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Scientific paper
ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.62638/ZasMat1336

Zastita Materijala 66 ()
(2025)

Study on the effectiveness of SAP, PEG-400, and PVA as self-curing agents: A comparative approach

ABSTRACT

Concrete's performance essentially depends on the hydration process, requiring adequate moisture and a controlled environment for curing. The traditional curing is challenging in water-scarce regions and in high-altitude areas. The self-curing concrete as an emerging sustainable and efficient alternative in conventional curing method scenarios and in challenging environments. Self-curing, or internal curing, is an innovative solution that ensures sufficient moisture for hydration and minimizes evaporation to enhance properties of concrete. This study explores the impact of various self-curing agents Superabsorbent Polymers (SAP), Polyethylene Glycol-400 (PEG-400), and Polyvinyl Alcohol (PVA) on the fresh and mechanical properties of self-curing concrete. The nine mix designs were developed, with self-curing agents incorporated at dosages of 1%, 2%, and 3% by mass of cement. The mechanical properties analysed include compressive strength,splitting tensile strength, and flexural strength, while workability was assessed using slump tests.The results expose that PEG-400 at 1% dosage the highest performance in terms of strength and workability, with compressive, tensile, and flexural strengths of 26.29 N/mm², 2.19 N/mm², and 2.27 N/mm², respectively. The SAP exhibited moderate performance with enhanced internal curing, while PVA offered balanced hydration benefits but lower strength compared to PEG-400. The increasing dosages of all agents led to a decline in mechanical performance due to reduced hydration efficiency and increased viscosity.The PEG-400 of optimizing self-curing agents to achieve a balance between curing efficiency and mechanical performance, contributing to the development of sustainable, high-quality concrete with reduced water consumption.

Keywords: *Self-curing concrete, PEG-400, SAP, PVA, mechanical strength, sustainable construction*

1. INTRODUCTION

Concrete is a widely used construction material due to its workability and strength. Its durability is largely controlled by completing the hydration of cement, which requires sufficient moisture and favourable curing conditions. Improper curing can lead to incomplete hydration, porous concrete, reduced strength, and increased susceptibility to environmental attacks, resulting in accelerated corrosion, structural deterioration, and drying-shrinkage cracking [1, 2]. Traditional curing methods require high water resources, making it difficult in water-scarce regions and high-altitude areas to achieve adequate curing [3]. The construction industry consumes large amounts of water, necessitating the development of innovative solutions to minimize water consumption without compromising concrete quality [4].

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Rad primljen: 07.01.2025.
Rad korigovan: 02.05.2025.
Rad prihvaćen: 10.05.2025.

Self-curing concrete is an alternative to traditional curing methods, addressing water scarcity and improper curing. It uses internal curing to ensure adequate hydration, conserving water resources and saving time and labour. This consistent hydration leads to uniform strength development and durability enhancement, making it a suitable solution for current construction challenges [5]. Self-curing concrete uses various agents to maintain water within itself during mix preparation. The research on self-curing agents includes water-soluble polymers, superabsorbent materials, and hydrophilic compounds. Superabsorbent polymers (SAPs), polyethylene glycol-400 (PEG-400), and polyvinyl alcohol (PVA) are most commonly used due to their ability to increase hydration and reduce evaporation [6].

SAPs reduce shrinkage due to hydration-induced water consumption, minimizing cracking and durability risk. They also prevent self-curing or internal curing, as moisture evaporation in concrete mix dries faster than wetting, which can affect the hydration process and reduce strength development in large structures or high- SAPs are ionic polymers that absorb and retain water within their structure, ensuring moisture levels during concrete hydration [7, 8]. This is beneficial for low water content concrete mixes where conventional curing may not provide enough moisture temperature areas [9].SAPs enhance the hydration process in concrete, even in water-starved conditions, allowing better microstructure formation and enhanced properties. However, their incorporation requires careful optimization, as higher dosages may decrease mechanical strength due to excess water hindering bonding. Accurate dosing is crucial to enjoy SAP benefits without sacrificing strength. An optimized SAP can create a sustainable hydration solution and mitigate cracking and shrinkage problems, especially in self-curing concrete applications [5, 10].

PEG-400 is an efficient self-curing agent that ensures proper hydrogen bonding with water molecules in concrete mixtures, allowing for better hydration and better strength development. It maintains internal moisture levels, preventing surface moisture loss, which is beneficial in dry or hot climates where rapid evaporation can cause weaker concrete [11]. PEG-400 also prevents early age cracking and shrinkage, enhancing early strength and is particularly useful for prefabricated concrete elements or projects requiring rapid strength gains [12]. PEG-400 aids in moisture retention in concrete during early stages, but excessive usage can negatively affect its mechanical properties. Overdosing can disrupt the cement paste's structural framework and reduce particle bonding, leading to deterioration in strength and durability. Compatibility with other admixtures and additives is also crucial. To maximize effective ness, dosage needs to be optimized to strengthen early hydration without compromising long-lasting durability and mechanical properties [5, 13].

PVA is a versatile additive that enhances concrete's workability self-curing and. It acts as a lubricant between cement particles, allowing them to move smoothly and improve the concrete mix's consistency. PVA also aids in retaining moisture within the concrete matrix, which is crucial for hydration and strength build-up over time. This moisture supports cement particle reactions, completing hydration uniformly, especially during early stages of strength gain. PVA's unique properties make it an attractive addition to concrete construction. Self-curing concrete with PVA internal retention reduces the need for external curing methods. However, overuse of PEG-400 and PVA can negatively affect the concrete's long-term performance. Excessive use increases pore structure, causing shrinkage, cracking, and chemical attack, potentially reducing concrete durability. PVA increases workability and hydration, but its amount needs to be adjusted to prevent long-term damage. Proper dosage and careful integration with other self-curing agents are essential for optimizing PVA in concrete mixes [5, 14, 15].

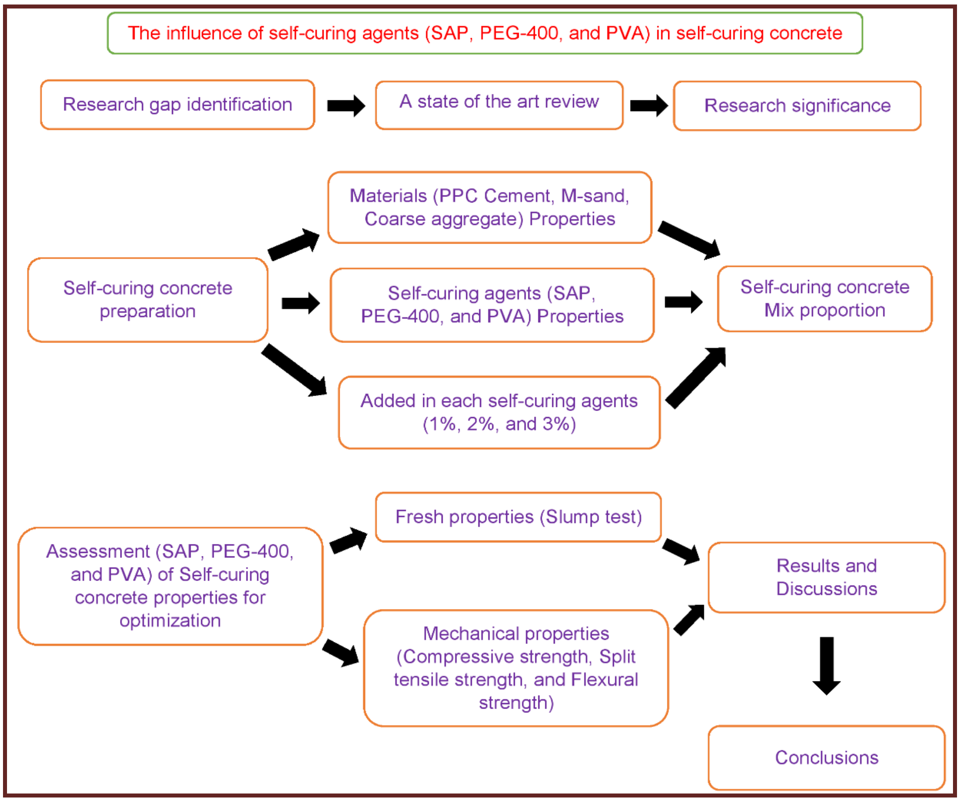

Figure 1. To identify the aim of study

2. RESEARCH SIGNIFICANCE

This study investigates the influence of different self-curing agents such as Superabsorbent Polymers (SAP), Polyethylene Glycol-400 (PEG-400), and Polyvinyl Alcohol (PVA) at varying dosages levels of 1%, 2% and 3% respectively on the mechanical properties (compressive strength, split tensile strength, and flexural strength) of M_{20} grade concrete. The main objective of this study is to identify the ideal self-curing agent and dose in order to bring out the possibility of improving the sustainable solution for the self-curing concrete. High dosage, however, might adversely affect the concrete's mechanical strength, hence careful optimization is required [16–18]. The detailed flow of this research study is given below in the Fig.1

3. MATERIALS USED

3.1. Cement

The Portland pozzolanic cement (PPC) of grade 53 was utilized in the experimental study. PPC is utilized in accordance with Indian Standard IS 12269-1987 [16]. Since it has a lesser heat of hydration at early ages and able to achieve higher durability. According to preliminary testing, this cement has a standard consistency of 32.5%, a specific gravity of 3.12, an initial setting time of 35 minutes, and a final setting time of 457 minutes and other properties such as compressive strength is 35 N/mm^2 respectively.

3.2 Fine aggregate

M-sand from a local source, as classified according to Zone II of IS: 383-2016 criteria, was utilized for this experimental investigation. The choice of M-sand was decided because it is fully concordance with the size distribution and the characteristics requirements [17]. The M-sand utilized in this investigation had a bulk density of 1640 kg/m^3, a specific gravity of 2.58, a fineness modulus of 2.23, a capacity to absorb water of 2.45%, and SO_3 content is 0.40% by mass respectively.

3.3. Coarse aggregate

A locally accessible coarse aggregate with a maximum size of 20 mm in accordance with IS: 383-2016 specifications [17], was utilized for this study. From the initial testing, it is found that, the bulk density of the coarse aggregate is 1728 kg/m^3, its specific gravity is 2.68, its fineness modulus is 6.54, and its water absorption capacity is 0.45%. Additionally, it is found that the aggregate's crushing value is 23.5%, impact strength is 21.5% and SO_3 content is 0.92% by mass.

3.4. Water

The water used for this study has met the required quality criteria and observed that there is no detrimental impact on the mixes characteristics. The water used is in complied with IS: 456-2000's standards, including having a pH value of 7.1 which quite fit in the acceptable range between 6.5 and 58.0 [18].

3.5. Self-curing agents

As described earlier, three self-curing agents Superabsorbent Polymers (SAP), Polyethylene Glycol-400 (PEG-400), and Polyvinyl Alcohol (PVA) were used in this study. The basic properties such as appearance, colour, density, molecular weight, particle size, pH and specific gravity of each of the self-curing agents are presented in the Table 1.

Table 1. Properties of self-curing agents

S.No	Property	SAP	PEG-400	PVA
1	Appearance	powder	Viscous liquid	Slightly cloudy liquid
2	Colour	White	Colourless	Colourless
3	Density	0.9 g/cm^3 (Dry state)	1.13 g/cm^3 at 20°C	1.12 g/cm^3 at 20°C
4	Molecular Weight	-	400 g/mol	-
5	Particle Size	500 µm	-	-
6	pH	7.5	7.3	7.1
7	Specific gravity	0.92	1.12	1.23

SAP is an ionic polymer, because it can collect and retain the large volume of water and gradually release the water during hydration process. This property helps in the reduction of autogenic shrinkage, especially for the concrete mixes with lower water content and also for the conditions where water curing is impossible [19-21].PEG-400 binds to the water molecules and thus forming hydrogen bonds. This process lowers the vapour pressure and thereby preventing the loss of moisture from the concrete surface. In the early phases of curing, this retained moisture helps in achieving better hydration and strength development [5, 22, 23]. PVA has a lubricating effect between the cement particles and thereby reducing water bleeding, which enhances the flow ability of concrete. It helps in supporting the strength development process by keeping the internal moisture, which is favourable for facilitating the hydration processes. The dosages must be careful, at larger dosages level, mechanical properties of concrete may get affected [24-26].

3.6. Mix proportion & casting

In this experimental investigation, nine different self-curing concrete mixtures were made in the proportion of 1:1.51:3.02 with a w/c ratio of 0.45 as per the confirmation of IS: 10262-2009 codal provisions [27]. The primary objective of the study is to assess the influence of the various self-curing agents, like SAP, PEG-400, and PVA, at different dosage levels of 1%, 2% and 3% on the M_{20} grade concrete. Table 2 indicates the mix proportions of the materials used for self-curing concrete made up of various self-curing agents.

Table 2. Mix proportions of conventional and self-curing concrete with various self-curing agents

Mix id	Self-curing agents	Self-curing agents (kg/m^3)	Cement (kg/m^3)	M-sand (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
CC Mix	---	---	420.25	634.58	1268.48	186.23
MSP1	1% SAP	4.20	420.25	634.58	1268.48	186.23
MSP2	2% SAP	8.40	420.25	634.58	1268.48	186.23
MSP3	3% SAP	12.60	420.25	634.58	1268.48	186.23
MPG1	1% PEG-400	4.20	420.25	634.58	1268.48	186.23
MPG2	2% PEG-400	8.40	420.25	634.58	1268.48	186.23
MPG3	3% PEG-400	12.60	420.25	634.58	1268.48	186.23
MPA1	1% PVA	4.20	420.25	634.58	1268.48	186.23
MPA2	2% PVA	8.40	420.25	634.58	1268.48	186.23
MPA3	3% PVA	12.60	420.25	634.58	1268.48	186.23

Cement, M-sand, and coarse aggregates were mixed together in a dry manner for about 3 minutes in a pan mixer. Then any one of the self-curing agents SAP, PEG-400, and PVA were added with the water according to the mix proportion specified and mixed for further 2 to 3 minutes so that wet mixing was properly completed with adequate consistency. The prepared self-curing concretes were cast in the moulds of cube of size 100 mm x 100 mm x 100 mm, cylinder of size 100 mm x 200 mm, and prism of size 100 mm x 100 mm x 500 mm with proper compaction allowing it to occupy all spaces in the mould. After casting, the specimens were allowed for 24 hours and then demoulded. Then the specimens were placed at ambient conditions for the period of 28 days to test the hardened properties [28-32]. Fig. 2 representative the preparation of self-curing concrete with different self-curing agents.

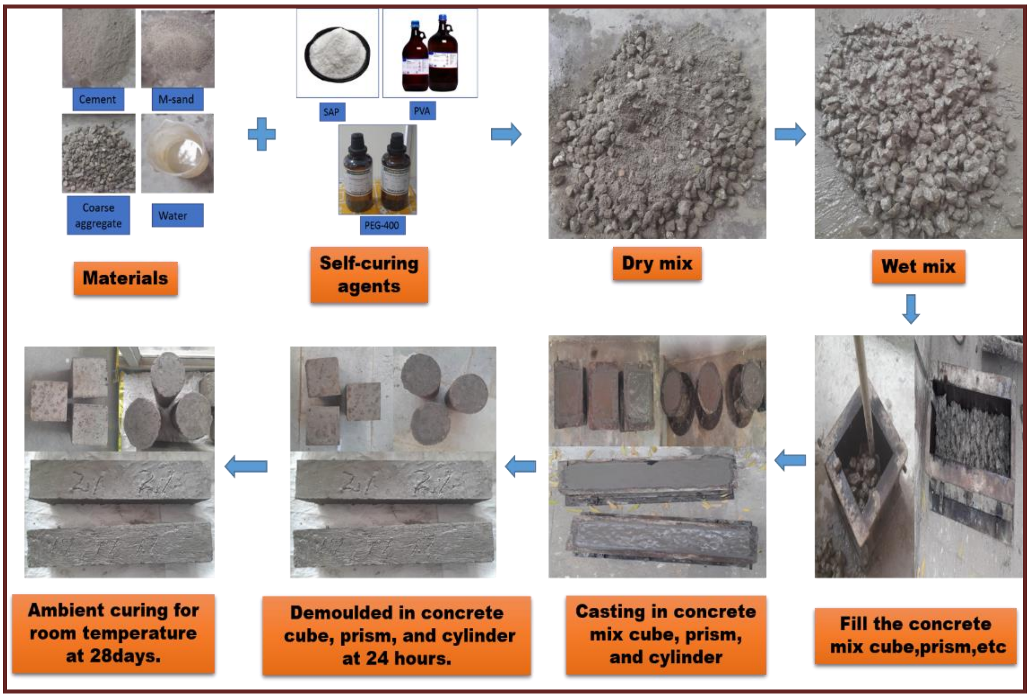

Figure 2. Mixing and Casting of Specimens

3.7. Experimental testing

Fresh properties of the self-curing concrete made up of various self-curing agents such as SAP, PEG-400, and PVA were tested for workability using the slump test. Mechanical properties such as compressive strength, splitting tensile strength, and flexural strength were conducted on self-curing concrete specimens of cubes, cylinder and prism respectively at the age of 28 days of curing at ambient conditions as per 516:1959 [33].

The tests on mechanical properties were performed on a 200 TON capacity compressive testing machine and a 400 KN capacity universal testing machine as shown in Fig. 3.

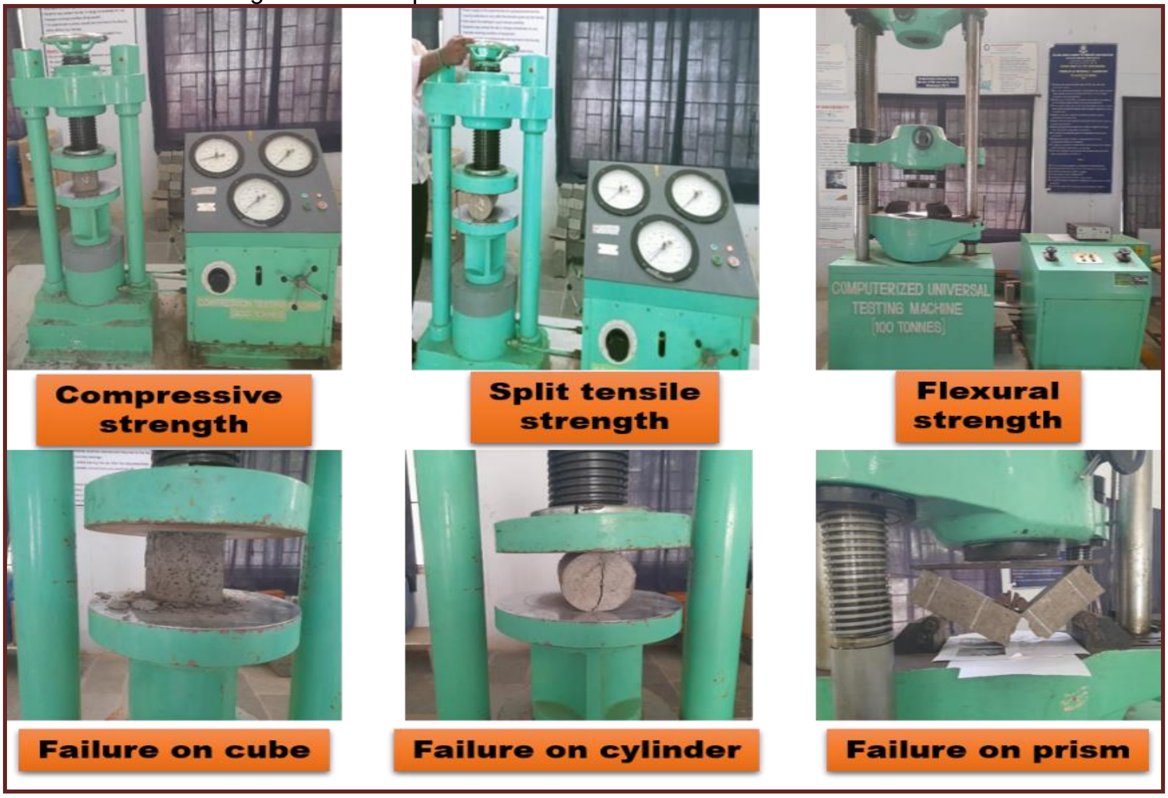

Figure 3. Experimental testing on specimens

4. RESULT AND DISCUSSION

4.1. Slump test

Table 3 presents the results of a measurement of the workability of conventional andvarious self-curing concrete mixtures using self-curing agents of SAP, PEG-400, and PVA. Fig.4 indicates the variation of slump values for the conventional mix andvarious self-curing agents (PVA, PEG-400, and SAP). The conventional concrete (control mixCC), without self-curing agents, achieved a slump value of 70 mm.

Table 3. Fresh and Mechanical properties of conventional and self-curing concrete based on self-curing agents

Mix id	Self-curing agents	Slump test in (mm)	Compressive strength (N/mm^2)	Splitting tensile strength (N/mm^2)	Flexural strength (N/mm^2)
CC Mix	---	70	20.18	1.09	1.03
MSP1	1% SAP	87	24.65	1.82	1.95
MSP2	2% SAP	79	23.21	1.48	1.52
MSP3	3% SAP	73	22.25	1.20	1.23
MPG1	1% PEG-400	108	26.29	2.19	2.27
MPG2	2% PEG-400	95	24.51	1.78	1.93
MPG3	3% PEG-400	80	23.36	1.36	1.51
MPA1	1% PVA	85	22.80	1.65	1.68
MPA2	2% PVA	76	21.58	1.29	1.35
MPA3	3% PVA	71	20.53	1.15	1.10

The addition of different self-curing agents, namely PVA, PEG-400, and SAP, led to an increased slump value than the conventional concrete. Since the PEG-400 retains water and has lubricating qualities, it had the highest slump values, measuring 108 mm at 1% (MPG1). At high viscosity, the slump value decreased to 80 mm when the dosage was increased to 3% (MPG3), further restricting particle mobility. The most significant impact on workability was shown in SAP, where slump values dropped from 87 mm at 1% (MSP1) to 73 mm at 3% (MSP3), mostly due to water absorption, which reduced the amount of free water in the mixture while simultaneously increasing internal curing. The PVA mixes showed a slump at moderate values, ranging from 85 mm at 1% (MPA1) to 71 mm at 3% (MPA3), despite their general tendency to thicken their mixes. These findings show that PEG-400 is ideal for workability-intensive applications such as self-curing concrete. SAP reduces workability but is beneficial for internal cures and shrinking issues. PVA provides in a balancing way of promoting hydration while maintaining moderate workability. The findings highlights an optimizing dosage to achieve workability within the intended curing performance, with each agent tailored to distinct construction requirements.

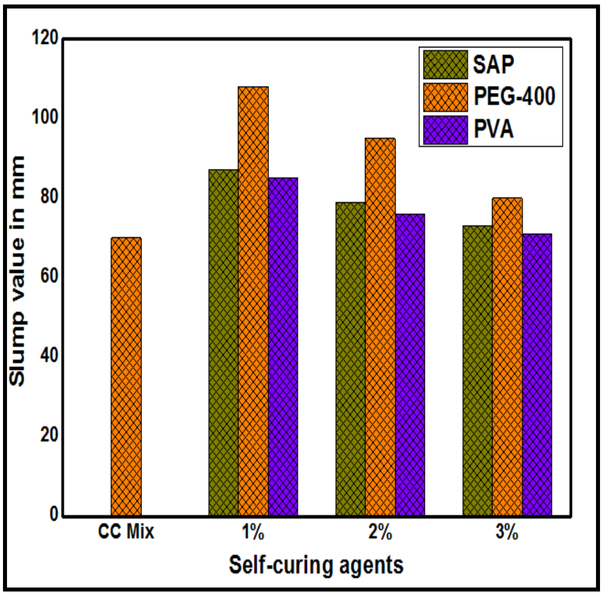

Figure 4. Test results of Slump test of conventional and self-curing concretes

4.2. Compressive strength

Table 3 shows the experimental test results of compressive strength of conventional and self-curing concrete mixes with varying dosages of self-curing agents (SAP, PEG-400, and PVA). Fig.5 depicts the variance in compressive strength values due to conventional concrete and different self-curing chemicals and dosage levels. The conventional concrete, showed a compressive strength value of 20.18 N/mm². The addition of various self-curing agents like PVA, PEG-400 and SAP gave increasing values of compressive strength compared to the control mix. The PEG-400-based mixes achieved the highest compressive strength, reaching 26.29 N/mm² at 1% dose (MPG1) which is 6.6% greater than SAP's 1% (MSP1) and 15.3% higher than PVA (MPA1). It is observed that, the compressive strength is dropped as dosage level is increased, by 6.8% at 2% (MPG2) and 11.1% at 3% (MPG3) compared to 1%. This degradation is caused by high water retention and increased viscosity factors, which slows down the hydration process. SAP-based mixes had a moderate compressive strength of 24.65 N/mm² at 1% dosing (MSP1), decreasing by 5.9% at 2% (MSP2) and 9.8% at 3% (MSP3). Although SAP promotes internal curing, the absorbed water reduces free water for hydration in cement, resulting in a slight decrease in the strength. PVA-based mixes had the lowest compressive strength among all, by dropping from 22.80 N/mm² at 1% (MPA1) to 20.53 N/mm² at 3% (MPA3). The drop percentages were 5.3% at 2% (MPA2) and 9.9% at 3% (MPA3). PVA's setting effects cause delays in hydration efficiency and strength development. PEG-400 will be preferred for situations requiring greater strength. SAP and PVA provide better curing and moisture retention. The optimal doses should be significant in balancing workability, curing, and strength.

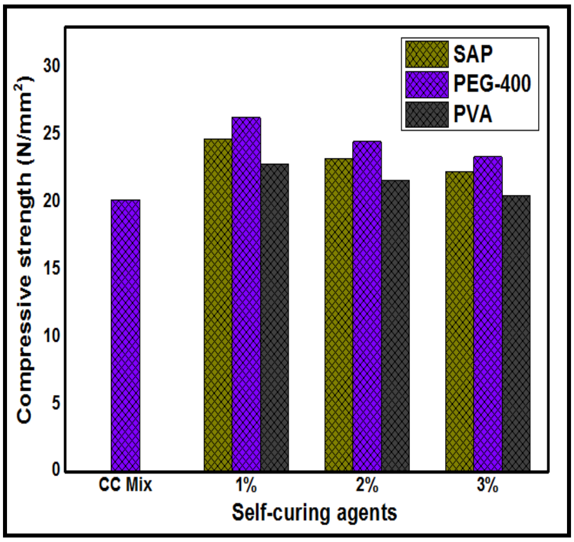

Figure 5. Test results of compressive strength of conventional and self-curing concretes

4.3. Splitting tensile strength

Table 3 shows the splitting tensile strength test results of conventional and self-curing concrete mixtures with varying dosages of self-curing agents such as SAP, PEG-400, and PVA. The effects of these without and with self-curing agents on tensile performances at different dose levels were shown in Fig. 6. The conventional concrete showed a splitting tensile strength of 1.09 N/mm². The incorporation of self-curing agents like PVA, PEG-400, and SAP leads to an increase in the splitting tensile strength values compared to the control mix. The tensile strength of the mix was highest for PEG-400 mix, with the maximum tensile strength of 2.19 N/mm² at 1% (MPG1), which is 20.3% more than SAP (MSP1) and 32.7% more than PVA (MPA1) with the same amount of dosage level. However, tensile strength decreased with the increase in dosage, which it dropped by 18.7% at 2% (MPG2) and 37.9% at 3% dosage level than at 1% dosage, and this is happened because of the weakened effect of the interfacial bond strengths by the increase in viscosity of the mix. While the split tensile strength test results is 1.82 N/mm² for 1% (MSP1) and further it is decreased by 18.7% (MSP2) and 34.1% (MSP3) for the dosage levels 2% and 3% respectively. This is because the SAP was absorbing water, which decreased the amount of water available for hydration and, as a result, there is a subsequent reduction in the tensile strength. The PVA mixes exhibited the lowest tensile strength, ranging from 1.65 N/mm² at 1% (MPA1) to 1.15 N/mm² at 3% (MPA3). Because of the setting effect that inhibited reverse hydration, the PVA mixes with the lowest tensile strength ranged from 1.65 N/mm² at 1% (MPA1) to 1.15 N/mm² at 3% (MPA3), which were declines of 21.8% at 2% (MPA2) and 30.3% at 3% (MPA3). PEG-400 considerably increased the tensile strength, while SAP and PVA are helpful for internal curing but show worse behaviour against tensile performance at higher dosages levels.

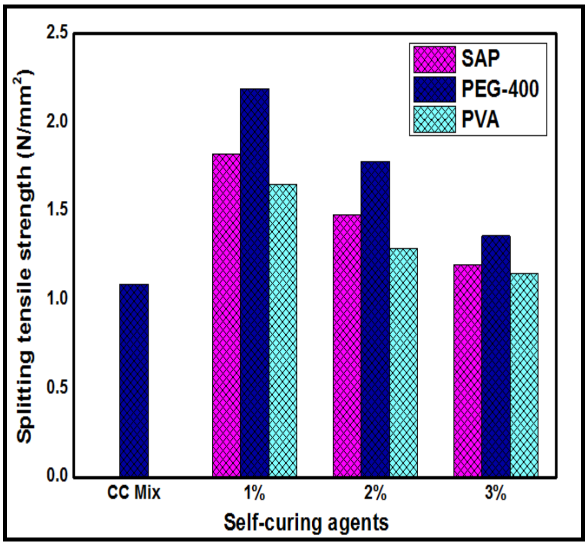

Figure 6. Test results of splitting tensile strength of conventional and self-curing concretes

4.4. Flexural strength

The flexural strength performance of conventional and self-curing concrete with different dosage levels of SAP, PEG-400, and PVA is shown in Table 3. The flexural strength results of the conventional and self-curing concrete mixes with different SAP, PEG-400, and PVA doses are shown in Fig.7. The flexural strength of the conventional concrete, which did not contain any self-curing agents, was 1.03 N/mm². With the addition of self-curing agents like PVA, PEG-400, and SAP, the values for flexural strength were higher than the control mix. The maximum flexural strength was achieved by the PEG-400 based mixtures, attaining 2.27 N/mm² at a 1% dosage (MPG1), which is 35.1% greater than that of PVA (MPA1) and 16.4% higher than that of SAP (MSP1). However, strength decreased by 15% at 2% (MPG2) and 33.5% at 3% (MPG3) as dosage levels increased. This is to be expected because of the higher viscosity which weakens the inter particle bonding strength of the self-curing concrete. At 1% dosage (MSP1), the SAP-based mixes' flexural strength was 1.95 N/mm2, but it decreased by 22% at 2% (MSP2) and 37% at 3% (MSP3). It corresponds with SAP's water absorption, which reduces the amount of water that is free to be used for hydration and, as a result, this lowers the mix's performance. PVA-based mixes exhibited the lowest flexural strength, measuring just 1.68 N/mm2 at 1% dosing, which decreased by 19.6% at 2% and 34.5% at 3%.This is because it has a condensing action that restricts bond formation and hydration. In general, PEG-400 suggests higher flexural strength, whereas PVA and SAP rely more on internal curing but at larger dosages compromise bending resistance. Hence, the optimal dosages ensure a balance between the mechanical performance and curing advantages.

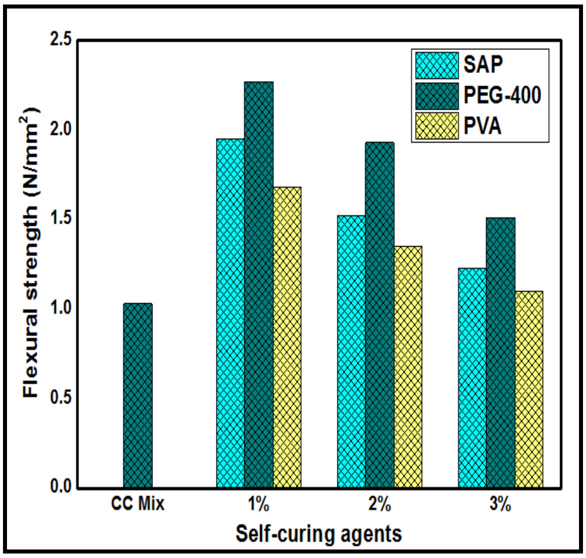

Figure 7. Test results of flexural strength of conventional and self-curing concretes

5. CONCLUSION

The effects of the self-curing chemicals SAP, PEG-400, and PVA on the mechanical and fresh characteristics of conventional and self-curing concrete that has been cured in water and ambient circumstances have been studied. The major findings of this study are briefly described as follows:

1. The conventional concrete without self-curing agents, exhibited workability with a slump value of 70 mm. It had compressive, splitting tensile, and flexural strengths of 20.18 N/mm², 1.09 N/mm², and 1.03 N/mm², respectively.
2. With a dosage of 1%, PEG-400 had its highest slump value, of 108 mm, due to its exceptional water-retention ability. PVA and SAP has demonstrated a moderate level of workability. SAP's free water availability is decreased as a result of water absorption, while PVA has a condensing effect on the mix, which results in comparatively low slump values at higher dosages.
3. PEG-400 exhibited its finest performance at 1% dosage, with compressive strength of 26.29 N/mm², split tensile strength of 2.19 N/mm², and flexural strength of 2.27 N/mm², all of which were attributed to its capacity to retain water. By keeping internal curing and hydration in balance, SAP demonstrated moderate strength. As a result of its delayed hydration effects, PVA had the lowest strength.
4. At 1% dosage level, the optimum self-curing agents of PEG-400 were found to be most active self-curing agent providing improved workability and mechanical properties. At higher dosage level, SAP reduces strength and workability but is helpful in reducing shrinkage and encouraging internal curing. Although PVA advises mild hydration assistance, delayed hydration lowers mechanical performance.
5. Based on the study, it is found that, the PEG-400 is well suited for high-performance self-curing concrete. SAP is appropriate for shrinkage control applications where workability and strength are critical, but PVA can be utilized for applications needing curing improvement with significant endurance.

Acknowledgments

The author Ganesan Sundaramoorthy is grateful to the International Research Centre (IRC), Kalasalingam Academy of Research and Education (KARE) for providing University Research Fellowship (URF) and instrumental research facilities

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Izvod

STUDIJA O EFIKASNOSTI SAP, PEG-400 I PVA KAO SREDSTAVA ZA SAMOOČVRŠĆAVANJE: UPOREDNI PRISTUP

Performanse betona u suštini zavise od procesa hidratacije, što zahteva odgovarajuću vlagu i kontrolisano okruženje za očvršćavanje. Tradicionalno očvršćavanje je izazovno u regionima sa oskudicom vode i na velikim nadmorskim visinama. Samoočvršćavajući beton je nova održiva i efikasna alternativa u scenarijima konvencionalnih metoda očvršćavanja i u izazovnim okruženjima. Samoočvršćavanje, ili unutrašnje očvršćavanje, je inovativno rešenje koje obezbeđuje dovoljnu vlagu za hidrataciju i minimizira isparavanje kako bi se poboljšala svojstva betona. Ova studija istražuje uticaj različitih sredstava za samoočvršćavanje - superapsorbujućih polimera (SAP), polietilen glikola-400 (PEG-400) i polivinil alkohola (PVA) - na sveža i mehanička svojstva samoočvršćavajućeg betona. Razvijeno je devet mešavina, sa sredstvima za samoočvršćavanje ugrađenim u dozama od 1%, 2% i 3% po masi cementa. Analizirana mehanička svojstva obuhvataju čvrstoću na pritisak, zateznu čvrstoću na cepanje i čvrstoću na savijanje, dok je obradivost procenjena testovima sleganja. Rezultati pokazuju da PEG-400 u dozi od 1% ima najbolje performanse u pogledu čvrstoće i obradivosti, sa čvrstoćama na pritisak, zatezanje i savijanje od 26,29 N/mm², 2,19 N/mm² i 2,27 N/mm², respektivno. SAP je pokazao umerene performanse sa poboljšanim unutrašnjim očvršćavanjem, dok je PVA ponudio uravnotežene prednosti hidratacije, ali nižu čvrstoću u poređenju sa PEG-400. Povećanje doza svih agenasa dovelo je do pada mehaničkih performansi zbog smanjene efikasnosti hidratacije i povećane viskoznosti. PEG-400 optimizuje sredstva za samoočvršćavanje kako bi se postigla ravnoteža između efikasnosti očvršćavanja i mehaničkih performansi, doprinoseći razvoju održivog, visokokvalitetnog betona sa smanjenom potrošnjom vode.

Ključne reči: *Samoočvršćavajući beton, PEG-400, SAP, PVA, mehanička čvrstoća, održiva gradnja*

Naučni rad
Rad primljen: 07.01.2025.
Rad korigovan: 02.05.2025.
Rad prihvaćen: 10.05.2025.

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