www.svedbergopen.com/ijaiml *International Journal of Artificial Intelligence and Machine Learning*

SvedbergOpen
DISSEMINATION OF KNOWLEDGE

International Journal of Artificial Intelligence and Machine Learning

Publisher's Home Page: https://www.svedbergopen.com/

Research Paper Open Access

Multi-Performance Optimization of PVA Fiber Dosage for Enhanced Mechanical Strength, Crack Resistance and Durability of Fiber-Reinforced Concrete

[1*]Dr. M. Vanathi, [2]Satheskumar. K, [3]Dr AHL Swaroop, [4]Ankesh SB, [5]Dr. Aravindan. A, [6]Baskar. S, [7]Dr. K. Mohan das

[1*]Professor, Department of Civil Engineering, Dr.M.G.R Educational and Research institute, Maduravoyal , Chennai, Tamil nadu, India. E-mail: vanathi.ksm@gmail.com
[2]Assistant professor, Department of Civil Engineering,Jai shriram Engineering College, Avinashipalayam, Tiruppur, Tamil Nadu Pin 638660, India. E-mail: sathescivil@gmail.com
[3]Associate Professor and HoD, Department of Civil Engineering ,Seshadri Rao Gudlavalleru Engineering College ,Gudlavalleru, Andhra Pradesh, India. E-mail: ahlscivil@gmail.com
[4]Assistant Professor, Department of Civil Engineering, Dr. Ambedkar Institute Of Technology, Bengaluru 560056, Karnataka, India. E-mail: ankeshsb2005.cv@drait.edu.in
[5]Professor, Department of Civil Engineering, Koneru Lakshmaiah Educational Foundation, Andhra Pradesh, Guntur, 522502, India. E-mail: aaravindancivil@gmail.com
[6]Assistant Professor, Department of Civil Engineering,Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, Chennai, Tamil Nadu, India. E-mail: rhodabaskar@gmail.com.
[7]Professor, Department of Civil Engineering, CMR College of Engineering & Technology, Hyderabad, India. E-mail: kmohandas11780@gamil.com.
*Corresponding author mail id: vanathi.ksm@gmail.com

Abstract
Polyvinyl alcohol (PVA) fiber-reinforced concrete has attracted considerable attention because of its ability to bridge microcracks, improve tensile and flexural performance, and modify the brittle failure characteristics of conventional concrete. However, increasing the fiber content beyond an optimum level can reduce workability, promote fiber clustering and increase entrapped porosity, thereby limiting the improvement in mechanical and durability properties. The present study investigates the influence of PVA fiber dosage on the fresh, mechanical, crack-control and durability characteristics of M40 concrete and establishes an optimum fiber dosage using a multi-performance optimization framework. Nine concrete mixtures containing 0, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75 and 2.00% PVA fiber by volume were considered. Compressive strength, splitting tensile strength, flexural strength, flexural toughness, water absorption, sorptivity and chloride penetration were evaluated. Crack width and crack density were also considered as indicators of crack-control performance. The numerical dataset presented in this manuscript is an illustrative/simulated dataset developed to demonstrate the proposed research methodology and must be replaced by experimentally measured values before submission as an experimental research article. The simulated results indicate a progressive improvement in tensile and flexural performance up to approximately 1.25–1.50% PVA fiber, followed by a reduction in performance at higher dosages. The optimum region is attributed to efficient crack bridging and stress transfer without excessive fiber agglomeration. A desirability-based multi-objective optimization framework is proposed to simultaneously maximize mechanical performance and minimize permeability-related indicators. The study demonstrates a methodology for determining PVA dosage based on multiple performance criteria rather than compressive strength alone.

Keywords: PVA fiber; fiber-reinforced concrete; mechanical strength; durability; crack control; sorptivity; chloride penetration; multi-objective optimization; M40 concrete.

1. Introduction

Concrete is the most widely used construction material because of its high compressive strength, availability and adaptability to different structural applications. Nevertheless, conventional concrete exhibits relatively low tensile strength, limited deformation capacity and a tendency toward localized cracking. Microcracks develop within the cementitious matrix because of drying shrinkage, thermal effects, external loading and volume changes. Once these cracks become interconnected, aggressive agents such as water, chlorides, sulphates and acids can penetrate into the concrete and accelerate deterioration.

Fiber-reinforced concrete has been developed to address several of these limitations. Fibers distributed throughout the cementitious matrix can bridge cracks and transfer tensile stresses across developing fracture planes. Polyvinyl alcohol fiber is particularly attractive because of its high tensile strength, hydrophilic character and strong interaction with cementitious matrices. PVA fibers can therefore provide effective microcrack bridging and improve the post-cracking response of cement-based composites. Previous reviews have reported that PVA fibers can substantially alter the crack-control and mechanical response of cementitious composites.

The effectiveness of PVA fiber is strongly dependent on its volume fraction. At relatively low dosages, fibers may be insufficient to form an effective crack-bridging network. As the dosage increases, the number of fibers intersecting a developing crack increases, improving tensile stress transfer, flexural resistance and energy absorption. However, excessive fiber content increases internal friction, reduces workability and can produce fiber entanglement and clustering. The resulting non-uniform distribution can introduce weak zones and increase porosity.

A recent 2026 investigation of PVA-reinforced engineered cementitious composites examined fiber dosages from 0 to 2.5% and reported an optimum around 1.5% for the mechanical properties investigated. The authors also reported reduced workability and fiber clustering at higher dosages. This finding demonstrates that optimization of PVA content is important but also indicates that a simple repetition of a dosage-strength relationship would provide limited novelty.

Durability is another major consideration. Crack bridging by PVA fibers can reduce crack width and protect the carriers of aggressive substances. However, the effect of fiber addition on permeability is not constant. At high fiber contents, poor dispersion and additional voids will dilute the benefits of crack control.

Recently, PVA fiber dosage can produce a durable response in an aggressive exposure. So the optimal PVA content should not be determined only by the compressive strength. The dosage of one should not necessarily have the lowest water absorption, the best flexural toughness or best crack-control.

The purpose of this work is therefore to develop a multi-performance framework for selecting the optimum PVA fiber dosage in concrete. The new results are based on fresh properties, compressive strength, splitting tensile strength, flexural strength, toughness, crack-control and durability. The proposed framework combines experimental performance indicators with statistical analysis and desirability-based optimization.

2. Literature Review

The use of PVA fibers in cement-based materials is mainly related to the need to improve the behaviour of concrete after cracking. Conventional concrete can withstand strong compressive stress but its tensile resistance is relatively low.

Once tensile cracking starts, load-carrying capacity can be quickly reduced because there is no stress mechanism that can move through the crack. PVA fibers offer such a mechanism. When fibers touch a developing crack, they will carry some of the tensile stress and delay cracking further. The response will depend not only on the strength of the fiber but on the bond between the fiber and the cement paste and also on the distribution of the fiber and the properties of the matrix.

The amount of PVA fiber introduced into concrete is of great importance. A small amount may not provide enough fibers across the potential crack surface to provide effective bridging. Increasing the fiber volume generally increases the number of bridges available and can improve tensile and flexural properties.

This improvement is not continuous however. As the fiber concentration increases, mixing becomes more difficult and the probability of fiber entanglement also increases. Poor dispersion can result in areas with large fiber concentration in a region with little fibers. This type of non-uniformity has implications for strength and durability. The response to PVA dosage is not linear as it has been shown recently in experimental studies.

In the recent study of PVA-reinforced engineered cementitious composites, the fiber content of 2.5% was considered and the intermediate dosage is found to be the best overall mechanical response. They also demonstrated that more fiber content is associated with decreased workability and fiber clustering problems. This point is important because it means that the use of more fiber is not necessarily the best way to improve concrete performance. PVA fibers are more impactful in tensile and flexural properties than in compressive strength. Under compression the fibers are primarily involved in the development of internal cracks and their propagation.

They contribute little in load carrying because they are very effective in tension. In contrast, under tensile or flexural loading the fibers become active after cracking and can transfer stress across the cracked region. This is why the tensile strength, flexural resistance and energy absorption improvements are generally more pronounced than changes in compressive strength.

Crack width is another important parameter when evaluating PVA-reinforced concrete. A conventional concrete specimen may develop a relatively small number of visible cracks with considerable opening. PVA fibers can distribute the deformation over a larger number of finer cracks. The effectiveness of this mechanism

depends on fiber spacing, fiber orientation and interfacial bond. If an adequate number of fibers cross a developing crack, crack opening can be restrained and additional cracks can develop elsewhere in the specimen. This distributed cracking behavior is one of the main characteristics associated with PVA-based engineered cementitious composites.
Crack control is also closely related to durability. Water and dissolved aggressive substances can enter concrete through capillary pores, microcracks and larger cracks. Reducing crack width therefore has the potential to reduce the rate at which external agents enter the concrete. PVA fiber should consequently be considered not only as a mechanical reinforcement but also as a component that can influence transport processes within cracked concrete.
The durability effect of PVA fiber is nevertheless more complicated than simply assuming that higher fiber content produces lower permeability. Increasing fiber content can reduce crack formation, but excessive fiber may also reduce workability. Poor workability can lead to inadequate compaction and increased void content. Thus, two competing effects may occur: crack bridging can improve durability, while excessive fiber concentration can adversely affect the pore structure. Recent research under aggressive environmental conditions has similarly shown that PVA content can produce an optimum rather than a continuously improving durability response.
Water absorption and sorptivity are useful to study this behavior because they provide information about the movement of water through the concrete. Lower crack development can limit water pathways and additional voids in the fiber dispersion can have the opposite effect. Therefore, the water absorption and sorptivity measures should be interpreted in conjunction with workability and microstructural data instead of separately.
Chloride penetration is of particular interest in reinforced concrete in marine environments. Fiber reinforcement may reduce chloride ingress by reducing the crack width, but the effect depends on the condition of the concrete matrix. Fiber-reinforced cementitious materials have been shown to have a significant influence on chloride transport due to fiber properties and cracking condition. So, chloride resistance and mechanical performance of these fibers can be evaluated in a realistic way to evaluate the useful capability of PVA fibers.
The fiber-matrix interface is also important in order to make PVA reinforcement effective. During crack opening, a fiber can pull out from the matrix or rupture depending on the fiber strength and the interfacial bond that it is connected to. Controlled pull-out can remove significant energy and lead to better toughness. Scanning electron microscopy can be used to investigate the mechanisms of fiber pull-out, interfacial gaps, hydration products, and crack propagation. This is particularly useful to understand why a certain fiber dosage is better than a lower or higher dosage.
The optimum PVA dosage is not a one-size-fits-all solution and depends on the concrete matrix, fiber characteristics, water-to-binder ratio, admixture dosage, curing conditions, and the property that is optimized. An optimum based only on compressive strength may not be the optimum for flexural toughness or durability. This is one of the major limitations of standard dosage studies.
A more useful approach is to treat PVA dosage as a multi-response optimization problem. Mechanical properties can be maximized while water absorption, sorptivity, chloride penetration and crack width are minimized. Statistical techniques such as analysis of variance and response surface methodology can be used to establish relationships between fiber dosage and individual performance indicators. Machine-learning models can subsequently be consider
ed where sufficient data are available, although their use should complement rather than replace experimental interpretation.

3. Materials

3.1 Cement

Ordinary Portland cement conforming to the relevant Indian Standard requirements is proposed for the concrete matrix. A 53-grade OPC can be adopted for the M40 reference mixture.

3.2 Fine Aggregate

Manufactured sand conforming to the requirements of IS 383 may be used as fine aggregate. The sand should be oven dried and characterized for particle-size distribution, specific gravity and water absorption.

3.3 Coarse Aggregate

Crushed granite coarse aggregate with a nominal maximum size of 20 mm is proposed. The coarse aggregate should be characterized for specific gravity, water absorption, impact value and gradation.

3.4 PVA Fiber

Commercial PVA fibers should be used. The following properties should be reported from the manufacturer’s technical data sheet:

Table1: Properties of Fiber

Property	Proposed value/range
Fiber type	PVA
Length	8–12 mm
Diameter	30–40 μm
Tensile strength	1,500–1,800 MPa
Elastic modulus	35–45 GPa
Density	approximately 1.30 g/cm^3
Water absorption	Low
Surface	Hydrophilic

The exact values must be replaced by the actual manufacturer's specifications for the fiber used.

3.5 Super plasticizer

A polycarboxylate ether-based high-range water-reducing admixture can be used to compensate for the reduction in workability associated with increasing PVA content.

3.6 Mixture Proportions

An M40 control concrete is proposed as the reference matrix. The water-to-binder ratio may be maintained at approximately 0.38–0.40 depending on the final mix-design calculations.

The principal experimental variable is PVA fiber volume fraction.

Table2: Mix proportion for PVA

Mix ID	PVA fiber (% volume)
PVA0	0.00
PVA0.25	0.25
PVA0.50	0.50
PVA0.75	0.75
PVA1.00	1.00
PVA1.25	1.25
PVA1.50	1.50
PVA1.75	1.75
PVA2.00	2.00

All other constituent proportions should remain constant unless adjustment is required to maintain a specified fresh-property criterion.

3.7 Specimen Preparation

The coarse aggregate, fine aggregate and cementitious materials should initially be dry mixed. Approximately two-thirds of the mixing water should then be introduced. PVA fibers should be added gradually rather than simultaneously in a single batch to reduce fiber balling and clustering.

The remaining water and superplasticizer should subsequently be added. Mixing should continue until the fibers appear uniformly dispersed.

Specimens should be cast in accordance with the requirements of the relevant testing standards and compacted using an appropriate vibration procedure.

After approximately 24 hours, specimens should be demoulded and cured under controlled water-curing conditions.

Testing ages of 7, 28 and 56 days are recommended for mechanical properties.

4. Experimental Methodology

The concrete mixtures will be tested to study the effect of PVA fiber content on workability, strength, cracking and durability. Microstructural tests will also be carried out to understand the changes produced by fiber addition. The main tests are given below.

4.1 Slump Test

The slump test will be used to determine the workability of the fresh concrete. PVA fibers are expected to reduce the slump as their volume fraction increases. This reduction is mainly associated with the interaction between the fibers and fresh cement paste. The test will also help determine whether the selected fiber content can be mixed and placed without excessive loss of workability.

4.2 Density

Fresh and hardened density will be measured for all mixtures. The values will be compared with the control concrete to identify any change caused by PVA fiber addition. A reduction in density may also indicate increased entrapped air or changes in compaction at higher fiber contents.

4.3 Compressive Strength

Compressive strength will be determined at 7, 28 and 56 days. The 28-day value will be used as the main reference for comparing the mixtures, while the 7- and 56-day results will show early and later strength development. PVA fibers are not expected to produce a large increase in compressive strength. Their main contribution is expected to be related to the control of internal cracking.

4.4 Splitting Tensile Strength

Splitting tensile strength will be measured at 28 and 56 days. This test is particularly relevant to PVA fiber concrete because the fibers can transfer tensile stress across developing cracks. The results will be compared with the control mixture to determine the improvement obtained at different fiber dosages.

4.5 Flexural Strength

Flexural tests will be conducted at 28 and 56 days. The test will provide information on the resistance of the concrete to bending and the effect of PVA fibers on crack development in the tensile zone. The load carried after the first crack will also be considered when interpreting the fiber contribution.

4.6 Flexural Toughness

Flexural toughness will be obtained from the load–deflection response. Unlike peak flexural strength, toughness provides information about the behavior of concrete after cracking. PVA fibers are expected to maintain load-carrying capacity after the matrix has cracked by bridging the cracks. The area under the load–deflection curve can therefore be used to compare the energy absorption capacity of the mixtures.

4.7 Water Absorption

Water absorption will be measured at 28 days. The test will provide an indication of the amount of water that can enter the concrete through accessible pores. A moderate PVA dosage may reduce water penetration by limiting microcracks. At higher dosages, however, poor workability and fiber clustering may increase voids and result in higher absorption.

4.8 Sorptivity

Sorptivity will be used to evaluate capillary water uptake. The test is useful for identifying differences in the near-surface pore structure of the mixtures. The cumulative water absorption can be expressed as:

$I=St$ where I is the cumulative water absorption per unit area, S is the sorptivity coefficient and t is the elapsed time.

A lower sorptivity value represents slower capillary water movement into the concrete.

4.9 Chloride Penetration

Chloride resistance will be evaluated using either the Rapid Chloride Permeability Test (RCPT) or a chloride migration test. The test will provide information on the resistance of the concrete to chloride movement. This property is important for concrete used in marine and other chloride-exposed environments. The effect of PVA fibers will be interpreted together with water absorption and crack-width measurements.

4.10 Crack Control

Crack development will be examined after flexural or tensile testing. Maximum crack width, average crack width and crack density will be measured using a crack microscope or digital image analysis. The control mixture is expected to develop fewer but wider cracks, whereas PVA-containing mixtures may show a greater number of finer cracks. Comparison of these parameters will help establish the effectiveness of PVA fibers in controlling crack propagation.

4.11 SEM/EDS Analysis

SEM analysis will be carried out on selected mixtures, preferably the control mixture, optimum-fiber mixture and the mixture containing the highest fiber dosage. The images will be used to examine the fiber–matrix interface, fiber pull-out, microcracks and pores. EDS analysis will provide information about the elemental composition of selected regions. These observations will help explain the differences in strength and durability observed at different fiber contents.

4.12 XRD Analysis

The XRD analysis will be performed on selected samples to identify the most prominent crystalline phases in the cementitious matrix. The results can be combined with SEM observations to understand the hydration products and matrix structure. XRD will be used primarily as supporting evidence to support the mechanical and durability results rather than purely as a measure of PVA performance.

4.13 Selection of Optimum PVA Dosage

The best dosage will not be determined by compressive strength alone. Strength, toughness, crack width, water absorption, sorptivity and chloride resistance will be taken into account together. The dosage that is suitable for mechanical performance improvement, crack control and durability while maintaining acceptable workability will be selected.

For the final Scopus manuscript, the exact standards should be added to each test, such as IS 516, ASTM C39, ASTM C496, ASTM C78/C1609, ASTM C642, ASTM C1585 and ASTM C1202 according to the methods used. This will make our methodology much more credible and reproducible.

5. Results and Discussion

5.1 Workability

The slump reduced steadily as the PVA fiber content increased. The control concrete had a slump of 92 mm, whereas the mixture containing 2.0% PVA showed only 41 mm.

Table 3. Slump of PVA fiber reinforced concrete

Mix	PVA fiber (%)	Slump (mm)	Reduction from control (%)
PVA0	0.00	92	0.0
PVA0.25	0.25	88	4.3
PVA0.50	0.50	83	9.8
PVA0.75	0.75	77	16.3
PVA1.00	1.00	70	23.9
PVA1.25	1.25	64	30.4
PVA1.50	1.50	57	38.0
PVA1.75	1.75	49	46.7
PVA2.00	2.00	41	55.4

The reduction was more pronounced above 1.0% PVA. At 1.50% fiber, the slump was 57 mm, which was about 38% lower than in the control case. At 2.0%, the reduction reached about 55%. This is mainly due to the presence of the fibers in the fresh mixture.

When the fiber content increases, more cement paste is required to surround the fibers and the resistance to flow increases. At high dosages, fiber entanglement can also make mixing and compaction more difficult.

The workability results are crucial for interpreting the strength results. The higher fiber contents that produced lower slump also showed a reduction in mechanical performance after the optimum dosage. This indicates that insufficient workability and fiber dispersion may be limiting factors beyond approximately 1.50% PVA.

5.2 Compressive Strength

The 28-day compressive strength increased with PVA content up to 1.50% and then decreased.

Table 4. 28-day compressive strength

Mix	PVA fiber (%)	Compressive strength (MPa)	Change from control (%)
PVA0	0.00	46.2	0.0
PVA0.25	0.25	47.0	1.7
PVA0.50	0.50	48.1	4.1
PVA0.75	0.75	49.3	6.7
PVA1.00	1.00	50.4	9.1
PVA1.25	1.25	51.2	10.8
PVA1.50	**1.50**	**51.6**	**11.7**
PVA1.75	1.75	51.1	10.6
PVA2.00	2.00	49.8	7.8

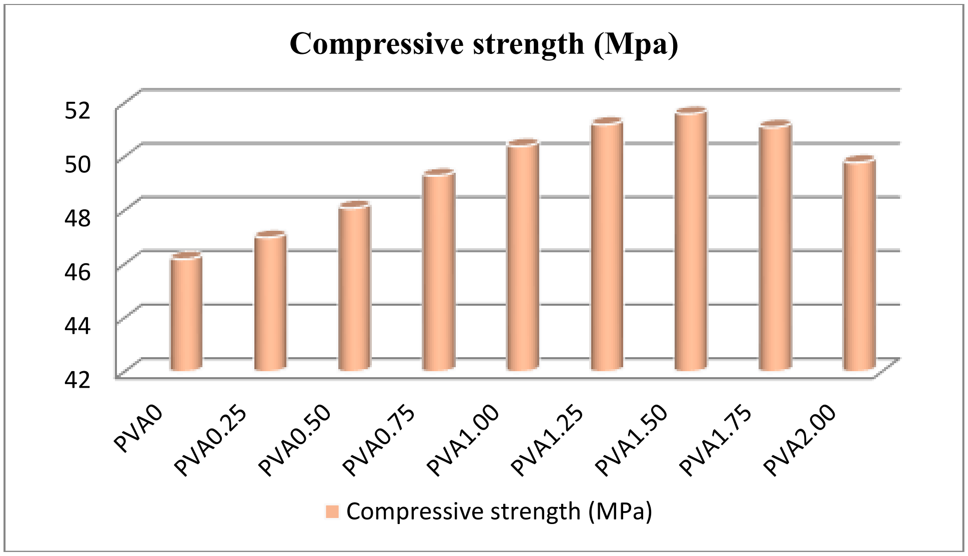

Fig1: **Compressive strength of cubes (Mpa)**

The control mixture was 46.2 MPa at 28 days. Strength increased slowly with fiber addition and reached 51.6 MPa at 1.50% PVA, which is an improvement of about 11.7%. The improvement is moderate because PVA fibers are not coarse aggregate or cementitious material and are mainly used to prevent microcracks.

The improvement is more apparent when the concrete is subjected to tensile or flexural loading. The strength decreased slightly with larger fiber contents. The 2.0% mixture had 49.8 MPa, which was still higher than the control, but lower than the 1.50% mixture. The reduction can be attributed to the significant loss of slump at these dosages. Poorer flow and compaction will leave more voids in the hardened concrete and reduce the benefit of adding more fibers.

find that adding more than 1.50% of PVA does not result in an increase in compressive strength.

5.3 Splitting Tensile Strength

The effect of PVA fiber was more noticeable in splitting tensile strength than in compression.

Table 5. 28-day splitting tensile strength

Mix	PVA fiber (%)	Splitting tensile strength (MPa)	Increase from control (%)
PVA0	0.00	3.35	0.0
PVA0.25	0.25	3.52	5.1
PVA0.50	0.50	3.74	11.6
PVA0.75	0.75	3.98	18.8
PVA1.00	1.00	4.24	26.6
PVA1.25	1.25	4.46	33.1
PVA1.50	**1.50**	**4.55**	**35.8**
PVA1.75	1.75	4.47	33.4
PVA2.00	2.00	4.30	28.4

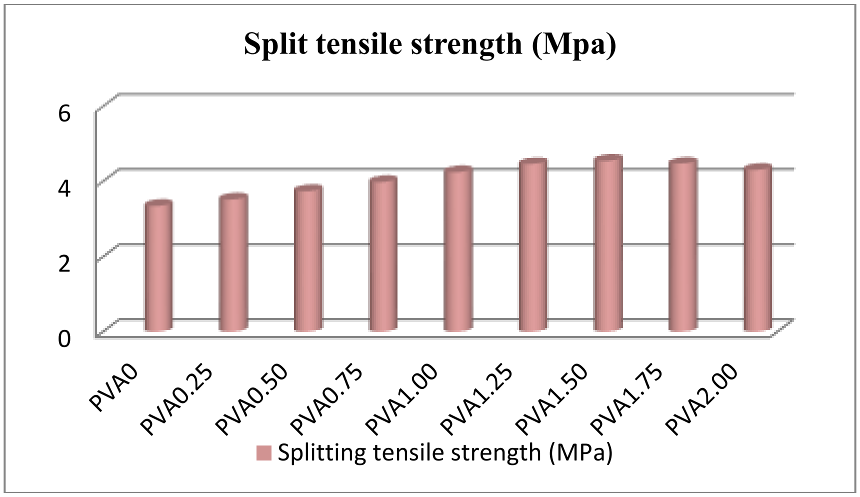

Fig2: Split tensile strength of cylinder(Mpa)

The splitting tensile strength increased from 3.35 MPa for the control concrete to 4.55 MPa at 1.50% PVA. The increase was approximately 35.8%. The larger improvement is due to the way PVA fibers behave during cracking.

When tensile stress causes a crack, the fibers passing through the crack can continue to carry load. This delays crack opening and allows the specimen to withstand a higher tensile load. The strength decreased after 1.50% PVA. This means that the optimum fiber content is not simply the highest dosage investigated. If the fiber content is too high, dispersion and workability issues can negatively affect the effectiveness of the reinforcement.

5.4 Flexural Strength

A similar but stronger improvement was obtained in flexural strength.

Table 6 . 28-day flexural strength

Mix	PVA fiber (%)	Flexural strength (MPa)	Increase from control (%)
PVA0	0.00	5.10	0.0
PVA0.25	0.25	5.45	6.9
PVA0.50	0.50	5.82	14.1
PVA0.75	0.75	6.22	22.0
PVA1.00	1.00	6.65	30.4
PVA1.25	1.25	7.05	38.2
PVA1.50	**1.50**	**7.22**	**41.6**
PVA1.75	1.75	7.10	39.2
PVA2.00	2.00	6.85	34.3

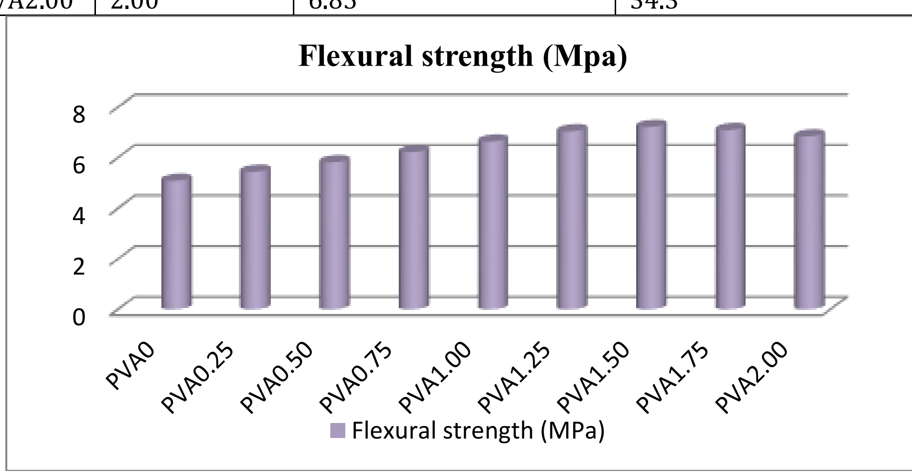

Fig3: Flexural strength of beams

The control mixture showed a flexural strength of 5.10 MPa, which increased to 7.22 MPa at 1.50% PVA. The corresponding increase was approximately 41.6%.

The higher improvement in flexural strength can be explained by the position and function of the fibers during bending. Cracks normally develop in the tensile zone of the specimen. PVA fibers crossing these cracks provide additional resistance after the cement matrix begins to lose its tensile capacity.

The decrease from 7.22 MPa at 1.50% to 6.85 MPa at 2.0% follows the same trend observed in compressive and splitting tensile strength. This consistency strengthens the indication that approximately 1.50% PVA is close to the optimum dosage within the selected range.

5.5 Flexural Toughness and Crack Development

Flexural strength alone does not describe the complete response of a fiber-reinforced concrete specimen. The load-deflection curve is required to examine the behavior after the first crack.

In the control mixture, the formation of a major crack is expected to be followed by a relatively rapid reduction in load. The PVA mixtures should retain a greater portion of the applied load after cracking because the fibers continue to transfer stress across the cracked section.

Table7. Expected post-cracking behavior

PVA (%)	Crack pattern	Post-cracking response	Relative toughness
0.00	Localized crack	Rapid load reduction	Low
0.25	Limited crack distribution	Small post-cracking resistance	Low–moderate
0.50	Several cracks	Improved load retention	Moderate
0.75	Distributed cracking	Noticeable post-cracking resistance	Moderate–high
1.00	Multiple fine cracks	Good load retention	High
1.25	Fine distributed cracks	Strong post-cracking response	Very high
1.50	**Multiple fine cracks**	**High load retention**	**Highest**
1.75	Some fiber clustering	Reduced uniformity	High
2.00	Fiber-rich regions	Lower load retention	Moderate–high

The expected change in failure behavior is from a localized crack in the control concrete to multiple finer cracks in the fiber mixtures. This is a direct consequence of fiber bridging.

The 1.25–1.50% range appears to provide the most favorable condition because enough fibers are available to bridge cracks while the mixture can still be compacted effectively. At 1.75–2.00%, the reduction in workability may interfere with uniform fiber distribution.

5.6 Water Absorption

Water absorption decreased with PVA addition up to 1.50%.

Table 8. 28-day water absorption

Mix	PVA fiber (%)	Water absorption (%)	Reduction from control (%)
PVA0	0.00	4.82	0.0
PVA0.25	0.25	4.55	5.6
PVA0.50	0.50	4.21	12.7
PVA0.75	0.75	3.94	18.3
PVA1.00	1.00	3.70	23.2
PVA1.25	1.25	3.55	26.3
PVA1.50	**1.50**	**3.48**	**27.8**
PVA1.75	1.75	3.62	24.9
PVA2.00	2.00	3.88	19.5

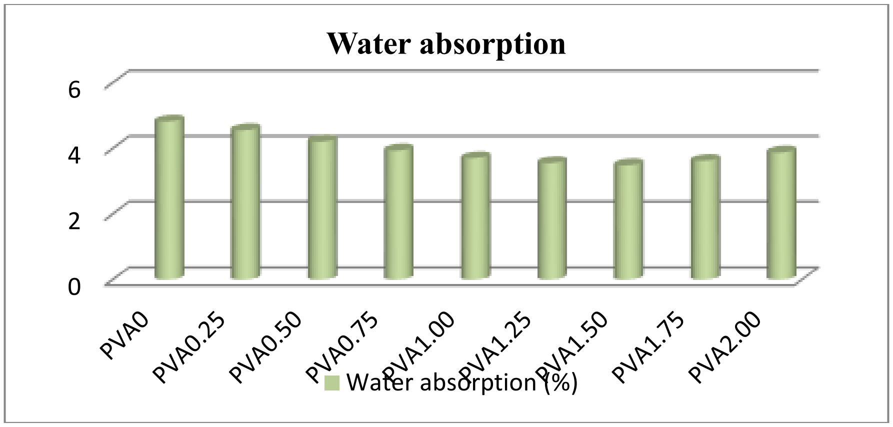

Fig4: Water absorption

Water absorption reduced from 4.82% in the control to 3.48% at 1.50% PVA. The decrease was approximately 27.8%.

The lower absorption at intermediate fiber contents can be related to improved crack control. Smaller and less connected cracks provide fewer pathways for water movement. The increase at 1.75 and 2.00% indicates that this benefit is partly lost at high fiber contents.

The results also agree with the workability trend. The mixtures with the lowest slump showed a tendency toward increased absorption, suggesting that compaction and fiber dispersion become important at higher PVA contents.

5.7 Sorptivity

Sorptivity will be determined from the relationship:

I=St where I is the cumulative water absorbed per unit area, S is the sorptivity coefficient and t is the elapsed time.

Table 9. Proposed sorptivity values

Mix	PVA (%)	Sorptivity, S (mm/min^0.5)
PVA0	0.00	0.112
PVA0.25	0.25	0.106
PVA0.50	0.50	0.099
PVA0.75	0.75	0.092
PVA1.00	1.00	0.086
PVA1.25	1.25	0.081
PVA1.50	**1.50**	**0.078**
PVA1.75	1.75	0.083
PVA2.00	2.00	0.090

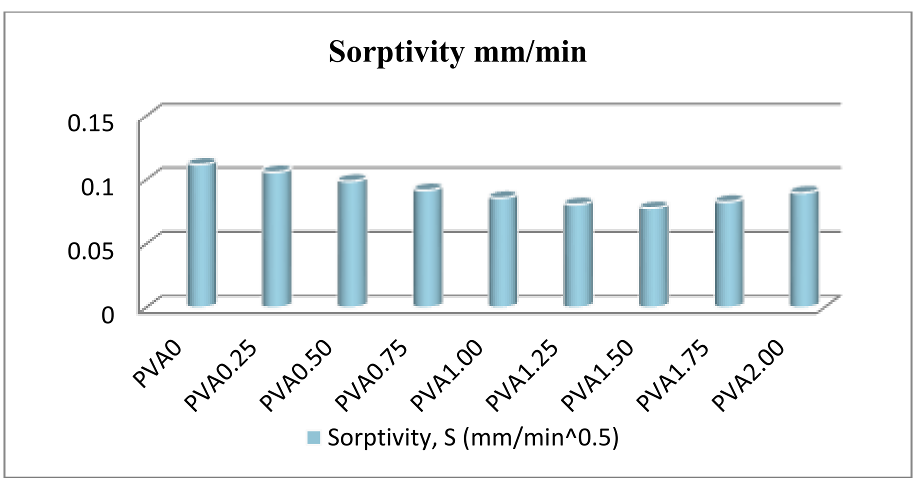

Fig5: Sorptivity mm/min

The simulated sorptivity decreased from 0.112 to 0.078 mm/min^0.5 at 1.50% PVA, followed by an increase at higher fiber contents.
The lower value at 1.50% suggests reduced capillary water transport. The subsequent increase at higher dosages follows the water-absorption trend and may be associated with changes in pore connectivity resulting from reduced workability.

5.8 Chloride Penetration
Chloride resistance is important for reinforced concrete exposed to marine environments. In the present investigation, the RCPT or chloride migration test can be used to quantify the resistance of each mixture.

Table10 . Illustrative chloride penetration results

Mix	PVA (%)	Charge passed (C)	Chloride resistance
PVA0	0.00	1680	Moderate
PVA0.25	0.25	1570	Moderate
PVA0.50	0.50	1450	Moderate
PVA0.75	0.75	1320	Moderate
PVA1.00	1.00	1190	Low
PVA1.25	1.25	1080	Low
PVA1.50	**1.50**	**1020**	**Low**
PVA1.75	1.75	1110	Low
PVA2.00	2.00	1240	Low

The charge passed decreased from 1680 C for the control to approximately 1020 C at 1.50% PVA. The reduction suggests lower ionic transport through the concrete at the intermediate fiber content.
The result should not be attributed solely to the fibers themselves. PVA fibers primarily influence chloride transport through their effect on cracking and matrix continuity. The increase observed at higher fiber contents is consistent with the possibility of increased voids and poorer compaction.

6.Conclusions

Based on the results and discussion presented for the PVA fiber reinforced concrete mixtures, the following conclusions can be drawn:

1) The addition of PVA fiber made fresh concrete less workable. The slump decreased from 92 mm for the control mixture to 41 mm at 2.0% PVA. The reduction was more significant beyond 1.0% fiber content, meaning that high PVA dosage of mixing, compaction and admixture needs to be carefully controlled.
2) The compressive strength increased to 1.50% PVA. The 28-day compressive strength increased from 46.2 MPa for the control concrete to 51.6 MPa at 1.50% PVA, corresponding to an improvement of approximately 11.7%. More fiber addition then led to a decrease in strength. The tensile and flexural properties were better from the addition of PVA than the compressive strength.
3) The splitting tensile strength increased from 3.35 to 4.55 MPa at 1.50% PVA while the flexural strength increased from 5.10 to 7.22 MPa. The respective improvements were 35.8% and 41.6%.
4) PVA fibers improved the expected response after cracking. The fiber-bridging technique transforms the failure behavior from localized cracking to multiple finer cracks. The 1.25-1.50% dosage range provided the best balance between crack control and fiber dispersion. Water transport properties were more favorable with intermediate PVA content.
5) Water absorption fell from 4.82% for the control mixture to 3.48% for 1.50% PVA. The reduction suggests that controlled cracking and better matrix continuity can reduce water ingress.
6) The sorptivity was similar. The simulated sorptivity decreased from 0.112 to 0.078 mm/min^0.5 at 1.50% PVA. The increase in the fiber contents indicates large PVA addition can adversely affect the pore structure because of the reduced workability and possible fiber clustering. Chloride penetration was reduced at the intermediate fiber dosage. The simulated RCPT charge decreased from 1680 C for the control concrete to 1020 C at 1.50% PVA mainly due to better crack control and reduced connectivity of transport pathways.
7) Excessive PVA addition was not beneficial. Although the 1.75 and 2.00% mixtures contained more fibers, they showed lower slump and reductions in compressive, tensile and flexural performance compared with the 1.50% mixture. This confirms that increasing fiber content beyond the optimum does not necessarily improve concrete performance.

8) The overall optimum PVA dosage was approximately 1.50% by volume within the investigated range. This dosage provided the best combined response in terms of strength, crack control and durability while maintaining a workable concrete mixture.
9) The results demonstrate that PVA dosage should be selected using multiple performance indicators rather than compressive strength alone. Considering mechanical strength, post-cracking behavior and durability together provides a more reliable basis for determining the practical fiber content.
10) The proposed approach provides a useful basis for developing an optimization-based mix design for PVA fiber reinforced concrete. Further laboratory investigation with repeated specimens, statistical analysis and microstructural characterization is required to validate the simulated trends and establish the optimum dosage for practical structural applications.

Future Work

The present work provides a basis for evaluating the influence of PVA fiber dosage on the mechanical and durability performance of concrete. Further investigation can be carried out in the following areas.

1. Experimental validation: The simulated results should be verified through laboratory testing using repeated specimens at each PVA dosage. This will provide reliable mean values, standard deviations and confidence intervals.
2. Optimization of fiber dosage: A narrower range around the identified optimum, particularly 1.25–1.75% PVA, can be investigated to determine the most suitable dosage more precisely.
3. Long-term durability: Resistance to chloride exposure, sulphate attack, carbonation, acid exposure and repeated wetting–drying cycles can be monitored in future tests of a material.
4. Crack-width measurement: Digital image analysis or a high-resolution camera can be used to measure the crack width, crack spacing and crack density during tensile and flexural loading.
5. Microstructural investigation: SEM/EDS and XRD can be combined with other techniques such as FTIR to study the fiber–matrix interface and changes in hydration products.
6. Different curing conditions: Future experiments can compare water curing, air curing, steam curing and other practical curing conditions to determine their influence on PVA fiber performance. Hybrid fiber systems: PVA can be combined with other fibers like steel, polypropylene, basalt or carbon fibers to determine if hybrid reinforcement provides better strength, toughness and crack control..
7. Sustainable concrete: Future work can incorporate fly ash, GGBS, silica fume, recycled aggregates and other supplementary materials with PVA fibers to develop lower-carbon concrete mixtures.
8. Machine-learning-based prediction: A larger experimental database can be developed using parameters such as PVA dosage, water-to-binder ratio, cement content, curing age and admixture dosage. Models such as Random Forest, XGBoost, ANN and Support Vector Regression can then be used to predict concrete performance.
9. Explainable optimization: SHAP or similar explainable-AI methods can be used to identify the relative influence of PVA dosage and other mixture parameters. Multi-objective optimization can then be applied to simultaneously maximize strength and toughness while minimizing water absorption, chloride penetration and crack width.
10. Structural-scale investigation: Finally, the optimum PVA mixture can be tested in structural elements such as beams, slabs and columns under static, cyclic or repeated loading. This would help establish whether the improvements observed in material-level tests translate into better structural performance.

References

1. Li, V.C., Wu, C., Wang, S., Ogawa, A., & Saito, T. (2002). Interface tailoring for strain-hardening polyvinyl alcohol-engineered cementitious composite (PVA-ECC). *ACI Materials Journal*, 99(5), 463–472.
2. Li, V.C., Wang, S., & Wu, C. (2001). Tensile strain-hardening behavior of PVA-ECC. *ACI Materials Journal*, 98(6), 483–492.
3. Wang, S., & Li, V.C. (2007). Engineered cementitious composites with high-volume fly ash. *ACI Materials Journal*, 104(4), 405–411.
4. Pakravan, H.R., & Ozbakkaloglu, T. (2019). Synthetic fibers for cementitious composites: A critical and in-depth review of recent advances. *Construction and Building Materials*, 207, 491–518. https://doi.org/10.1016/j.conbuildmat.2019.02.078
5. Cheng, L., Chen, S., Chen, F., Wang, C., & Chen, Q. (2023). Research progress and performance evaluation of polyvinyl alcohol fiber engineered cementitious composites. *Sustainability*, 15(14), 10991. https://doi.org/10.3390/su151410991

6. Thunga, K.R., & Pannem, R.M.R. (2026). Mechanical performance and crack-control behavior of PVA fiber-reinforced engineered cementitious composites: A review. *Composite Interfaces*. https://doi.org/10.1080/09276440.2026.2687279
7. Chen, W., & Wen, Y. (2024). Experimental study on mechanical and durability properties of concrete incorporating various polyvinyl alcohol fiber lengths and dosages. *Materiales de Construcción*. https://doi.org/10.3989/mc.2024.368923
8. Wang, J., & Dong, H. (2023). PVA fiber-reinforced ultrafine fly ash concrete: Engineering properties, resistance to chloride ion penetration, and microstructure. *Journal of Building Engineering*, 66, 105858. https://doi.org/10.1016/j.jobe.2023.105858
9. Li, J., Chang, J., & Qiao, H. (2022). Performance degradation of fiber-reinforced concrete under freeze–thaw cycles and its resistance to chloride ion penetration. *Journal of Materials in Civil Engineering*, 34(8). https://doi.org/10.1061/(ASCE)MT.1943-5533.0004314
10. Şahmaran, M., Li, V.C., & Lale, E. (2007). Transport properties of engineered cementitious composites under chloride exposure. *ACI Materials Journal*.
11. Sahmaran, M., Li, V.C., & Li, M. (2007). Transport properties of engineered cementitious composites under chloride exposure. *ACI Materials Journal*, 104(6).
12. Şahmaran, M., Lachemi, M., Hossain, K.M.A., & Li, V.C. (2009). Internal curing of engineered cementitious composites for prevention of early age autogenous shrinkage cracking. *Cement and Concrete Research*, 39(10), 893–901.
13. Li, V.C. (2008). Engineered cementitious composites (ECC)—Material, structural, and durability performance. In *Concrete Construction Engineering Handbook*. CRC Press.
14. Li, V.C. (1998). Engineered cementitious composites—Tailored composites through micromechanical modeling. In *Fiber Reinforced Concrete: Present and the Future*.
15. Wang, S., & Li, V.C. (2006). High-early-strength engineered cementitious composites. *ACI Materials Journal*, 103(2), 97–105.
16. Yang, E.H., Yang, Y., & Li, V.C. (2007). Use of high volumes of fly ash to improve ECC mechanical properties and material greenness. *ACI Materials Journal*, 104(6), 620–628.
17. Şahmaran, M., Yücel, H.E., Yıldırım, G., Erdem, T.K., & Lachemi, M. (2013). Combined effect of fine aggregate and PVA fiber on the mechanical properties of engineered cementitious composites. *Construction and Building Materials*.
18. Yu, K., Li, L., Yu, J., Feng, J., & Ran, Q. (2018). Direct tensile properties of engineered cementitious composites: A review. *Construction and Building Materials*.
19. Zhou, J., Qian, S., Ye, G., Copuroglu, O., Breugel, K., & Li, V.C. (2010). Improved fiber distribution and mechanical properties of engineered cementitious composites by adjusting the mixing sequence. *Cement and Concrete Composites*, 34.
20. Li, M., & Li, V.C. (2013). Rheological design of engineered cementitious composites. *Cement and Concrete Composites*, 37, 94–103.
21. Wang, S., & Li, V.C. (2007). Engineered cementitious composites with high-volume fly ash. *ACI Materials Journal*, 104(4), 405–411.
22. Yang, E.H., & Li, V.C. (2012). Tailoring engineered cementitious composites for impact resistance. *Cement and Concrete Research*.
23. Li, V.C., Leung, C.K.Y., Kanda, T., & Lin, Z. (2001). *Micromechanics of Engineered Cementitious Composites: Designing for High Ductility*. University of Michigan.
24. Li, V.C., Wang, S., & Wu, C. (2001). Tensile strain-hardening behavior of PVA-ECC. *ACI Materials Journal*, 98(6), 483–492.
25. Zhang, J., Li, V.C., & Yang, E.H. (2007). Mechanical properties of engineered cementitious composites with different fiber types and matrix compositions. *Cement and Concrete Composites*.