# Performance Evaluation of PVA Fiber-Reinforced Concrete Roof Slabs under Hot–Humid Climate Conditions

*Tianzhu Song[1], Chaiporn Supahitanukool[1*], Phanupong Samol[1] and Winai Ouypornprasert[2]*
*Faculty of Engineering and Technology, Pathumtani University [1]*
*Faculty of Engineering and Technology, Pathumtani Universit[1*]*
*College of Engineering, Rangsit University[2]*
*Corresponding author's e-mail: chaiporn.s@ptu.ac.th*

## Abstract

Concrete roof slabs in hot–humid climates are highly susceptible to shrinkage cracking, moisture ingress, and durability deterioration due to coupled temperature and humidity cycling, making the enhancement of crack resistance a critical engineering challenge. Polyvinyl alcohol (PVA) fiber is widely recognized for its crack-bridging capability and strong bonding with cementitious matrices; however, the appropriate fiber dosage for roof slab applications exposed to humidity cycling remains insufficiently defined. This study investigated the performance of PVA fiber-reinforced C30 concrete designed for roof slab applications under hot–humid conditions. Five fiber volume fractions (0.00 %, 0.05 %, 0.10 %, 0.20 %, and 0.50 %) were evaluated through compressive and flexural strength testing, water absorption measurement, and accelerated temperature–humidity cycling durability tests. The results indicated that at 0.10 % fiber content, compressive strength increased by 3.4 %, flexural strength improved by 20.5 %, water absorption was reduced by 11.5 %, crack width was reduced by 69 %, and mass loss was reduced by 65 % after 30 humidity cycles. Excessive fiber dosage (0.50 %) led to reduced workability and fiber agglomeration, resulting in performance decline. Among the investigated mixtures, 0.10 % fiber content by volume demonstrated the optimal balance between strength, durability, crack control, and constructability, providing practical guidance for durable roof slab concrete design in hot–humid climates.

**Keywords**: PVA fiber concrete; roof slabs; hot–humid climate; durability; fiber dosage optimization

## Introduction

Concrete roof slabs in hot–humid climates were continuously exposed to severe environmental conditions, including high temperature, elevated relative humidity, intense solar radiation, and seasonal rainfall. The combined effects of temperature–humidity cycling accelerated drying shrinkage, induced thermal stresses, and promoted microcrack formation, leading to increased permeability and long-term durability deterioration (Ding et al., 2022; Zhang et al., 2022). As a result, roof slabs in such environments often experienced premature cracking, moisture ingress, and reduced service life, which significantly increased maintenance and repair costs. Therefore, improving the crack resistance and durability performance of concrete roof slabs under hot–humid climatic conditions was considered a critical challenge in modern construction and infrastructure development.

Fiber-reinforced concrete (FRC) had been widely adopted to enhance the tensile capacity, ductility, and crack resistance of cementitious materials (Siddika et al., 2021). Among various fiber types, polyvinyl alcohol (PVA) fiber exhibited superior crack-bridging capability and strong interfacial bonding with the cement matrix, which contributed to improved toughness and durability performance (Chen et al., 2021; Jiang et al., 2021). Although numerous studies had investigated the mechanical behavior of PVA fiber-reinforced concrete under laboratory-controlled conditions, most research had focused on beam elements, mortar specimens, or short-term strength evaluation. Limited attention had been given to roof slab applications subjected to coupled temperature–humidity cycling typical of hot–humid climates, where shrinkage and cracking were significantly intensified (Liu et al., 2022; Nguyen et al., 2024). Furthermore, the optimal fiber dosage that balanced mechanical enhancement, durability improvement, and practical workability remained insufficiently defined (Wang et al., 2023; Zhou et al., 2024). This gap highlighted the need for a systematic performance evaluation of PVA fiber-reinforced concrete specifically designed for roof slab applications in hot–humid environmental conditions.

Accordingly, this study aimed to evaluate the performance of PVA fiber-reinforced concrete for roof slab applications under hot–humid climate conditions. The research focused on (1) assessing mechanical performance, including compressive and flexural tensile strength; (2) investigating crack resistance and water absorption behavior; and (3) evaluating durability through accelerated temperature–humidity cycling. By identifying the optimal fiber dosage that provided a balanced improvement in strength, durability, crack control, and workability, this study sought to provide practical mix design guidance for durable and climate-adaptive concrete roof slabs.

To achieve these objectives, a controlled laboratory experimental program was designed, including material characterization, mix proportioning, specimen preparation, mechanical testing, water absorption evaluation, and accelerated temperature–humidity cycling durability assessment, as described in the following Materials and Methods section.

## Materials and Methods

### 1. General

This study employed a controlled laboratory experimental design to determine the optimal PVA fiber dosage for C30 concrete roof slabs under simulated hot–humid climatic conditions. The methodology included material characterization, mix design, specimen preparation, mechanical testing, water absorption evaluation, and accelerated humidity cycling durability testing. All procedures complied with national testing standards GB/T 50081-2019 and GB/T 50082-2009 to ensure reliability and reproducibility.

### 2. Materials

In this study, the selection of constituent materials was carried out to ensure consistency with typical construction practices and to maintain experimental reliability. All materials were commercially available construction materials that were selected based on compliance with relevant standards and suitability for producing C30 concrete for roof slab applications. As summarized in Table 1, five main materials were used, including cement, coarse aggregate, fine aggregate, PVA fiber, and mixing water, together with their corresponding specifications.

**Table 1**. Specifications of Materials Used in the Experimental Program

| Material | Specification |
|---|---|
| Cement | Ordinary Portland Cement P·O 42.5 |
| Coarse aggregate | Crushed stone 5 – 10 mm |
| Fine aggregate | Medium sand (FM ≈ 2.6) |
| Fiber | Polyvinyl Alcohol (PVA), length 12 mm |
| Water | Potable tap water |

## 3. Concrete Mix Proportion

To accurately evaluate the effect of PVA fiber dosage, the base concrete mix was kept constant for all specimens, with only the fiber content varied. As shown in Table 2, five fiber volume fractions (0.00 %, 0.05 %, 0.10 %, 0.20 %, and 0.50 %) were adopted, while all other mix components remained unchanged. The maximum fiber content of 0.50 % by volume was selected based on findings from previous studies (Wang et al., 2023; Zhou et al., 2024), which reported that PVA fiber dosages exceeding 0.50 % typically resulted in significant fiber agglomeration, severe workability reduction, and difficulties in achieving uniform fiber dispersion within the concrete matrix, thereby negating potential performance benefits. The selected range of 0.00 % to 0.50 % was therefore considered representative of practically applicable fiber dosages for structural concrete applications.

**Table 2.** Concrete Mix Proportions for Different PVA Fiber Volume Fractions

| Fiber Vol.% | Cement (kg/m³) | Water | Sand | Gravel | PVA Fiber |
|---|---|---|---|---|---|
| 0.00% | 380 | 171 | 720 | 1100 | 0 |
| 0.05% | 380 | 171 | 720 | 1100 | 0.65 |
| 0.10% | 380 | 171 | 720 | 1100 | 1.30 |
| 0.20% | 380 | 171 | 720 | 1100 | 2.60 |
| 0.50% | 380 | 171 | 720 | 1100 | 6.50 |

The water–cement ratio was fixed at 0.45.

## 4. Experimental Program

### 4.1. Specimen Preparation

Concrete specimens were prepared using a forced mixer to ensure uniform fiber dispersion. Cubes (150 mm) were cast for compressive strength and water absorption tests, while prisms were cast for flexural strength testing. The specimens were cured at 20 ± 2 °C and RH ≥ 95 % for 28 days before testing.

**Table 3**. Experimental Groups and Specimen Allocation

| Group | Fiber Vol. (%) | Specimens per Test | Total Specimens |
|---|---|---|---|
| F1 | 0.00 | Cubes + Prisms | 18 |
| F2 | 0.05 | Cubes + Prisms | 18 |
| F3 | 0.10 | Cubes + Prisms | 18 |
| F4 | 0.20 | Cubes + Prisms | 18 |
| F5 | 0.50 | Cubes + Prisms | 18 |

Each fiber dosage group consisted of multiple cube and prism specimens to ensure statistical reliability and to reduce experimental error.

**Figure 1.** Experimental Materials and Concrete Specimens

4.2. Mechanical Property Test

Compressive strength and flexural tensile strength were measured according to GB/T 50081-2019 using a hydraulic compression testing machine and a servo-hydraulic loading system. These tests represented the primary structural performance indicators of roof slab concrete.

**Figure 2.**Compressive Strength and Flexural Strength Testing Equipment

### 4.3. Water Absorption Test (WA)

Water absorption was measured after 28-day curing to evaluate capillary porosity and permeability. The specimens were oven-dried, immersed in water for 48 hours, and water absorption was calculated as follows:

$$\text{WA (\%)} = (M_{sat} - M_{dry}) / (M_{dry} \times 100)$$

$M_{dry}$ = Oven-dry mass of the specimen after drying at 105 °C until constant weight is achieved.
$M_{sat}$ = Saturated surface-dry mass of the specimen.

This parameter provides an indirect indicator of long-term durability.

### 4.4. Durability Tests

To simulate hot–humid climate conditions, specimens underwent 30 humidity cycles:

**Table 4.** Accelerated Temperature–Humidity Cycling Regime for Durability Testing of Concrete Roof Slabs

| Condition | Temperature | Relative Humidity |
|---|---|---|
| Daytime Simulation | 35 °C | 85 % |
| Night/Rain Simulation | 25 °C | 55 % |

The humidity fluctuation (ΔRH ≥ 30 %) reproduced real environmental stress conditions experienced by roof slabs. Crack width, crack distribution, mass loss, and surface deterioration were evaluated after cycling.

**Figure 3.** Water Absorption and Durability Testing Equipment

## 5. Data Analysis

Test results were evaluated using comparative statistical analysis. For each test, the mean value of at least three specimens was calculated together with the standard deviation to ensure data reliability. Mechanical strengths were compared across fiber dosages and were expressed as improvement percentages relative to the control mix. Water absorption results were used to assess permeability and durability performance. After humidity cycling, crack occurrence and crack width were analyzed to evaluate durability and serviceability. Statistical significance was evaluated at a 95 % confidence level.

## Results

### 1.Compressive Strength

The addition of PVA fibers exhibited a dosage-dependent influence on compressive strength. As shown in Figure 1, the 28-day compressive strength reached a maximum of 39.5 MPa at 0.10 % fiber content, representing a 3.4 % increase compared to plain concrete (38.2 MPa). At 0.20 % fiber dosage, the strength was 38.9 MPa (1.8 % increase), whereas at 0.50 % it decreased to 36.4 MPa (4.7 % reduction). The improvement at low dosage levels was primarily attributed to effective crack-bridging action and partial densification of the cement matrix, whereas the performance reduction at higher dosages was associated with fiber agglomeration and increased internal void content. These findings were consistent with those reported by Jiang et al. (2021), who observed that PVA fiber contents in the range of 0.10–0.15 % produced optimal compressive strength gains, and by Wang et al. (2023), who similarly reported strength reductions at fiber dosages exceeding 0.30 % due to fiber clustering effects.

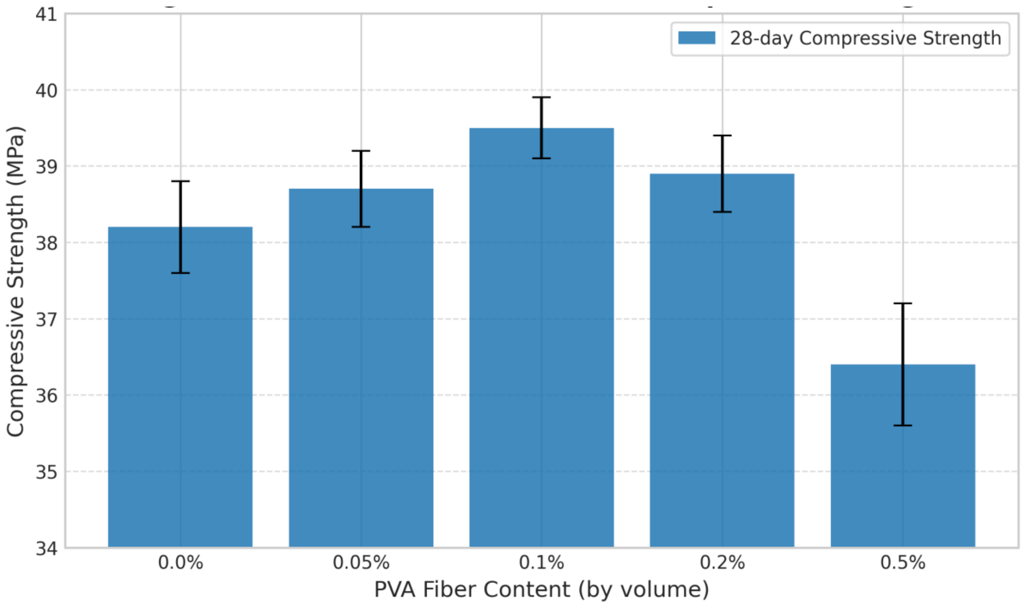

**Figure 4.** Effect of Fiber Content on 28-Day Compressive Strength

### 2.Flexural Tensile Strength

PVA fibers significantly enhanced flexural tensile behavior due to their efficient crack-bridging mechanism. As shown in Figure 2, the 0.10 % fiber dosage increased flexural tensile strength to 5.12 MPa, representing a 20.5 % improvement over plain concrete (4.25 MPa). The 0.20 % fiber content achieved the highest value of 5.28 MPa (24.2 % increase), while 0.50 % resulted in 4.86 MPa (14.4 % increase). The gain from 0.10 % to 0.20 % was only 0.16 MPa (3.1 %), indicating marginal improvement at higher dosage levels. The observed flexural improvement was in agreement with Chen et al. (2021), who reported that PVA fibers enhanced flexural performance by 15–25 % at low to moderate dosages due to effective stress transfer across microcracks. The diminishing returns at higher dosages were also consistent with findings by Siddika et al. (2021).

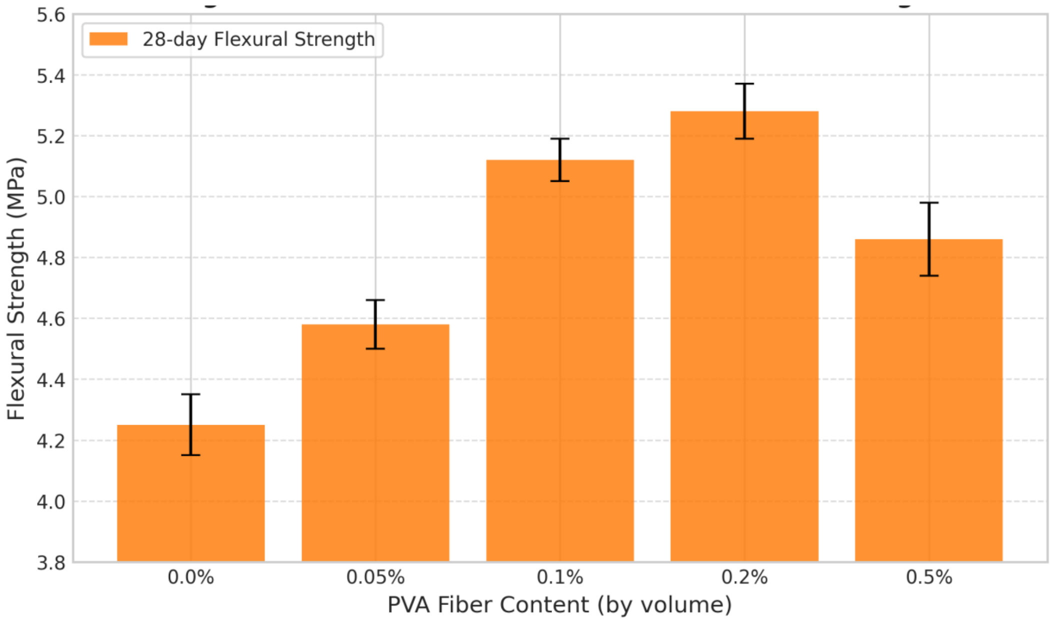

**Figure 5.** Effect of Fiber Content on 28-Day Flexural Strength

3.Water Absorption

Water absorption results indicated that fiber incorporation reduced capillary porosity and permeability, thereby enhancing durability under moisture exposure. As shown in Figure 3, water absorption decreased with increasing fiber content up to 0.20 %, reaching a minimum of 4.38 % (14.5 % reduction compared to plain concrete's 5.12 %). At 0.10 % fiber content, water absorption was 4.53 % (11.5 % reduction). At 0.50 %, absorption increased slightly to 4.72 %, possibly due to fiber agglomeration introducing additional interfacial pores.

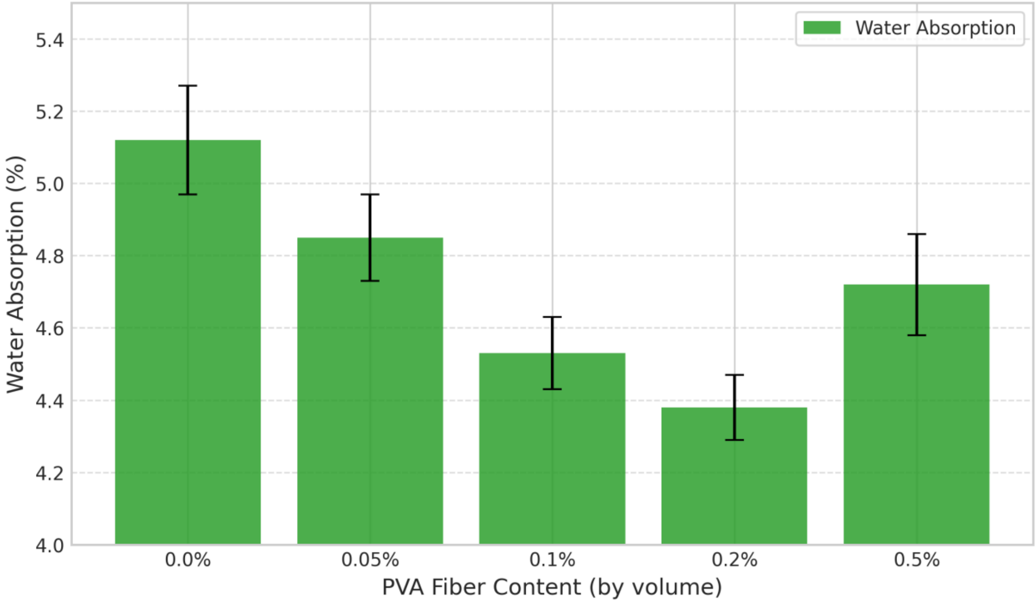

**Figure 6.** Effect of Fiber Content on Water Absorption

## 4.Accelerated Durability Performance

After 30 temperature–humidity cycles simulating hot–humid climate conditions, fiber-reinforced specimens demonstrated significantly improved crack resistance compared to plain concrete. As shown in Figure 4, the 0.10 % fiber dosage reduced the average crack width to 0.08 mm (69 % reduction from 0.26 mm) and reduced the total crack length by 80 %. The 0.20 % dosage achieved the smallest crack width of 0.05 mm (81 % reduction) and an 87 % reduction in crack length. Mass loss after cycling (Figure 5) decreased from 1.18 % for plain concrete to 0.41 % at 0.10 % (65 % reduction) and 0.28 % at 0.20 % (76 % reduction). The differences between 0.10 % and 0.20 % were relatively small, with a crack width difference of 0.03 mm and a mass loss difference of 0.13 percentage points. The substantial crack reduction observed in this study was comparable to the findings of Liu et al. (2022), who reported 50–70 % crack width reductions with synthetic fibers in hot and humid environments, and Nguyen et al. (2024), who demonstrated that PVA fiber incorporation significantly improved durability under tropical climate exposure. The durability enhancement observed in this study further supported the conclusions of Ding et al. (2022) and Zhang et al. (2022), who emphasized the importance of fiber reinforcement for concrete subjected to coupled environmental actions.

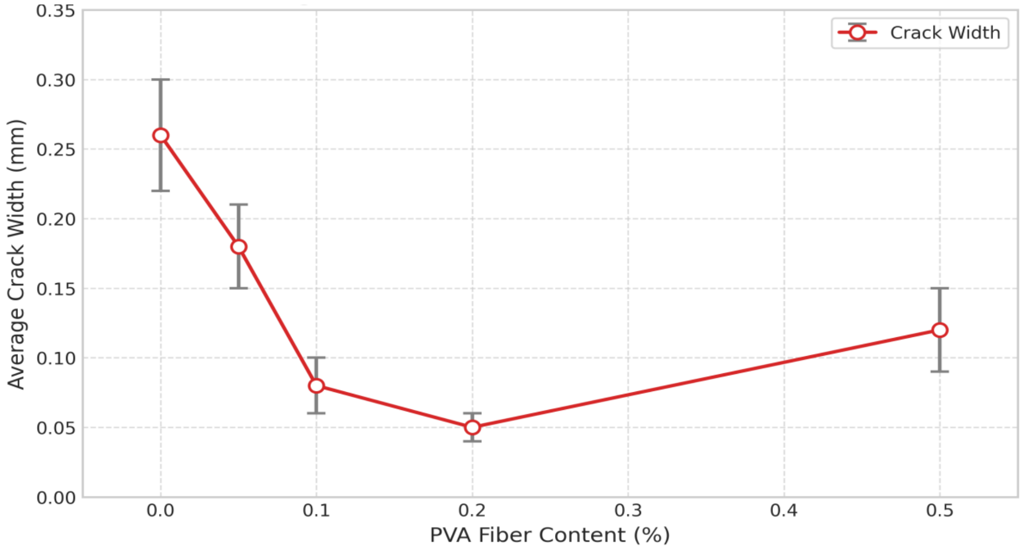

**Figure 7.** Effect of Fiber Content on Crack Width after Humidity Cycling

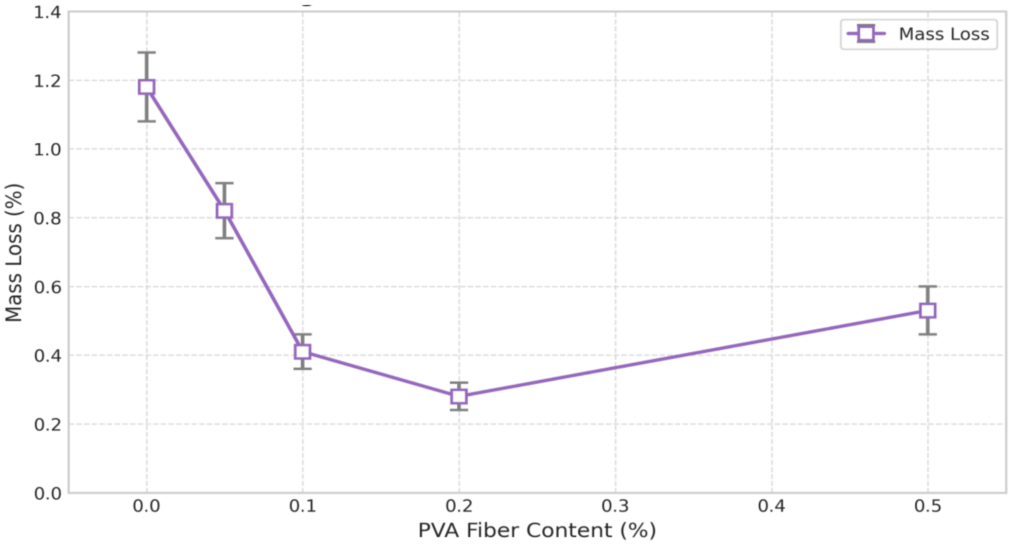

**Figure 8.** Effect of Fiber Content on Mass Loss after Humidity Cycling

5.Overall Performance Evaluation

Considering mechanical strength, water absorption, crack resistance, and durability together, the results indicated that 0.10 % PVA fiber by volume provided the most balanced performance, achieving simultaneous improvements of 3.4 % in compressive strength, 20.5 % in flexural strength, an 11.5 % reduction in water absorption, a 69 % reduction in crack width, and a 65 % reduction in mass loss under humidity cycling conditions.

## Conclusions

This study investigated the performance of PVA fiber-reinforced concrete for roof slab applications under simulated hot–humid climate conditions. The following conclusions were drawn:

1. Compressive strength was maximized at 0.10 % PVA fiber content, reaching 39.5 MPa, which was 3.4 % higher than plain concrete. A further increase to 0.20 % slightly reduced the strength, and 0.50 % caused a noticeable decrease.
2. Flexural strength improved significantly with fiber addition, peaking at 0.20 % (5.28 MPa, 24.2 % above plain concrete). However, the gain from 0.10 % (5.12 MPa, 20.5 % increase) to 0.20 % was only 0.16 MPa (3.1 %), which was marginal.
3. Water absorption decreased with fiber content up to 0.20 %, reaching a minimum of 4.38 % (14.5 % reduction). At 0.10 %, water absorption was 4.53 % (11.5 % reduction).
4. Durability under humidity cycling was greatly enhanced by PVA fibers. At 0.10 % fiber content, crack width was reduced by 69 % and mass loss was reduced by 65 % compared to plain concrete. At 0.20 %, further improvements were observed, but the differences from 0.10 % were small.
5. Considering all performance indicators together with cost and workability, 0.10 % fiber content offered the best balance. The marginal benefits of 0.20 % did not justify the doubling of fiber material cost and the increased risk of mixing difficulties.

Several limitations of this study should be acknowledged. First, the experimental program was conducted under laboratory-controlled conditions using accelerated humidity cycling, which may not fully replicate the complexity of real-world long-term environmental exposure, including ultraviolet radiation, carbonation, and chemical attack. Second, only one concrete grade (C30) and one type of PVA fiber (12 mm length) were investigated; the applicability of these findings to other concrete grades or fiber geometries requires further verification. Third, the study did not include full-scale structural testing of roof slab elements, and the results were based on standard-sized specimens; therefore, the influence of slab geometry, reinforcement detailing, and construction practices on actual performance remains to be evaluated. Finally, the cost–benefit analysis presented was based on material cost considerations only and did not account for potential savings from reduced maintenance and extended service life.

## Future Work

1. For practical roof slab construction in hot–humid climates, a PVA fiber dosage of approximately 0.10 % by volume (≈1.30 kg/m³) was recommended to achieve balanced improvements in crack resistance, durability, and mechanical performance while maintaining acceptable workability.
2. Future research was suggested to investigate long-term field performance, full-scale structural testing, and optimization of mix design parameters (such as water–cement ratio and the use of superplasticizers) to further enhance fiber dispersion and confirm the practical applicability of PVA fiber-reinforced concrete in real engineering conditions.

These future investigations were expected to support the practical implementation of fiber-reinforced concrete in real construction environments.

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