ck})** of each specimen is calculated using the formula: fck=PAf_{ck} = \frac{P}{A}fck=AP

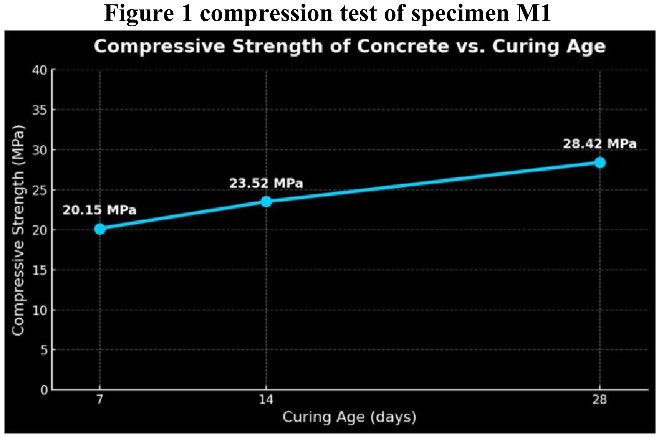
Where:

- fckf_{ck}fck = Compressive strength in **N/mm²** (also expressed as MPa)
- PPP = Maximum load applied in **Newtons (N)**
- AAA = Loaded area of the cube in **mm²** (for 150 mm cubes, A = 150 × 150 = 22,500 mm²)

Compression Test For 100% Cement and 0% GGBS

SAMPLE	07 DAYS	14 DAYS	28 DAYS
M1	**20.15MPA**	**23.52MPA**	**28.42MPA**

Figure 1 compression test of specimen M1



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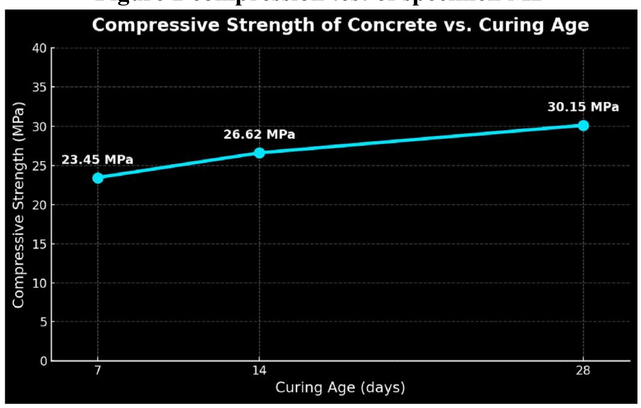
Compression Test For 95% Cement and 5% GGBS

SAMPLE	7 DAYS	14 DAYS	28 DAYS
M2	23.45MPA	26.62MPA	30.15MPA

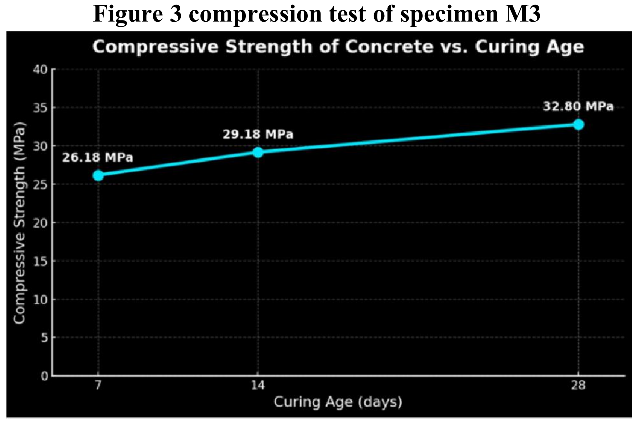
Figure 2 compression test of specimen M2



Compression Test For 90% Cement and 10% GGBS

SAMPLE	7 DAYS	14 DAYS	28 DAYS
M3	26.18MPA	29.18MPA	32.28MPA

Figure 3 compression test of specimen M3



Compression Test For 85% Cement and 15% GGBS

SAMPLE	7 DAYS	14 DAYS	28 DAYS
M4	28.20MPA	31.68MPA	34.19MPA

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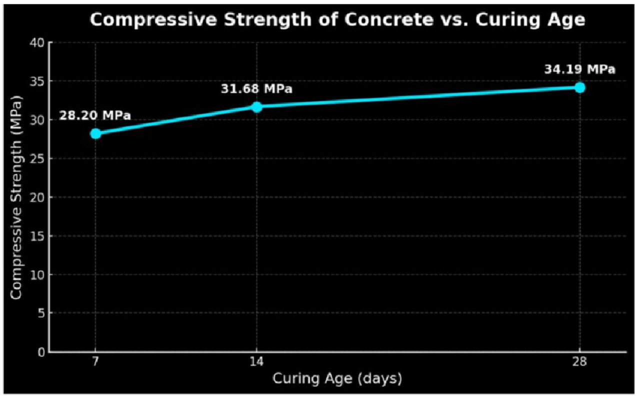
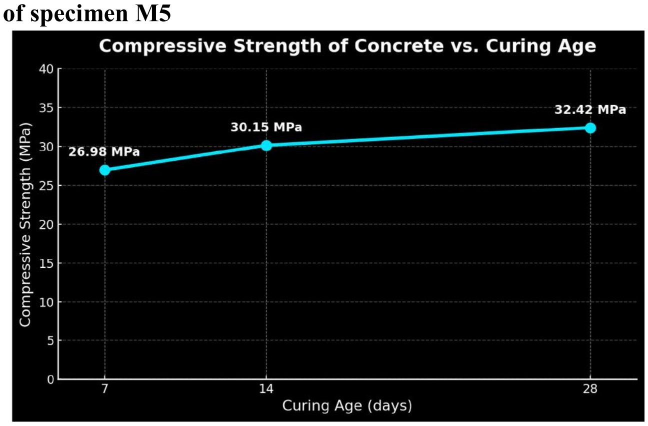
Figure 4 compression test of specimen M4



Compression Test For 80% Cement and 20% GGBS

SAMPLE	7 DAYS	14 DAYS	28 DAYS
M5	26.98MPA	30.15MPA	32..42MPA

Figure 5 compression test of specimen M5



Compression Combined test result at 7, 14 and 28 days

SAMPLE	7 DAYS	14 DAYS	28 DAYS
M1	20.15MPA	23.52MPA	28.42MPA
M2	23.45MPA	26.62MPA	30.15MPA
M3	26.18MPA	29.18MPA	32.28MPA

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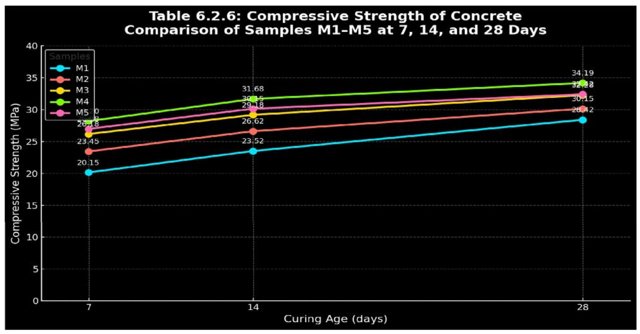
M4	28.20MPA	31.68MPA	**34.19MPA**
M5	**26.98MPA**	**30.15MPA**	**32..42MPA**

Figure 6 comparison of compression test of specimen



II. CONCLUSION

This report discusses a study on using (GGBS) as a partial substitute for cement and quarry stone dust as a partial substitute for fine aggregate in concrete. The aim was to assess how these industrial by-products affect the concrete mechanical properties, especially compressive strength, and to explore their role in promoting sustainable construction practices.

Concrete mixes were created using an M25 grade design mix (Cement: Fine Aggregate: Coarse Aggregate) with a ratio of 1:1:2 and water-cement ratios between 0.4 and 0.6. Different percentages of GGBS were used to replace cement partially, and the outcomes were compared to a control mix with 0% GGBS.

Key Findings:

Concrete compressive strength increased with GGBS up to 15% replacement, after which the strength started to decrease. At a 15% GGBS replacement, the compressive strength improved by about 21.11% after 28 days control mix curing compared to the mix. This strength enhancement is linked to the pozzolanic activity of GGBS, which aids in the long-term strength development of concrete. However, beyond 15%, the dilution effect and reduced cement content may result in lower strength.

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