Performance Evaluation of Self-Curing Concrete Incorporating Polyethylene Glycol and Fly Ash for Sustainable Construction

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***Abstract* -Adequate curing is essential for ensuring proper hydration, microstructural development, and long-term performance of concrete; however, conventional curing methods are often ineffective in water-scarce environments. This study investigates self-curing concrete using polyethylene glycol (PEG) as an internal curing agent and fly ash as a supplementary cementitious material. PEG enhances internal moisture retention by reducing surface tension and sustaining hydration, while fly ash contributes to secondary pozzolanic reactions, improving strength and durability.**

Concrete mixes of M20 grade were prepared with varying PEG dosages (0.2–0.9%) and fly ash replacement levels (5–20%). Mechanical properties, including compressive and flexural strength, were evaluated and compared with conventionally cured concrete. Results indicate improved hydration, reduced shrinkage, and enhanced strength in self-curing mixes. The optimal combination of 0.7% PEG and 10% fly ash demonstrated superior performance. This approach promotes sustainable construction by reducing water demand and cement consumption.

Index Terms— **Self-curing concrete, Polyethylene glycol (PEG), Fly ash, cementitious material, pozzolanic reactions, microstructural development**

I. INTRODUCTION

Concrete is the most widely used construction material in the world due to its versatility, durability, and cost-effectiveness. The strength and durability of concrete largely depend on the extent of hydration of cement, which requires adequate moisture over a sufficient period. Proper curing ensures complete hydration, minimizes shrinkage cracks, reduces permeability, and enhances overall performance of the structure. Traditional curing methods such as water ponding, wet covering, membrane curing, and steam curing are commonly employed, but they have several limitations, especially in regions facing water scarcity, high-rise buildings, congested construction sites, and hot arid climates where rapid evaporation occurs Inadequate curing leads to reduced strength, increased plastic and drying shrinkage, early-age cracking, lower durability, and ultimately shorter service life of concrete structures. With growing concerns over water conservation and sustainable construction practices, there is an urgent need to develop alternative curing techniques that eliminate or minimize the dependence on external water supply.

Self-curing concrete, also known as internal curing concrete, is an innovative approach that retains moisture within the concrete matrix itself, thereby promoting hydration without the need for external curing. This is achieved by incorporating water-soluble chemical agents or hydrophilic materials that reduce the evaporation of mixing water and maintain high internal relative humidity for a longer duration. Among various self-curing agents, **Polyethylene Glycol (PEG)** has gained significant attention due to its ability to form hydrogen bonds with water molecules, lower surface tension, and restrict water loss from the concrete. PEG acts as an internal sealing agent, ensuring sustained hydration even in adverse environmental conditions.

Additionally, the partial replacement of Ordinary Portland Cement (OPC) with supplementary cementitious materials like **fly ash** not only improves the workability and long- term strength through pozzolanic reaction but also contributes to environmental sustainability by utilizing industrial by-products and reducing CO_2 emissions associated with cement production. The combination of PEG and fly ash in concrete offers a synergistic effect: enhanced internal curing along with improved mechanical and durability properties.

This project aims to investigate the performance of self-curing concrete by incorporating varying percentages of Polyethylene Glycol and fly ash as partial cement replacement. The study evaluates the fresh properties, mechanical strength (compressive, split tensile, and flexural), water retention characteristics, and durability aspects of the developed mixes in comparison with conventionally cured concrete.

The primary objective of this study is to develop and evaluate the performance of self-curing concrete by incorporating Polyethylene Glycol (PEG) as an internal curing agent and fly ash as a partial replacement for cement. The specific objectives are as follows:

- To evaluate the effect of varying PEG dosages (0–2%) on the compressive strength of M20 grade concrete at different curing ages (7, 14, and 28 days), based on established self-curing mechanisms [2], [4].
- To investigate the influence of fly ash replacement levels (10–30%) on strength development and hydration characteristics, considering its pozzolanic behaviour and sustainability benefits [7], [8].
- To determine the optimal combination of PEG and fly ash that maximizes compressive strength and overall mechanical performance, ensuring results comparable to or better than conventional curing methods [3], [5].
- To analyze the rate of strength gain from early age to later stages and compare it with conventionally cured concrete specimens.
- To evaluate the flexural strength of self-curing concrete under varying PEG dosages and fly ash contents to assess resistance to bending stresses.
- To compare the mechanical performance (compressive and flexural strength) of self-curing concrete with conventional water-cured concrete.
- To establish an optimal mix proportion that ensures both structural performance and effective internal curing.
- To validate the feasibility of achieving target strength requirements while reducing water consumption and cement usage, thereby promoting sustainable construction practices [6], [9].

II. LITERATURE REVIEW

Conventional concrete curing methods rely heavily on external water application to ensure adequate hydration and strength development. However, in water-scarce regions and large-scale construction, maintaining continuous curing is challenging, leading to incomplete hydration, increased shrinkage, and reduced durability. To overcome these limitations, the concept of self-curing concrete has been extensively explored, wherein internal curing agents such as polyethylene glycol (PEG) are used to retain moisture within the concrete matrix [1].

Early work by A.S. El-Dieb (2007) established the fundamental mechanisms of self-curing, highlighting the role of internal water retention in enhancing hydration and reducing moisture loss [1]. Subsequent studies have demonstrated that PEG effectively reduces surface tension and improves internal humidity, thereby minimizing autogenous shrinkage and promoting continuous hydration. A state-of-the-art review by N.V.R.D. Annapurna (2023) emphasized that PEG dosages in the range of 1–1.5% are generally effective in improving strength and durability, particularly in lightweight and high-performance concrete [2].

Recent experimental investigations have focused on optimizing PEG dosage and incorporating supplementary cementitious materials. M.I. Mousa et al. (2024) reported that the use of PEG along with crushed ceramic waste and volcanic powder significantly improved workability, strength, and durability, demonstrating the feasibility of sustainable self-curing systems [3]. Similarly, C. Makendran (2023) observed that a PEG dosage of 1.5% yielded superior compressive and flexural strength in concrete designed for highway infrastructure, especially under limited curing conditions [4]. Studies by A.M. Maglad et al. (2022) further indicated that PEG not only enhances strength but also significantly reduces water absorption, sorptivity, and drying shrinkage, thereby improving durability characteristics [5].

The incorporation of fly ash as a partial replacement for cement has also been widely investigated due to its pozzolanic reactivity and sustainability benefits. Fly ash contributes to secondary hydration reactions, leading to pore refinement and improved long-term strength. B. Joseph et al. (2020) explored alternative bio-admixtures for internal curing in fly ash concrete and found comparable performance to PEG in terms of water retention and strength enhancement [6]. Similarly, studies by U. Venkata Rathnam (2022) [7] and J. Peteti et al. (2022) [8] confirmed that the combined use of PEG and fly ash improves compressive strength and durability while reducing dependence on conventional curing.

Further research has also examined the synergistic effects of PEG with other materials. P. Jaishankar et al. (2024) demonstrated enhanced performance of self-curing concrete with PEG and superabsorbent polymers [9], while V. Navaneetha (2025) reported improved hydration characteristics and strength development using PEG-based internal curing systems [10].

Research Gap

Despite extensive research, most studies have focused either on PEG-based self-curing or on fly ash incorporation independently, with limited emphasis on their combined optimization, particularly for normal-strength concrete such as M20 grade [2], [7], [8]. Moreover, there remains a need for systematic evaluation of multiple mechanical properties, including compressive and flexural strength, under varying dosages of PEG and fly ash [3], [4], [5]. Additionally, limited attention has been given to developing economical and field-applicable mix designs suitable for practical construction in water-scarce regions [6], [9]. Therefore, the present study aims to address this research gap by investigating the combined effect of PEG and fly ash on the performance of self-curing concrete, with a focus on optimizing mix proportions for sustainable and efficient construction practices.

III. PROPOSED METHODOLOGY

A. Materials used

- **Cement:** An ordinary Portland cement (OPC 43 grade) was used. Specific gravity is **3.29**.
- **Fly Ash:** Class F fly ash was used. Specific gravity is 2.2.
- **Natural sand:** Natural river sand passing through 4.75mm was used as fine aggregate and was tested following IS: 383-1970. The sand conformed to zone II. bulk density is Loose bulk density: 1450 kg/m³.Compacted bulk density: 1620 kg/m³,specific gravity=2.57.
- **Aggregate:** The aggregates were selected based on the limitation of IS 881 and 882 and the aggregate was 20mm. specific gravity=**2.59**
- ***PolyethyleneGlycol-400(PEG- 400*:Used a s an internal curing compound.** Polyethylene glycol is a condensation polymer of ethylene oxide and water with the general formula $H(OCH_2\ CH_2)_n\ OH$, where n is the average number of repeating polyethylene groups typically from 4 to about 180. One common feature of PEG appears to be the water-soluble nature. Polyethylene glycol is non-toxic, odorless, neutral, lubricating, non-volatile and non-irritating and is used in a variety of pharmaceuticals. Thus, it is a shrinkage reducing admixture.

B. Mix Proportioning

The mix design is done according to the IS method.M20 Grade concrete having mix proportion 1:1.5:3 was used with w/c ratio of 0.4.

Table 1: Mix proportion of specimens

S.NO.	M20	% MIX
1	Mix-1	5% FLYASH
2	Mix-2	10% FLYASH
3	Mix-3	15% FLYASH
4	Mix-4	20% FLYASH
5	Mix-5	10% FLYASH +0.2% PEG
6	Mix-6	10% FLYASH +0.5% PEG
7	Mix-7	10% FLYASH +0.7% PEG
8	Mix-8	10% FLYASH +0.9% PEG

Table 1.shows the mix proportions of specimens used for the tests. In this study, both the early-age properties of fresh concrete and the mechanical properties of hardened concrete, including compressive strength and flexural strength, were systematically evaluated. Initially, the properties of conventional concrete were determined to establish a baseline for comparison. Subsequently, fly ash was incorporated as a partial replacement for cement

at varying levels of 5%, 10%, 15%, and 20% by weight of cement to identify the optimum replacement level. Based on the optimum fly ash content, Polyethylene Glycol (PEG) was then added as a self-curing agent at different dosages of 0.2%, 0.5%, 0.7%, and 0.9% by weight of cement. This approach enabled a comprehensive assessment of the combined effects of fly ash and PEG on the performance of self-curing concrete.

IV. RESULTS AND DISCUSSIONS

A. Workability

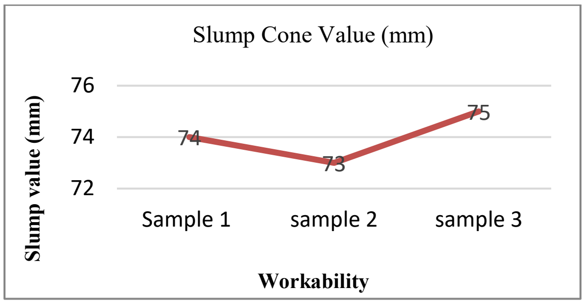

Fig 1: Slump cone value of conventional concrete

Fig 1 shows that the slump values range narrowly between 73 mm and 75 mm, indicating minimal variation among the samples. Sample 2 shows the lowest workability, while Sample 3 exhibits the highest slump value. The small differences suggest that all mixes have relatively consistent performance. Overall, the mixes fall within an acceptable workability range, with Sample 3 being the most workable.

B. Compressive strength of conventional concrete:

Table-2 :Compressive strength of conventional concrete

SAMPLES	COMPRESSIVE VALUES (MPA)
Test -1 (7 days)	19.55
Test -2 (14 days)	20.55
Test -3 (28 days)	21.77

Fig 2 shows that the compressive strength of conventional concrete increases steadily with curing time. At 7 days, the strength is about 19.55 MPa, which

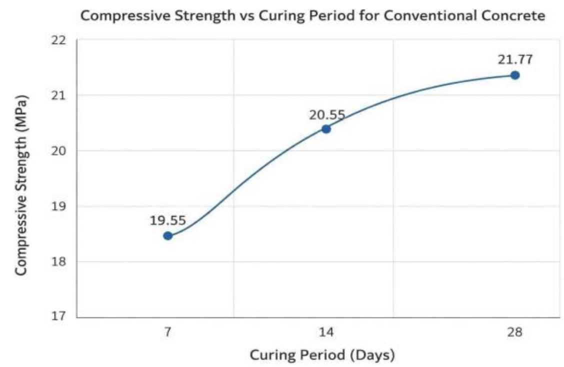

Fig 2: Compressive strength of conventional concrete

rises significantly to 20.55 MPa at 14 days, and further to 21.77 MPa at 28 days. This indicates that longer curing periods enhance the strength of concrete due to continued hydration. However, the rate of strength gain slows down after 14 days, suggesting that most of the strength development occurs in the early curing period, with gradual improvements thereafter.

C. Compressive strength with addition of different percentages of fly ash:

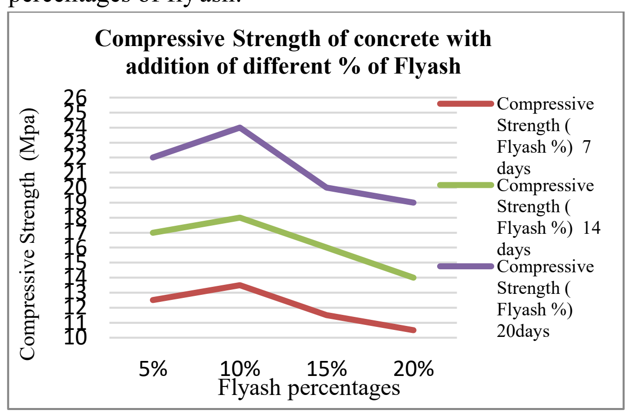

Fig 3 :Compressive strength of fly ash mix with different percentages

Fig 3 clearly shows that the compressive strength of the fly ash mix increases with the addition of fly ash up to an optimum level, after which it declines. At 10% fly ash content, the mix achieves the maximum compressive strength for all curing periods (7, 14, and 28 days), indicating this as the optimum percentage. Beyond 10%, the strength gradually decreases, likely due to excess fly ash reducing the effective bonding in the matrix. Additionally, strength consistently increases with curing time, with 28-day strength being the highest, followed by 14-day and 7-day strengths. Overall, 10% fly ash provides the best balance for strength enhancement.

D. Compressive strength with addition of 10% flyash and different percentages of PEG:

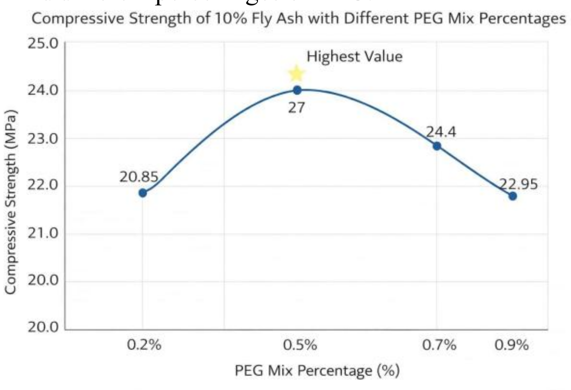

Fig 4: Compressive strength with addition of 10% flyash and different percentages of PEG

Fig 4 clearly indicates that the addition of PEG significantly influences the compressive strength of the 10% fly ash soil mix. The strength increases from 20.85 MPa at 0.2% PEG to a peak value of approximately 24 MPa at 0.5% PEG, demonstrating that moderate PEG content enhances bonding and improves soil structure. Beyond this optimum level, the compressive strength begins to decline, dropping to 24.4 MPa at 0.7% and further to 22.95 MPa at 0.9%.

This trend suggests that 0.5% PEG is the optimum mix proportion for achieving maximum compressive strength. Higher PEG contents likely lead to excess polymer presence, which may reduce inter-particle friction and weaken the matrix. Overall, controlled PEG addition improves strength, but excessive amounts negatively affect performance.

E. Flexural strength of conventional concrete

Fig 5: Flexural strength of conventional concrete

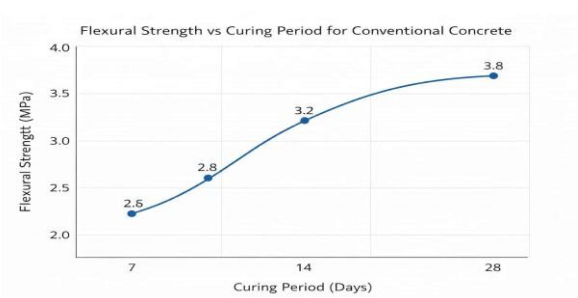

Fig 5 shows a clear positive relationship between curing period and flexural strength of conventional concrete. The strength increases steadily from about 2.2 MPa at 7 days to 2.6 MPa at 10 days, followed by a more significant rise to 3.2 MPa at 14 days, and finally reaching 3.8 MPa at 28 days.

This trend indicates that extended curing enhances hydration, leading to improved bonding within the concrete matrix and higher flexural strength. The rate of strength gain is more pronounced between 10 and 14 days, after which it continues to increase at a slower pace up to 28 days.

Overall, the results confirm that longer curing periods significantly improve flexural strength, with 28 days providing the maximum strength, emphasizing the importance of adequate curing in concrete performance.

F. Flexural strength with addition of different percentages of fly ash

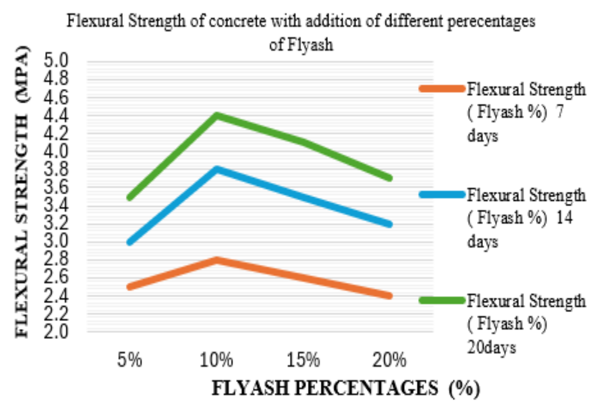

Fig 6 : Flexural strength with addition of different percentages of fly ash

Fig 6 indicates that the flexural strength of the fly ash mix increases with the addition of fly ash up to 10%, after which it gradually decreases. The maximum flexural strength is achieved at 10% fly ash content for all curing periods (7, 14, and 28 days), identifying it as the optimum percentage. Beyond this level, the reduction in strength may be due to excess fly ash affecting the cohesion and bonding within the matrix. Additionally, flexural strength improves with curing time, with 28-day strength being the highest, followed by 14-day and 7-day strengths. Overall, 10% fly ash provides the most effective enhancement in flexural performance.

G. Flexural strength with addition of 10% flyash and different percentages of PEG

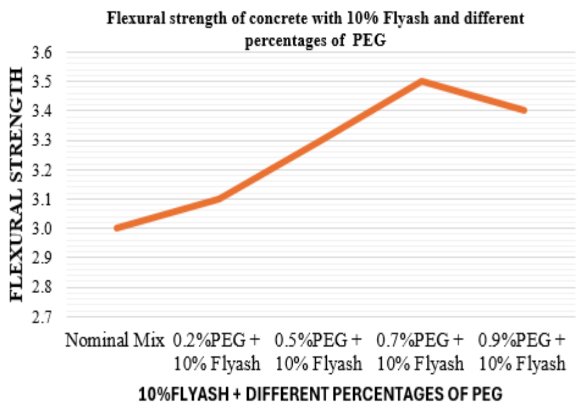

Fig 7: Flexural strength with addition of 10% flyash and different percentages of PEG

The graph shows a progressive increase in the measured parameter from the initial point to a peak value, followed by a slight decline at the final stage. Initially, the values rise gradually, indicating improving performance or effectiveness with the increase in the controlling variable. This increase becomes more pronounced in the middle range, suggesting an optimal interaction or enhancement effect.

The maximum value is observed at the second-to-last point, representing the optimum condition for the system. Beyond this point, a slight reduction is noted, which may be due to over dosage, saturation, or loss of efficiency of the influencing factor.

Overall, the results indicate that there exists an optimum level of the variable at which maximum performance is achieved, and any further increase beyond this level leads to a marginal decrease in effectiveness.

V. FUTUREWORK

The present study can be extended by investigating the long-term durability properties of self-curing concrete, including resistance to chloride penetration, carbonation, and sulfate attack under different environmental conditions. Further research may explore the use of alternative self-curing agents and supplementary cementitious materials such as silica fume, GGBS, or natural polymers to enhance performance and sustainability. In addition, studies on higher-grade concrete (M30 and above) and large-scale structural applications can provide better insights into field implementation and practical feasibility. Advanced microstructural analysis using techniques such as SEM and XRD can also be conducted to better understand the internal hydration mechanisms and bonding characteristics of PEG-based self-curing concrete.

VI. CONCLUSION

The present study was carried out to investigate the performance of self-curing concrete by incorporating Polyethylene Glycol (PEG) as an internal curing agent and fly ash as a partial replacement for cement in M20 grade concrete. The primary objective was to develop a concrete mix that eliminates or minimizes the need for external water curing while achieving comparable or superior mechanical properties and durability, thereby promoting water conservation and sustainable construction practices.

1.**Viability of the Self-Curing Mechanism** :The study successfully demonstrated that incorporating Polyethylene Glycol (PEG) acts as an effective self-curing agent. By retaining moisture within the concrete matrix, the PEG-modified mix achieved hydration levels and mechanical properties comparable to—and in some instances exceeding—those of conventionally water-cured control specimens across 7, 14, and 28-day intervals.

2.**Compressive Strength Development**

Impact of PEG and Fly Ash: The addition of PEG (varying from 0% to 2%) and the partial replacement of cement with industrial fly ash (10% to 30%) significantly influenced the compressive strength of the M20 mix.

Optimum Mix Ratio: The analysis revealed that the optimum combination for maximizing compressive strength was achieved at a PEG dosage of **0.7 %** and a fly ash replacement level of **10%**. At this specific matrix, the strength gain over 28 days effectively met the structural baseline required for M20 grade concrete.

3.**Flexural Performance and Bending Resistance**

Modulus of Rupture: The flexural strength evaluations at 7, 14, and 28 days confirmed that the self-curing concrete maintains a robust capacity to resist bending stresses.

Comparative Performance: When benchmarked against traditional water-cured concrete, the optimal PEG-fly ash mix exhibited long-term flexural reliability, ensuring its durability for practical applications where flexural loads are a primary concern.

Sustainability and Environmental Impact : Beyond mechanical performance, this project validates the environmental and economic viability of the proposed mix. By utilizing industrial fly ash, the concrete significantly reduces raw cement consumption and its associated carbon footprint. Furthermore, the successful implementation of PEG eliminates the need for continuous external water curing, conserving substantial amounts of water and making this mix highly suitable for arid regions or areas with water scarcity.

4.CHEMICAL BOND EQUATION :

A) The Strengthening Equation (Pozzolanic Reaction):The Fly Ash reacts with the byproduct of cement hydration (Ca(OH)2) to create Calcium Silicate Hydrate (C-S- H), which is the "glue" that gives your M20 concrete its 20+ MPa strength.

The equation is :

$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2H_2O \rightarrow C–S–H$ (Gel)

B) The Self-Curing Equation (PEG Hydrogen Bonding):The PEG acts as a "water magnet." It uses its ether oxygen atoms to form Hydrogen Bonds with the water molecules (H2O). This prevents the water from evaporating, ensuring the equation above has enough liquid to finish The chemical interaction is represented by the attraction between the Oxygen in PEG and the Hydrogen in Water:

The equation is :

$R–[O–CH_2–CH_2]_n–OH + H_2O \rightleftharpoons R–[O\cdots H–O–H\cdots O]_n–OH$

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