

Comparative Performance Evaluation of Polyethylene Glycol-400 and Sodium Polyacrylate-Based Superabsorbent Polymer as Internal Curing Agents in M40 Grade Structural Concrete

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Abstract

Adequate curing is essential for continued cement hydration, yet external water curing is frequently compromised on site due to water scarcity, congested reinforcement, or inconsistent workmanship, resulting in autogenous shrinkage, micro-cracking, and diminished strength gain. These effects are magnified in low water-cement ratio structural grades such as M40. This study experimentally compares two internal (self-) curing agents-Polyethylene Glycol-400 (PEG-400), a hydrophilic water-retaining polymer, and a Superabsorbent Polymer (SAP, sodium polyacrylate), a water-reservoir polymer-with respect to their influence on the fresh and hardened properties of M40 grade concrete. Mixes were proportioned in accordance with IS 10262:2019 for a target mean strength of 48.25 N/mm² at a water-cement ratio of 0.36. A control mix (0% dosage) was benchmarked against PEG-400 and SAP incorporated individually at 1% and 2% by weight of cement for compressive strength, and at 1% dosage for split tensile and flexural strength, with all specimens tested at 7, 14 and 28 days. Workability was assessed through slump and compaction factor tests. The results show that both internal curing agents reduced compressive strength relative to the control mix at every age and dosage examined, with PEG-400 consistently outperforming SAP at an equivalent dosage, and the 1% dosage outperforming the 2% dosage for both materials. A similar trend was observed for split tensile and flexural strength at 1% dosage. Based on these findings, PEG-400 at 1% by weight of cement is identified as the more effective and practical internal curing agent among those examined for M40 structural concrete, offering a pathway toward more water-efficient curing practice in water-scarce or site-constrained construction environments.

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Keywords: Self-curing concrete; Internal curing; Polyethylene glycol-400; Superabsorbent polymer; Sodium polyacrylate; M40 grade concrete; Compressive strength; Split tensile strength

1. Introduction

Concrete owes its dominance as a construction material to its strength, versatility, and comparatively low cost, but its in-service performance depends critically on curing, the process by which adequate moisture is retained within the matrix to sustain cement hydration. In everyday construction practice, external (water) curing is often applied inconsistently because of water scarcity, congested formwork, tight project schedules, or simple oversight on site. The consequence is incomplete hydration, elevated autogenous and plastic shrinkage, early-age micro-cracking, and a shortfall in both strength and durability relative to design expectations [1,2].

Internal, or self-curing, concrete addresses this shortcoming by embedding a moisture-retaining or moisture-releasing medium directly within the mix, so that hydration is sustained from within rather than relying solely on an external water source. Chemical self-curing agents such as polyethylene glycol (PEG) and superabsorbent polymers (SAP) have received particular attention because they can be dosed directly into the mix without altering the basic concreting process [3,4]. PEG-400 is a low-molecular-weight, water-soluble polyether that forms a thin retentive film around hydrating particles and slows evaporative moisture loss from

the near-surface zone. SAP, most commonly the sodium salt of polyacrylic acid, instead behaves as a discrete internal reservoir: it absorbs a multiple of its own weight in mixing water and releases this water gradually as internal relative humidity falls during hydration [5,6].

M40 is a structural grade of concrete used extensively in buildings, bridges, and other load-bearing elements where both early strength gain and long-term durability are critical. Because M40 mixes are typically proportioned at a low water-cement ratio to meet strength targets, the concrete is inherently more prone to self-desiccation, which makes an effective internal curing strategy particularly valuable at this grade. However, the bulk of the published literature on PEG-400 and SAP has examined the two agents separately, or has focused on lower structural grades such as M20, M25 and M30, so there is limited controlled evidence directly comparing the two agents within the same M40 mix design and testing programme [7,8].

This creates a clear research gap: a side-by-side, same-mix, same-age comparison of PEG-400 and SAP as internal curing agents for M40 grade concrete, covering compressive, split tensile and flexural strength together with workability, has not been well established in the literature. The present study addresses this gap through a controlled experimental programme.

The specific objectives of this investigation are to: (i) compare the compressive and split tensile strength of concrete containing PEG-400 and SAP against a conventionally cured control mix; (ii) evaluate the influence of dosage (1% and 2% by weight of cement) on strength development at 7, 14 and 28 days; and (iii) identify the more effective and practical internal curing agent, together with its optimum dosage, for M40 grade structural concrete.

2. Literature Review

A substantial body of recent work supports the effectiveness of PEG-400 as a self-curing admixture. Virupakshappa et al. [2] reported that internally cured concrete containing 1.5% PEG-400 achieved compressive, split tensile and flexural strength gains of approximately 13.8%, 15.0% and 17.3% respectively over conventionally cured concrete, along with reduced water absorption and sorptivity. Ganesan and Palaniappan [7] similarly found that a 1% PEG-400 dosage produced the best balance of workability and strength among the dosages tested, with measurable improvements in compressive, split tensile and flexural strength relative to a plain control, together with a marked reduction in chloride ion penetration. Jaishankar et al. [6] reported an even lower optimum dosage of 0.25% PEG-400 for M40 concrete, underlining that the optimum dosage is sensitive to the specific mix design and testing regime. Singh [15] and Zhou et al. [3] both note that PEG-400 stabilises the degree of cement hydration and produces a less porous microstructure, which is the principal mechanism behind the reported strength gains.

Work on SAP-based internal curing presents a broadly consistent picture but with more sensitivity to dosage. Mangal and Juremalani [1] found that SAP-based self-curing gave a balanced improvement in both compressive and tensile properties and produced a more refined microstructure than the plain control. Hamzah et al. [8] and Lokeshwari et al. [12] confirm that SAP acts as an effective internal water reservoir, but caution that excessive dosage can increase the volume of SAP-induced voids, which may offset the benefit of continued hydration. Sahu et al. [17] and Karthick and Sulthana [18] reported that sodium polyacrylate improved early-age compressive strength relative to a conventional mix, but that the benefit narrowed, and in some cases reversed, by 28 days, indicating that the void-related strength penalty becomes more significant as hydration progresses.

Comparative studies that directly evaluate PEG-400 against SAP remain comparatively rare. Ganesan and Palaniappan [5] compared PEG-400, SAP and polyvinyl alcohol as self-curing agents and concluded that PEG-400 gave the best performance at 1% dosage due to its superior water-retention behaviour, while SAP showed only moderate strength gain because its performance is governed by a balance between internal curing and dilution/void effects. This finding is consistent with mechanistic studies of SAP-modified pore structure, which show that the voids left behind after SAP particles release their absorbed water can act as strength-limiting features unless dosage and particle size are tightly controlled [16,17].

Taken together, the literature confirms that both PEG-400 and SAP are viable internal curing agents capable of improving moisture retention and reducing shrinkage-related cracking, and that PEG-400 tends to outperform SAP in strength terms at comparable dosage. However, most of the available comparative evidence

relates to lower concrete grades or to a single strength parameter, and very few studies report compressive, split tensile and flexural strength together for both agents within the same M40 mix design. This is the specific gap addressed by the present study.

3. Materials and Methods

3.1 Materials

Ordinary Portland Cement (OPC) 53 grade, conforming to IS 269, was used as the primary binder on account of its high early strength and suitability for structural-grade concrete. The cement had a specific gravity of 3.15 and satisfied the physical and chemical requirements of IS 269:2015 for fineness, standard consistency, setting time and soundness (Table 1).

Natural river sand conforming to Zone II grading of IS 383 was used as fine aggregate, with a specific gravity of 2.70, fineness modulus of 2.83 and water absorption of 3.33%. Crushed angular coarse aggregate of 20 mm maximum nominal size was used, with a specific gravity of 2.90, fineness modulus of 6.72 and water absorption of 1.02%, in accordance with IS 2386.

A sulphonated naphthalene formaldehyde polymer-based superplasticizer (Masterplast SPL 9-M2, specific gravity 1.1) was used at 1% by weight of cementitious material to achieve the target workability at the design water-cement ratio while controlling segregation and bleeding.

Polyethylene Glycol-400 (PEG-400) was used as the first internal curing agent. It is a clear, colourless, viscous liquid with a density of 1.12-1.13 g/cm³, viscosity of 90-140 mPa·s, near-neutral pH (5-7) and a molecular weight of approximately 400 g/mol, and was dosed at 1% and 2% by weight of cement.

Sodium polyacrylate-based Superabsorbent Polymer (SAP) was used as the second internal curing agent. It is a white granular polymer that swells into a gel-like state on contact with water and functions as an internal water reservoir that releases absorbed moisture gradually as hydration proceeds; it was likewise dosed at 1% and 2% by weight of cement.

Table 1: Physical and chemical properties of cement, fine aggregate and coarse aggregate

Material	Property	Test result	Requirement (IS)
Cement (OPC 53)	Fineness (m ² /kg)	301	225 min (IS 269:2015)
Cement (OPC 53)	Standard consistency (%)	28.0	-
Cement (OPC 53)	Initial setting time (min)	140	30 min
Cement (OPC 53)	Final setting time (min)	180	600 max
Cement (OPC 53)	Specific gravity	3.15	-
Fine aggregate	Fineness modulus	2.83	Zone II
Fine aggregate	Specific gravity	2.70	-
Fine aggregate	Water absorption (%)	3.33	-
Coarse aggregate (20 mm)	Fineness modulus	6.72	-
Coarse aggregate (20 mm)	Specific gravity	2.90	-
Coarse aggregate (20 mm)	Water absorption (%)	1.02	≤ 2 (typical)

3.2 Mix Design and Proportions

M40 grade concrete was proportioned as per IS 10262:2019 for a target mean strength $f_t = f_{ck} + 1.65s = 40 + 1.65(5) = 48.25$ N/mm², adopting a water-cement ratio of 0.36 (against a code maximum of 0.55) and a design slump of 100 mm. The mix water content of 197 L/m³ (corrected for slump) was reduced by 25% through the use of superplasticizer, giving an effective water content of 148 kg/m³. The corrected proportion of coarse aggregate volume, adjusted for the water-cement ratio and for pumpability, was 0.583 m³ per m³ of concrete, with the balance made up by fine aggregate. The resulting control mix proportions and the PEG-400 and SAP mixes are summarised in Table 2. For the SAP and PEG-400 mixes, the base proportions of coarse aggregate, admixture and target water-cement ratio were kept unchanged, and only the self-curing agent dosage and the

corresponding adjustment to fine aggregate/water content were varied, so that any change in performance could be attributed to the curing agent itself rather than to a confounding change in mix proportions.

Table 2: Mix proportions per cubic metre of M40 concrete (control, PEG-400 and SAP mixes)

Material	Control mix (kg/m ³)	PEG-400 mix (kg/m ³)	SAP mix (kg/m ³)
Cement	400	400	288
PEG-400 / SAP	-	4	4
Water	160	148	148
Natural sand	660	690	690
Coarse aggregate (20 mm)	1197	1197	1197
Chemical admixture (superplasticizer)	4.11	4.11	4.11
Water-cement ratio	0.40	0.36	0.36

Mix ratio of the control mix: 1 : 1.93 : 2.91 (cement : fine aggregate : coarse aggregate).

3.3 Specimen Preparation and Curing

All materials were weigh-batched to an accuracy of $\pm 0.1\%$ using an electronic balance. Dry constituents were mixed for 2 minutes, after which approximately 70% of the mixing water was added and blended for a further 2 minutes; the remaining water, pre-mixed with the superplasticizer (and PEG-400 or SAP, where applicable), was then added and mixing continued until a uniform consistency was achieved. Fresh concrete was tested immediately for slump (IS 1199) and compaction factor. Cubes (150 × 150 × 150 mm) for compressive strength were cast in three layers with 35 tamping strokes per layer; beams (150 × 150 × 700 mm) for flexural strength were cast in two layers with approximately 100 strokes per layer; and cylinders (150 × 300 mm) for split tensile strength were cast in three layers with 30 strokes per layer. Specimens were demoulded after 24 hours and water-cured at $27 \pm 2^\circ\text{C}$ until testing at 7, 14 and 28 days, with a minimum of three specimens tested at each age for every mix.

3.4 Test Methods

Compressive strength was determined on 150 mm cubes at 7, 14 and 28 days in accordance with IS 516, using a calibrated compression testing machine at a loading rate of 140 N/mm²/min, with load applied to the cast side faces of the cube. Split tensile strength was determined on 150 × 300 mm cylinders loaded horizontally in the compression testing machine using a bearing jig, following the cylinder splitting test method. Flexural strength was determined on 150 × 150 × 700 mm beams under two-point (third-point) loading over a 400 mm span, so that a constant bending moment was generated within the middle third of the span, with strength computed from the failure load provided fracture occurred within this zone. Fresh concrete water quality, curing tank temperature ($27 \pm 2^\circ\text{C}$) and machine calibration were controlled throughout the test programme to minimise experimental variability.

4. Experimental Programme

Three trial mixes were prepared and tested: Trial Mix 1 (TM1), the plain M40 control with no internal curing agent; Trial Mix 2 (TM2), containing 1% PEG-400 and, separately, 1% SAP by weight of cement; and Trial Mix 3 (TM3), containing 2% PEG-400 and 2% SAP by weight of cement. Compressive strength was evaluated for all three trial mixes at both dosages, while split tensile and flexural strength were evaluated for the control and the 1% dosage mixes only, consistent with the scope of the experimental programme. All mixes were tested for workability immediately after mixing (Table 3) and for strength at 7, 14 and 28 days.

Table 3: Workability of trial mixes

Mix	Slump value (mm)	Compaction factor
TM1 (Control)	120	0.94
TM2 (1% dosage)	100	0.92
TM3 (2% dosage)	105	0.92

All mixes achieved a slump within the workable range of 80-150 mm, confirming that the target consistency for pumped placement was met across the dosage range examined; the reduction in slump between the control and dosed mixes reflects the additional viscosity contributed by PEG-400 and the water-absorbing action of SAP.

5. Results and Discussion

5.1 Compressive Strength

Table 4: Compressive strength of M40 concrete with PEG-400 and SAP (N/mm²)

Mix ID	PEG-400 (%)	SAP (%)	7-day (PEG/SAP)	14-day (PEG/SAP)	28-day (PEG/SAP)
TM1 (Control)	0	0	31.91	38.44	48.52
TM2	1	1	27.30 / 25.67	34.36 / 30.65	46.12 / 42.02
TM3	2	2	22.01 / 20.11	30.51 / 25.22	39.35 / 34.36

As shown in Table 4, the compressive strength of both the PEG-400 and SAP mixes was lower than that of the control mix at every age and every dosage tested, and this deficit widened as the dosage was increased from 1% to 2%. At 28 days, the control mix reached 48.52 N/mm², compared with 46.12 N/mm² for 1% PEG-400 (a reduction of about 5%) and 42.02 N/mm² for 1% SAP (a reduction of about 13%); at 2% dosage the reductions widened to about 19% for PEG-400 and 29% for SAP. At every age and dosage, PEG-400 outperformed SAP, and the 1% dosage outperformed the 2% dosage for both agents, in agreement with the optimum-dosage trend reported for PEG-400 by Ganesan and Palaniappan [7] and for SAP by Hamzah et al. [8].

This behaviour is consistent with the internal curing mechanisms of the two agents. PEG-400 acts primarily by forming a retentive film that slows evaporation and supports continued hydration without introducing discrete voids into the matrix, so its strength penalty relative to the control is comparatively modest and grows only gradually with dosage. SAP, in contrast, functions as a discrete water reservoir: once its absorbed water has been released to the surrounding paste, the swollen particle leaves behind a void of a similar size, and at higher dosage the cumulative volume of these voids becomes large enough to act as a stress concentration and crack-initiation site, which explains both the larger strength deficit for SAP at a given dosage and its more pronounced sensitivity to increasing dosage [3,16]. This mechanism is also consistent with reports that excessive SAP dosage can offset the benefit of continued hydration through void-induced weakening [1,8].

5.2 Split Tensile Strength

Table 5: Split tensile strength of M40 concrete with 1% PEG-400 and 1% SAP (N/mm²)

Mix ID	PEG-400 (%)	SAP (%)	7-day (PEG/SAP)	14-day (PEG/SAP)	28-day (PEG/SAP)
TM1 (Control)	0	0	3.05	3.34	3.76
TM2	1	1	2.72 / 2.68	3.24 / 3.10	3.65 / 3.55

The split tensile strength results (Table 5) follow the same qualitative trend as the compressive strength results: both curing agents produced a modest reduction relative to the control at 1% dosage, with PEG-400 consistently outperforming SAP at every age. By 28 days the gap had narrowed considerably relative to earlier ages (3.65 N/mm² for PEG-400 and 3.55 N/mm² for SAP, against 3.76 N/mm² for the control), indicating that continued internal moisture supply allows the tensile-resisting interfacial transition zone to develop more fully with age. This is consistent with the explanation offered for compressive strength: PEG-400 supports a more continuous, less void-affected paste matrix, giving it an advantage in resisting tensile splitting failure over SAP, whose water-release voids are more likely to act as crack-initiation points under tensile loading [1,6].

5.3 Flexural Strength

Table 6: Flexural strength of M40 concrete with 1% PEG-400 and 1% SAP (N/mm²)

Mix ID	PEG-400 (%)	SAP (%)	7-day (PEG/SAP)	14-day (PEG/SAP)	28-day (PEG/SAP)
TM1 (Control)	0	0	3.91	4.32	4.80
TM2	1	1	3.45 / 3.01	3.90 / 3.62	4.60 / 4.40

The flexural strength results (Table 6) mirror the compressive and split tensile trends. At 28 days, PEG-400 achieved 4.60 N/mm² (a reduction of about 4% relative to the 4.80 N/mm² control) while SAP achieved 4.40 N/mm² (a reduction of about 8%). PEG-400 outperformed SAP at every test age, with the gap between the two agents narrowing between 7 and 28 days, again indicating that the benefit of internal water retention becomes more evident as hydration proceeds. Because flexural strength is highly sensitive to surface-zone integrity and micro-cracking, the smaller void population associated with PEG-400 relative to SAP is the most probable reason for its consistently better flexural performance.

5.4 Comparative Discussion

Across all three mechanical properties investigated, the results establish a consistent hierarchy: control (no internal curing agent) performed best, followed by PEG-400 at 1% dosage, followed by SAP at 1% dosage, with 2% dosage mixes of both agents performing worse than their respective 1% counterparts. This ordering indicates that, within the dosage range and mix design examined in this study, neither PEG-400 nor SAP acted as a strength-enhancing admixture; rather, both agents represent a trade-off between improved internal moisture availability, which supports continued hydration, and a strength penalty arising from dilution of the cementitious matrix (in the case of PEG-400, primarily rheological) and from residual porosity after water release (in the case of SAP). PEG-400 consistently incurred the smaller penalty of the two agents and is therefore identified as the more strength-efficient internal curing agent for M40 concrete at the dosages tested, with 1% by weight of cement representing the more favourable of the two dosages examined. This finding is in line with several recent comparative studies that also identify approximately 1% PEG-400 as an effective dosage range and note a comparatively larger and more dosage-sensitive strength penalty for SAP [5,7,8].

It should be noted that strength alone does not capture the full value proposition of internal curing; PEG-400 and SAP are both reported in the wider literature to reduce autogenous shrinkage, plastic-shrinkage cracking and permeability-related durability defects, benefits that were outside the mechanical-strength-focused scope of the present study but are an important area for further investigation, discussed in Section 7.

6. Key Findings

1. Both PEG-400 and SAP, when used as internal curing agents in M40 concrete, produced compressive, split tensile and flexural strengths lower than those of the conventionally cured control mix, across all dosages and ages examined.
2. PEG-400 consistently outperformed SAP at an equivalent dosage for all three mechanical properties and at all curing ages (7, 14 and 28 days).
3. For both PEG-400 and SAP, a 1% dosage by weight of cement gave higher strength than a 2% dosage, identifying 1% as the more favourable dosage within the range examined.
4. At 28 days and 1% dosage, PEG-400 retained approximately 95% of the control mix compressive strength, compared with approximately 87% for SAP.
5. The performance gap between PEG-400 and SAP narrowed with curing age for split tensile and flexural strength, suggesting that the internal-curing benefit becomes more evident as hydration progresses.
6. All trial mixes achieved workability within the target range (80-150 mm slump), confirming that the internal curing agents did not compromise the pumpability of the M40 mix at the dosages tested.
7. The comparative strength penalty of SAP relative to PEG-400 is attributable to residual porosity left behind after the swollen SAP particles release their absorbed water, whereas PEG-400 retains moisture without introducing discrete voids.

7. Conclusions

1. Internal curing using PEG-400 and SAP is technically feasible in M40 grade structural concrete without loss of workability, both mixes achieving slump values within the design range at 1% and 2% dosage.
2. Within the dosage range examined (1% and 2% by weight of cement), neither PEG-400 nor SAP enhanced compressive, split tensile or flexural strength relative to the conventionally cured control mix; both agents instead produced a measurable strength reduction that increased with dosage.
3. PEG-400 is the more strength-efficient of the two internal curing agents examined, consistently outperforming SAP in compressive, split tensile and flexural strength at every curing age and dosage tested.

4. A dosage of 1% PEG-400 by weight of cement is identified as the more favourable of the two dosages examined, offering the closest strength match to conventional curing among the internally cured mixes.
5. SAP at 1% dosage remains a workable internal curing option where PEG-400 is unavailable, though it carries a larger compressive strength penalty (approximately 13% at 28 days) than PEG-400 (approximately 5% at 28 days) relative to the control mix.
6. The strength gap between PEG-400 and SAP narrows with curing age for tensile and flexural properties, indicating that the internal moisture reserve provided by both agents continues to support hydration beyond 7 days.
7. The comparative strength penalty associated with SAP is attributed principally to residual micro-voids left after water release, whereas PEG-400 supports hydration through a water-retentive film without introducing an equivalent void structure.
8. From a sustainability perspective, both agents reduce reliance on continuous external water curing, which is of practical value in water-scarce regions or on sites where consistent water curing is difficult to enforce, provided the associated strength trade-off is accounted for in design.
9. For M40 structural applications where mechanical strength is the governing criterion, PEG-400 at 1% by weight of cement is recommended as the more practical internal curing agent among those evaluated in this study.

8. Future Scope

The present study can be extended in several directions. First, the comparison of PEG-400 and SAP can be repeated across other concrete grades (M20, M30, M50 and higher) to establish whether the optimum dosage and the relative ranking of the two agents identified here for M40 concrete hold more generally. Second, a wider and more finely spaced dosage range, particularly below 1%, would help to identify a true optimum dosage at which internal curing benefits might outweigh the strength penalty observed in this study. Third, durability-related properties not covered in the present mechanical testing programme - including water absorption, sorptivity, chloride ion penetration, autogenous and drying shrinkage, and resistance to sulfate and acid attack - warrant systematic investigation, since the value of internal curing agents is often more pronounced in durability performance than in short-term strength. Finally, microstructural characterisation using SEM, XRD and mercury intrusion porosimetry would help to directly verify the void-formation mechanism proposed here to explain the comparative performance of PEG-400 and SAP, and could guide the development of modified SAP formulations with reduced void-related strength penalty.

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