10.48047/jocaaa.2026.35.06.14

Experimental Study on the Properties of Self-Curing Concrete with PEG-400 as Self-Curing Agent and Cement Replacement by Ground Granulated Blast Furnace Slag (GGBS)

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Abstract

Concrete is widely recognized as the most commonly used material in construction because of its high compressive strength and long-lasting performance. For plain concrete to achieve its required strength, it must be cured under moist conditions for at least 28 days to ensure proper hydration. Neglecting this curing process can significantly reduce both the strength and durability of concrete. Self-curing concrete offers a solution in situations where conventional curing is difficult, such as in regions with water scarcity, remote or inaccessible construction sites, and areas where water containing fluorides adversely impacts concrete properties.

The present study focuses on evaluating the effectiveness of using water-soluble polyethylene glycol (PEG) as a self-curing agent. M25 grade concrete mixes were prepared with cement partially replaced by Ground Granulated Blast Furnace Slag (GGBS) at replacement levels of 10%, 20%, and 30%, along with the addition of 1% PEG. The experimental work investigates compressive strength, split tensile strength, and flexural strength of self-curing concrete, and the optimum performance with GGBS is compared against conventional concrete specimens.

Keywords: Self-Curing Concrete, PEG-400, GGBS, Internal Curing, Compressive Strength, Split Tensile Strength, Flexural Strength, Sustainable Concrete.

I. Introduction

Concrete is one of the most widely used construction materials due to its high strength, durability, and versatility. Proper curing is essential for achieving the desired strength and durability of concrete, as it ensures continuous cement hydration. However, conventional curing requires a sufficient water supply and regular maintenance, which may not be feasible in water-scarce regions or inaccessible construction sites.

Self-curing concrete, also known as internally cured concrete, is an effective solution to overcome the limitations of conventional curing. It incorporates self-curing agents that retain and gradually release water within the concrete, thereby promoting hydration and reducing moisture loss. Polyethylene Glycol (PEG-400) is a commonly used self-curing agent due to its water-retaining capability and ease of application.

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In addition to improving curing efficiency, the use of supplementary cementitious materials such as Ground Granulated Blast Furnace Slag (GGBS) enhances the sustainability of concrete. GGBS is an industrial by-product that can partially replace cement, reducing environmental impact while improving the mechanical and durability properties of concrete.

This study investigates the performance of self-curing concrete incorporating 1% PEG-400 and GGBS as a partial cement replacement at levels of 10%, 20%, and 30%. The mechanical properties, including compressive strength, split tensile strength, and flexural strength, are evaluated and compared with conventional concrete to identify the optimum GGBS replacement level.

1.1 Objectives

- To develop self-curing concrete using PEG-400 as a self-curing agent.
- To partially replace cement with GGBS at 10%, 20%, and 30% replacement levels.
- To evaluate the compressive strength, split tensile strength, and flexural strength of self-curing concrete.
- To compare the performance of self-curing concrete with conventional concrete.
- To determine the optimum percentage of GGBS for improved concrete performance.

1.2 Scope of the Study

- Preparation of M25 grade self-curing concrete mixes using 1% PEG-400.
- Partial replacement of cement with GGBS at different proportions.
- Investigation of fresh and hardened concrete properties.
- Assessment of compressive, split tensile, and flexural strengths at different curing ages.
- Identification of the optimum mix for strength enhancement and sustainable construction.

1.3 Need of the Project

- To overcome the challenges associated with conventional water curing.
- To reduce water consumption in concrete construction.
- To utilize industrial by-products such as GGBS effectively.
- To improve the sustainability and durability of concrete.
- To develop an economical and eco-friendly concrete suitable for water-scarce regions.

1.4 Significance of the Study

- Promotes sustainable construction practices through the utilization of GGBS.
- Reduces dependency on external curing water.
- Enhances the mechanical performance of concrete.
- Contributes to environmental protection by reducing cement consumption.
- Provides an effective alternative for construction in regions facing water scarcity.

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II. Literature Review

Several researchers have investigated the use of self-curing agents and supplementary cementitious materials to improve the performance and sustainability of concrete.

Studies on self-curing concrete have shown that Polyethylene Glycol (PEG) effectively reduces moisture loss and enhances cement hydration, resulting in improved strength and durability compared to inadequately cured concrete. PEG-based self-curing concrete has demonstrated satisfactory compressive, tensile, and flexural strength properties without the need for external curing.

Research on Ground Granulated Blast Furnace Slag (GGBS) indicates that partial replacement of cement with GGBS improves workability, long-term strength, and durability while reducing the environmental impact associated with cement production. The pozzolanic and latent hydraulic properties of GGBS contribute to the formation of additional calcium silicate hydrate (C-S-H) gel, leading to a denser concrete matrix.

Previous studies combining self-curing agents with GGBS have reported positive results in terms of strength development and sustainability. The incorporation of PEG facilitates internal curing, while GGBS enhances the mechanical and durability characteristics of concrete. However, the optimum percentage of GGBS replacement in self-curing concrete varies depending on the mix composition and curing conditions.

Based on the findings of earlier research, the present study investigates the combined effect of 1% PEG-400 and varying percentages of GGBS (10%, 20%, and 30%) on the mechanical properties of M25 grade self-curing concrete and compares the results with conventional concrete.

III. PROPOSED RESEARCH METHODOLOGY

The methodology shows the step-by-step procedure and their detailed explanation about b experimental process and observations are explained

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Figure 3.1: Flow chart of Methodology

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M25 grade self-curing concrete was prepared using 1% PEG-400 as a self-curing agent. Cement was partially replaced with GGBS at replacement levels of 10%, 20%, and 30%. A control mix without GGBS and PEG-400 was also prepared for comparison.

Concrete specimens were cast and tested for compressive strength, split tensile strength, and flexural strength at specified curing ages. The test results were analyzed to evaluate the effect of PEG-400 and GGBS on the mechanical properties of concrete and to determine the optimum GGBS replacement level.

4.1 Mix Design

The mix design for M25 grade self-curing concrete was carried out in accordance with the guidelines of IS 10262:2019. The nominal mix proportion adopted for the study was 1:1.65:2.75 with a water-cement ratio of 0.45. Polyethylene Glycol (PEG-400) was used as a self-curing agent at 1% by weight of cement.

4.2 Mix Proportion

Ground Granulated Blast Furnace Slag (GGBS) was used as a partial replacement of cement at replacement levels of 10%, 20%, and 30%. Based on the selected mix proportions, concrete specimens were prepared and tested to evaluate their mechanical properties. The nominal mix proportion for M25 grade concrete is presented in Table 4.1.

Table 4.1 Mix Proportion

Materials	Quantity (kg/m³)
Cement	413
Fine Aggregate	684
Coarse Aggregate	1136
Water	186
PEG-400	4.13 (1% of cement)

4.3 Tests on Hardened Concrete

4.3.1 Compressive Strength Test

The compressive strength test was conducted in accordance with IS 516 on concrete cube specimens of size 150 mm × 150 mm × 150 mm. The specimens were cast and subjected to self-curing using 1% PEG-400. The compressive strength was determined at the ages of 7, 14, and 28 days. Before testing, the specimens were cleaned and placed centrally in a Compression Testing Machine (CTM). The load was applied gradually until failure occurred, and the maximum load was recorded. The compressive strength was calculated by dividing the ultimate load by the loaded area of the cube specimen.

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Figure 4.1 Compressive Strength Test

Table 4.1 Compressive Strength of M25 Grade Self-Curing Concrete

S. No	Mix ID	Cement (%)	GGBS (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
1	CC	100	0	23.1	28.4	31.5
2	G10	90	10	24.4	29.8	32.8
3	G20	80	20	25.5	31.3	34.6
4	G30	70	30	24.0	30.2	33.7

Calculation:

Size of Cube = 150 mm × 150 mm × 150 mm

Area of Cube = Length × Breadth

= 150 × 150

= 22,500 mm²

Failure Load of Cube at 28 Days (G20 Mix) = 780 kN

Compressive Strength = Failure Load / Loaded Area

= (780 × 1000) / 22,500

= 34.67 N/mm² ≈ 34.6 MPa

From the test results, it is observed that the compressive strength increased with the replacement of cement by GGBS up to 20%. The maximum compressive strength of 34.6 MPa was achieved for the G20 mix at 28 days. Further increase in GGBS content to 30% resulted in a slight reduction in strength, although the values remained higher than the control mix.

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4.3.2 Split Tensile Strength Test

The split tensile strength test was conducted in accordance with IS 516 on cylindrical concrete specimens of size 150 mm diameter and 300 mm height. The specimens were tested at 7, 14, and 28 days. The load was applied gradually along the diameter of the cylinder until failure occurred, and the split tensile strength was determined.

Figure 4.2 Split Tensile Strength Test

Table 4.2 Split Tensile Strength of M25 Grade Self-Curing Concrete

S. No	Mix ID	PEG-400 (%)	GGBS (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
1	M1	0	0	2.40	2.95	3.40
2	M2	1	10	2.62	3.18	3.68
3	M3	1	20	2.88	3.42	3.95
4	M4	1	30	2.70	3.20	3.72

Calculation:

Diameter of Cylinder (D) = 150 mm

Length of Cylinder (L) = 300 mm

Split Tensile Strength,

$f_t = 2P / \pi DL$

Where,

P = Ultimate Load (N)

D = Diameter of Cylinder (mm)

L = Length of Cylinder (mm)

From the test results, the maximum split tensile strength of **3.95 MPa** at 28 days was obtained for Mix M3 containing **20% GGBS and 1% PEG-400**.

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4.3.3 Flexural Strength Test

The flexural strength test was conducted in accordance with IS 516 on beam specimens of size 150 mm × 150 mm × 700 mm. The specimens were tested under two-point loading at 7, 14, and 28 days. The maximum load at failure was recorded, and the flexural strength was calculated.

Figure 4.3 Flexural Strength Test

Table 4.3 Flexural Strength of M25 Grade Self-Curing Concrete

S. No	Mix ID	PEG-400 (%)	GGBS (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
1	M1	0	0	3.10	4.00	4.80
2	M2	1	10	3.35	4.32	5.12
3	M3	1	20	3.70	4.72	5.60
4	M4	1	30	3.48	4.42	5.28

Calculation:

Size of Beam = 150 mm × 150 mm × 700 mm

Flexural Strength,

$f_r = PL / bd^2$

Where,

P = Ultimate Load (N)

L = Span Length (mm)

b = Width of Beam (mm)

d = Depth of Beam (mm)

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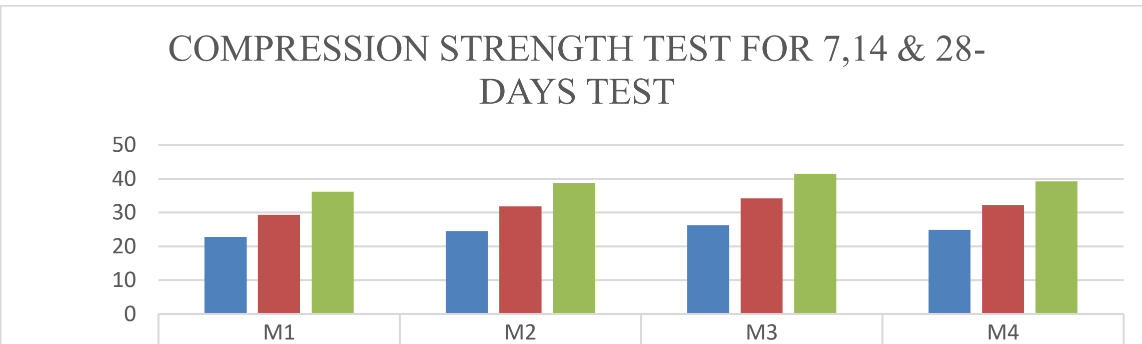
From the test results, the maximum flexural strength of **5.60 MPa** at 28 days was achieved by Mix M3 containing **20% GGBS and 1% PEG-400**. The results indicate that the incorporation of GGBS up to 20% improves the flexural performance of self-curing concrete.

V. RESULT AND DISCUSSION

5.1 COMPRESSIVE STRENGTH TEST

Compressive strength test is one of the most important tests conducted on hardened concrete. It determines the ability of concrete to resist compressive loads. The test was conducted on cube specimens of size 150 mm × 150 mm × 150 mm using a Compression Testing Machine (CTM).



	M1	M2	M3	M4
7-Days	22.8	24.5	26.2	24.9
14-Days	29.4	31.8	34.2	32.2
28-Days	36.2	38.8	41.5	39.2

Fig. 5.1.4 Compression Test for 7, 14 and 28 Days

• The graph represents the compressive strength of M25 grade self-curing concrete containing 1% PEG-400 and different percentages of GGBS replacement at curing ages of 7, 14, and 28 days.

• The compressive strength of all concrete mixes increased with curing age due to continuous hydration and the internal curing effect provided by PEG-400.

• Mix M1 (Conventional Concrete) achieved compressive strengths of 22.80 MPa, 29.40 MPa, and 36.20 MPa at 7, 14, and 28 days respectively.

• Mix M2 containing 10% GGBS and 1% PEG-400 showed improved compressive strengths of 24.50 MPa, 31.80 MPa, and 38.80 MPa at 7, 14, and 28 days respectively.

• Mix M3 containing 20% GGBS and 1% PEG-400 exhibited the highest compressive strength values of 26.20 MPa, 34.10 MPa, and 41.50 MPa at 7, 14, and 28 days respectively.

• Mix M4 containing 30% GGBS and 1% PEG-400 achieved compressive strengths of 24.90 MPa, 32.20 MPa, and 39.20 MPa at 7, 14, and 28 days respectively.

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• The results indicate that the compressive strength increased with GGBS replacement up to 20%. The improvement in strength can be attributed to the pozzolanic reaction of GGBS and the enhanced hydration caused by the self-curing action of PEG-400.

• Beyond 20% GGBS replacement, a slight reduction in compressive strength was observed. However, the strength remained higher than that of conventional concrete.

• At 28 days, Mix M3 recorded the maximum compressive strength of 41.50 MPa, which was significantly higher than the conventional concrete strength of 36.20 MPa.

• Therefore, Mix M3 containing 20% GGBS and 1% PEG-400 is considered the optimum mix for achieving maximum compressive strength in self-curing concrete.

5.2 SPLIT TENSILE STRENGTH TEST

Split tensile strength test is conducted to determine the tensile strength of concrete. Cylindrical specimens were tested under compression along the diameter.

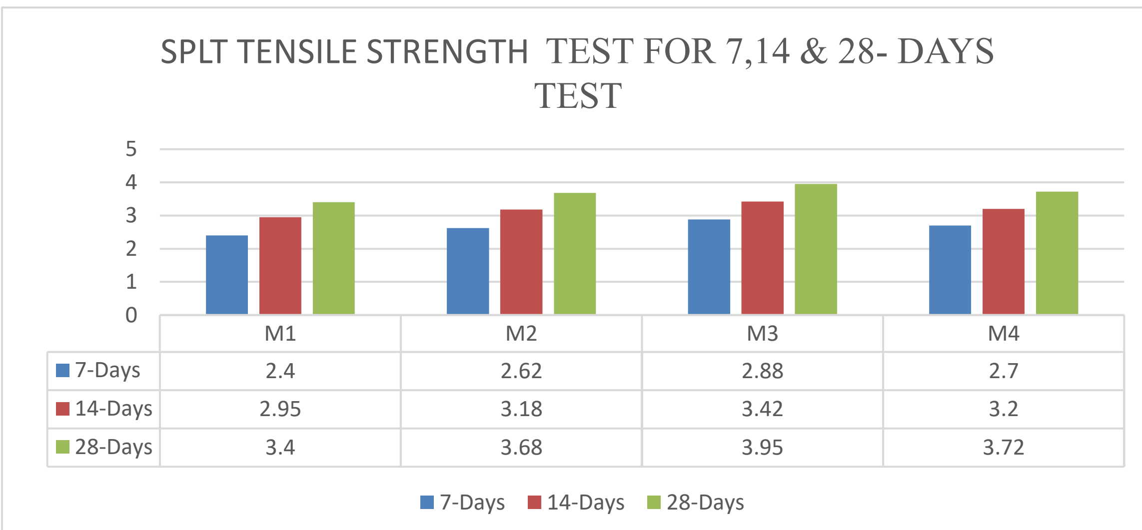

Fig. 5.2.4 Split Tensile Strength Test for 7, 14 and 28 Days

• The graph represents the split tensile strength of M25 grade self-curing concrete containing 1% PEG-400 and varying percentages of GGBS replacement at curing ages of 7, 14, and 28 days.

• The split tensile strength of all concrete mixes increased with curing age due to continuous hydration and improved bonding within the concrete matrix.

• Mix M1 (Conventional Concrete) recorded split tensile strengths of 2.40 MPa, 2.95 MPa, and 3.40 MPa at 7, 14, and 28 days respectively.

• Mix M2 containing 10% GGBS and 1% PEG-400 achieved split tensile strengths of 2.62 MPa, 3.18 MPa, and 3.68 MPa at 7, 14, and 28 days respectively.

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• Mix M3 containing 20% GGBS and 1% PEG-400 exhibited the highest split tensile strengths of 2.88 MPa, 3.42 MPa, and 3.95 MPa at 7, 14, and 28 days respectively.

• Mix M4 containing 30% GGBS and 1% PEG-400 achieved split tensile strengths of 2.70 MPa, 3.20 MPa, and 3.72 MPa at 7, 14, and 28 days respectively.

• The results indicate that the split tensile strength increased with GGBS replacement up to 20%. The enhancement in tensile strength can be attributed to the pozzolanic reaction of GGBS and the internal curing action of PEG-400, which improved the microstructure of concrete.

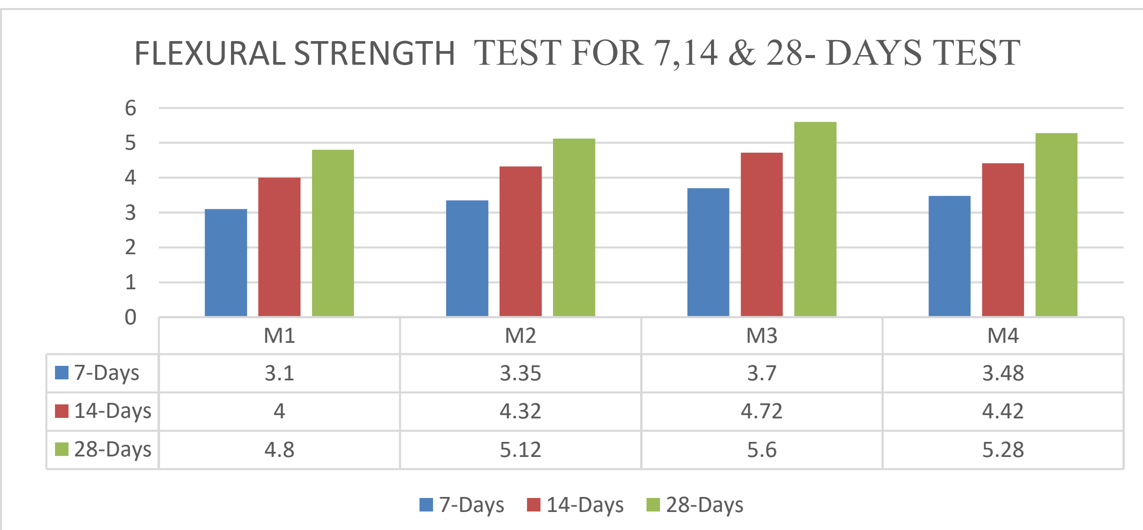
• Although Mix M4 showed higher strength than the control mix, a slight reduction was observed when compared to Mix M3, indicating that excessive GGBS replacement may reduce the availability of cementitious compounds required for strength development.

• At 28 days, Mix M3 recorded the maximum split tensile strength of 3.95 MPa, whereas the conventional concrete mix achieved 3.40 MPa.

• Therefore, Mix M3 containing 20% GGBS and 1% PEG-400 is considered the optimum mix for achieving maximum split tensile strength in self-curing concrete.

5.3 FLEXURAL STRENGTH TEST

Flexural strength test determines the bending strength of concrete beams. The test was conducted using beam specimens under two-point loading.



	M1	M2	M3	M4
7-Days	3.1	3.35	3.7	3.48
14-Days	4	4.32	4.72	4.42
28-Days	4.8	5.12	5.6	5.28

Fig. 5.3.4 Flexural Strength Test for 7, 14 and 28 Days

• The graph represents the flexural strength of M25 grade self-curing concrete containing 1% PEG-400 and different percentages of GGBS replacement at curing ages of 7, 14, and 28 days.

• The flexural strength of all concrete mixes increased with curing age due to the continued hydration of cement and the self-curing action of PEG-400.

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• Mix M1 (Conventional Concrete) recorded flexural strengths of 3.10 MPa, 4.00 MPa, and 4.80 MPa at 7, 14, and 28 days respectively.

• Mix M2 containing 10% GGBS and 1% PEG-400 achieved flexural strengths of 3.35 MPa, 4.32 MPa, and 5.12 MPa at 7, 14, and 28 days respectively.

• Mix M3 containing 20% GGBS and 1% PEG-400 exhibited the highest flexural strengths of 3.70 MPa, 4.72 MPa, and 5.60 MPa at 7, 14, and 28 days respectively.

• Mix M4 containing 30% GGBS and 1% PEG-400 achieved flexural strengths of 3.48 MPa, 4.42 MPa, and 5.28 MPa at 7, 14, and 28 days respectively.

• The results indicate that the flexural strength increased with GGBS replacement up to 20%. The improvement may be attributed to the formation of additional calcium silicate hydrate (C-S-H) gel due to the pozzolanic reaction of GGBS, resulting in a denser concrete matrix.

• Although Mix M4 showed better flexural strength than conventional concrete, a slight decrease was observed when compared to Mix M3, indicating that the optimum GGBS replacement level is 20%.

• At 28 days, Mix M3 recorded the maximum flexural strength of 5.60 MPa, whereas the conventional concrete mix achieved 4.80 MPa.

• Therefore, Mix M3 containing 20% GGBS and 1% PEG-400 is considered the optimum mix for achieving maximum flexural strength in self-curing concrete.

Observations:

• Flexural strength increased with curing age for all mixes.

• The incorporation of PEG-400 and GGBS enhanced the flexural performance of concrete compared to conventional concrete.

• Mix M3 (20% GGBS + 1% PEG-400) exhibited the highest flexural strength at all curing periods.

• A slight reduction in flexural strength was observed beyond 20% GGBS replacement.

• Self-curing concrete containing PEG-400 and GGBS demonstrated superior bending resistance and durability characteristics compared to conventional concrete.

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VI. SUMMARY AND CONCLUSIONS

6.1 SUMMARY

The study reviewed various journals and literature related to self-curing concrete using PEG-400 and partial replacement of cement with GGBS. Based on the literature survey, the objectives, scope, and methodology were formulated.

The materials used in this study were Ordinary Portland Cement (OPC), fine aggregate, coarse aggregate, PEG-400 as a self-curing agent, and GGBS as a partial cement replacement. M25 grade concrete was prepared with 1% PEG-400 and 10%, 20%, and 30% GGBS replacement levels.

The mechanical properties of concrete, namely compressive strength, split tensile strength, and flexural strength, were evaluated at 7, 14, and 28 days.

6.2 CONCLUSIONS

The experimental investigation showed that the use of PEG-400 as a self-curing agent improved the hydration process and enhanced the strength properties of concrete.

Partial replacement of cement with GGBS increased the compressive, split tensile, and flexural strengths up to an optimum replacement level of 20%.

The maximum compressive strength of 41.50 MPa, split tensile strength of 3.95 MPa, and flexural strength of 5.60 MPa were achieved by Mix M3 containing 1% PEG-400 and 20% GGBS.

The improvement in strength is attributed to the self-curing action of PEG-400 and the pozzolanic reaction of GGBS, which produces additional C-S-H gel and enhances the concrete matrix.

Although 30% GGBS replacement also performed better than conventional concrete, a slight reduction in strength was observed compared to the 20% replacement level.

The use of GGBS reduces cement consumption and environmental impact, while PEG-400 minimizes the need for external curing water.

Therefore, 1% PEG-400 with 20% GGBS replacement is recommended as the optimum mix for producing sustainable and durable self-curing concrete.

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