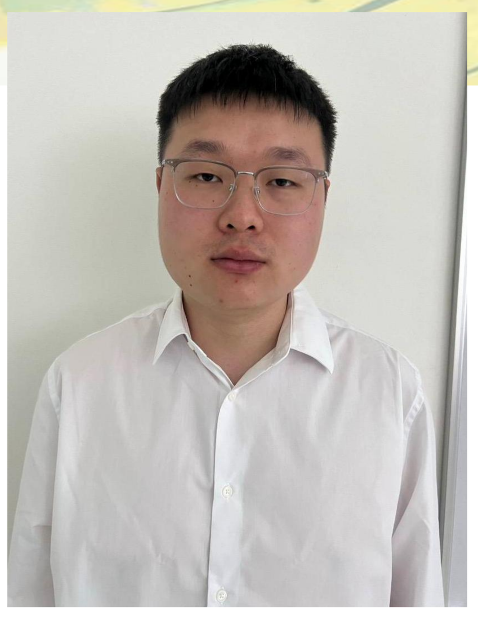
Effect of Pretreated Waste Cotton Fiber on Crack Control Performance of Concrete Pavement in Jintang, Sichuan



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Abstract

Concrete pavements in hot-humid, high-rainfall regions are vulnerable to crack propagation driven by coupled thermal and hydrodynamic actions. This study evaluates NaOH-pretreated waste cotton fiber (WCF) as a sustainable crack control measure in C30 concrete. Six mixes (0.00–0.50% WCF by volume) were tested for compressive strength, flexural strength, and crack width development under thermal cycling (20–40°C) followed by 72-hour hydraulic scouring at 1 m/s. The 0.20% volume fraction yielded optimal performance — lowest crack width increment (Δw), minimal mass loss and spalling — while preserving mechanical strength. The findings demonstrate that pretreated WCF is a viable, low-cost strategy for enhancing pavement durability in climate-vulnerable regions and advancing textile waste reuse in infrastructure.

Keywords: Waste cotton fiber; concrete pavement; crack control; hydraulic scouring; thermal cycling; sustainability

Introduction

Concrete pavements in subtropical monsoon regions such as Jintang, Sichuan, suffer accelerated deterioration due to coupled thermal cracking and hydrodynamic scouring during frequent heavy rainfall and flooding events. Literature confirms that crack permeability increases by orders of magnitude as widths grow from 0.05 to 0.3 mm, making post-crack width control — rather than crack prevention alone — the critical durability parameter for flood-prone pavements.Fiber reinforcement is proven to bridge cracks and limit their propagation; however, the behavior of waste-derived natural fibers under combined thermal cycling and hydraulic action remains insufficiently studied. Jintang generates substantial waste cotton fiber (WCF), presenting a local, low-cost reinforcement source with potential environmental co-benefits.This study therefore pursues three objectives: (1) quantify the effect of NaOH-pretreated WCF on compressive and flexural strength; (2) evaluate crack width development control under sequential thermal cycling and hydraulic scouring; and (3) identify the optimal fiber dosage balancing mechanical integrity with superior crack resistance. The work aims to deliver practical mix design guidance for climate-adaptive concrete pavements while promoting textile waste reuse.

Materials and Methods

1. General

A controlled laboratory program was designed to optimize pretreated WCF dosage in C30 concrete under simulated Jintang climatic conditions, comprising material characterization, mix design, mechanical testing, and a coupled thermal-cycling/hydraulic-scouring durability assessment — all conducted per applicable national and international standards.

2. Materials

Five commercially available materials were used to produce C30 pavement concrete (Table 1): P·O 42.5 OPC, 5–20 mm crushed stone, medium sand (FM ≈ 2.6), potable water, and waste cotton fiber (WCF, length 18 mm, diameter 18–25 μm). WCF was pretreated by 24-hour immersion in 5% w/v NaOH solution, followed by rinsing and oven-drying at 60°C to improve surface roughness and cement-matrix bonding. All materials were selected in compliance with relevant standards to ensure experimental reliability and consistency with typical construction practice.

Table 1. Specifications of Materials Used in the Experimental Program

Material	Specification
Cement	Ordinary Portland Cement P·O 42.5
Coarse aggregate	Crushed stone 5–20 mm
Fine aggregate	Medium sand (FM ≈ 2.6)
Fiber	Waste Cotton Fiber (WCF), length 18 mm,Diameter: 18–25 μm, NaOH-pretreated
Water	Potable tap water

3. Concrete Mix Proportion

A constant base mix (cement 380, water 190, sand 684, gravel 1026 kg/m³; w/c = 0.50) was maintained across all groups to isolate the effect of fiber dosage. As detailed in Table 1, WCF was incorporated at six volume fractions — 0.00% (control), 0.10%, 0.20%, 0.30%, 0.40%, and 0.50% — corresponding to 0–7.20 kg/m³ based on a fiber density of 1440 kg/m³.

Table 1. Concrete Mix Proportions for Different WCF Volume Fractions

Fiber Vol.%	Cement (kg/m³)	Water(kg/m³)	Sand(kg/m³)	Gravel(kg/m³)	WCF(kg/m³)
0.00%	380	190	684	1026	0
0.10%	380	190	684	1026	1.44
0.20%	380	190	684	1026	2.88
0.30%	380	190	684	1026	4.32
0.40%	380	190	684	1026	5.76
0.50%	380	190	684	1026	7.20

4. Experimental Program

Six groups (F0–F5, 0.00–0.50% WCF by volume) of 11 specimens each were prepared, comprising 150 mm cubes for compressive testing and 100 × 100 × 400 mm prisms for flexural and crack development tests. Fibers were added during dry mixing with an extended 180-second duration to ensure uniform dispersion. All specimens were cured at 20 ± 2°C and RH ≥ 95% for 28 days.Compressive and flexural strengths were tested per GB/T 50081-2019 and ASTM C78/C78M-22 (third-point loading), respectively. A multi-stage durability protocol was then applied: prisms were pre-cracked to 0.10–0.20 mm at mid-span, subjected to 7 thermal cycles (40°C/8 h – 20°C/16 h), and exposed to 72-hour hydraulic scouring at 1 m/s and 20 ± 2°C.Crack width was measured at 1/4, 1/2, and 3/4 span (digital caliper, ±0.01 mm) before cycling (w_0) and after scouring (w_1) per GB/T 50152-2012. Performance indices included crack width increment ($\Delta w = w_1 - w_0$), Crack Control Performance Index ($CCPI = \Delta w/w_0$), mass loss ratio (R_m), and spalling area ratio (R_a), referenced to GB/T 50082-2024 and GB/T 50784-2013.

5. Data Analysis

Results were evaluated through comparative statistical analysis, reporting mean, standard deviation, and coefficient of variation for each test. Mechanical strengths were compared across fiber dosages, and one-way ANOVA ($\alpha = 0.05$) was conducted to assess the statistical significance of WCF content on crack width increment (Δw), mass loss rate (R_m), and spalling area ratio (R_a).

Results

Workability decreased with increasing WCF dosage due to fiber interlocking, though mixes at ≤ 0.20% maintained acceptable slump for pavement applications. Compressive and flexural strengths improved slightly (2–3% and 4–6%, respectively) at 0.10–0.20% WCF but declined at higher dosages owing to fiber agglomeration and increased void content.

Crack control performance varied markedly with fiber content. As shown in Figure 1, plain concrete exhibited severe crack propagation ($\Delta w \approx 0.095$ mm, CCPI ≈ 0.95), whereas the 0.20% WCF mix achieved the lowest crack width increment ($\Delta w \approx 0.025$ mm) and CCPI (≈ 0.25) — representing a 50–55% reduction relative to the control, with final crack widths well below 0.25 mm. Performance deteriorated at 0.40–0.50% due to fiber clustering and weakened matrix bonding; ANOVA confirmed a significant dosage effect on Δw ($p < 0.05$).

Surface deterioration followed a consistent pattern: the 0.20% mix reduced mass loss by 60–65% and spalling area by 70–75% versus the control, while higher dosages showed increased erosion. Overall, 0.20% pretreated WCF by volume provides the optimal balance of mechanical strength, crack control, and hydraulic erosion resistance.

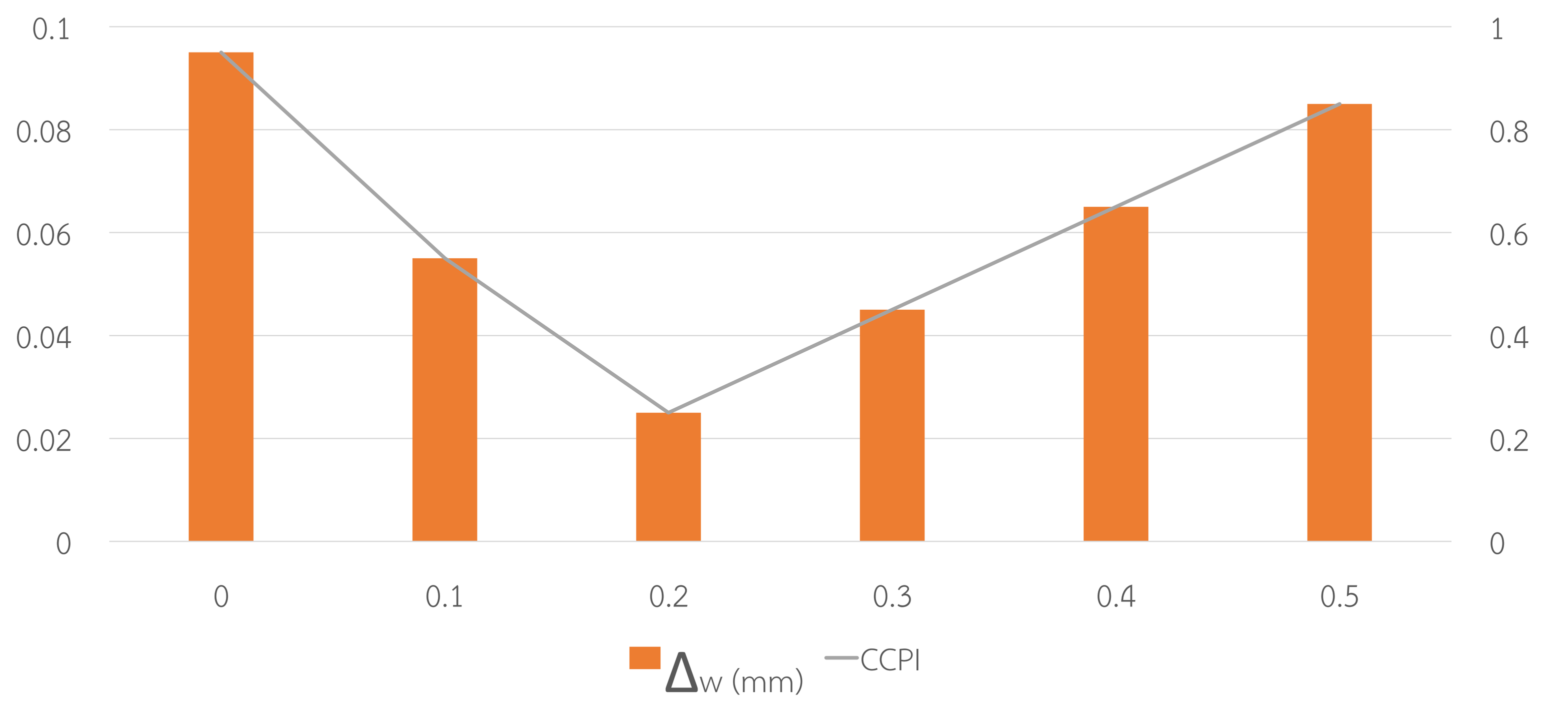

Figure 1 Crack width increment (Δw) and CCPI versus WCF volume fraction after thermal cycling and hydraulic scouring.

conclusions

This study investigated the performance of NaOH-pretreated waste cotton fiber (WCF) in C30 concrete under simulated hot-humid and hydraulic scouring conditions representative of Jintang, Sichuan. Laboratory results confirm that pretreated WCF significantly enhances crack control performance compared with plain concrete. The optimal dosage of 0.20% by volume (≈ 2.88 kg/m³) achieved the lowest crack width increment ($\Delta w \approx 0.025$ mm) and CCPI (≈ 0.25), representing a 50–55% improvement over the control, while reducing mass loss by 60–65% and spalling area by 70–75%. Compressive and flexural strengths were maintained or slightly improved at this dosage. Fiber contents exceeding 0.30% led to reduced workability, fiber agglomeration, and diminished performance efficiency. Although limited to laboratory-scale specimens and controlled simulation conditions, these findings provide practical mix design guidance for durable, climate-adaptive concrete pavements and support the sustainable reuse of textile waste in infrastructure applications. Future research should address field-scale validation and long-term durability assessment.

Future Work

A pretreated WCF dosage of 0.20% by volume (≈ 2.88 kg/m³) is recommended for pavement construction in high-rainfall regions. Future research should focus on long-term field performance validation, optimization of pretreatment parameters (alternative chemicals, treatment durations), and use of superplasticizers to improve fiber dispersion at higher dosages. Full-scale structural testing and life-cycle assessment of economic and environmental benefits are also needed to confirm the practical applicability of WCF-reinforced concrete in real engineering conditions.

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