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Discussion on the fracture behavior and crack resistance mechanism of high-performance fiber-reinforced concrete

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Abstract High-performance fiber-reinforced composite materials have emerged as a promising option in the field of construction concrete due to their unique mechanical properties and durability. This study focuses on UHMWPE high-performance fiber bundles, incorporating their structural characteristics, material properties, and mechanical properties. Two fiber content levels and single/mixed fiber addition methods were tested for concrete's dry shrinkage rate and early crack resistance. The fracture performance and fracture mechanism of UHMWPE fiber concrete were systematically analyzed. The research conclusions are as follows: Compared to steel fiber concrete with the same fiber content, UHMWPE fiber concrete exhibits greater slump. Compared to the control group without fibers, the drying shrinkage rate of concrete with a UHMWPE fiber content of 0.20% was reduced by 51.28%. Therefore, UHMWPE fibers can increase the tensile strength within concrete and enhance its crack resistance.

Index Terms UHMWPE fibers, concrete, drying shrinkage rate, crack resistance

I. Introduction

Concrete is a common building material with advantages such as high strength, high durability, and corrosion resistance. However, in some special applications, it still has some drawbacks, such as insufficient crack resistance and impact damage [1]-[4]. Due to the characteristics of concrete's setting and hardening, it forms a non-uniform macroscopic aggregate structure, with numerous primary microcracks, voids, and defects of varying sizes within it [5]-[7]. This results in concrete failure typically beginning from internal cracks, which gradually develop and expand into macro-cracks, ultimately leading to failure [8], [9]. To address these issues, high-performance fiber-reinforced concrete has emerged [10].

Fiber-reinforced concrete refers to concrete reinforced with fiber materials to enhance its crack resistance, impact resistance, and durability [11], [12]. Fiber materials are typically fiber-reinforced concrete, a composite material based on concrete, composed of reinforcing materials such as metal fibers, inorganic non-metallic fibers, synthetic fibers, or natural organic fibers [13]-[15]. When fibers are incorporated into concrete, they can prevent crack propagation. Additionally, fibers have good bonding and bridging properties with the paste, thereby providing crack-resistant effects [16], [17]. Under load, concrete structures will develop cracks, but the fibers' excellent bonding properties will inhibit crack propagation [18], [19]. Concrete has low tensile strength and is highly prone to cracking under load. Once cracking occurs, the fibers connecting the two ends of the crack will bear the tensile stress, thereby inhibiting further cracking [20]-[22]. When the fiber content reaches a certain threshold, fiber-reinforced concrete structures can continue to function under high loads and large deformations. However, once the fibers reach their tensile limit or the bond between fibers and concrete is disrupted, the structure will fail [23]-[26]. It can be concluded that the tensile strength of fiber-reinforced concrete is higher than that of ordinary concrete, and the ductility of ordinary concrete is significantly improved [27]-[29]. With the continuous development of concrete, the use of fibers to enhance concrete performance has become an inevitable trend. Meanwhile, fiber concrete theory and application technology are becoming increasingly mature, industry standards and specifications for fiber-reinforced concrete are being continuously improved, and the mechanical properties and durability requirements for concrete in actual engineering projects are becoming increasingly stringent [30-33].

Reference [34] investigated the fracture energy of ultra-high-performance fiber-reinforced concrete at high strain rates. By assessing the influence of fracture strength, fracture work, and softening fracture energy on fracture resistance as a function of strain rate, it was found that fracture strength and fracture work are highly sensitive to strain rate, while softening fracture energy is not. Reference [35] introduces the development and applications of high-performance fiber-reinforced concrete (HPFRC) and reviews the mechanical, physical, and durability-related properties of concrete. It points out that incorporating fibers into concrete can reduce shrinkage and creep deformation but may also cause negative effects such as plasticity. Literature [36] investigates the fracture behavior of steel fiber-reinforced high-strength concrete (SFHSC), examining the effects of steel fiber volume fraction and type on the fracture toughness and fracture energy of SFHSC specimens. The results indicate that increasing the addition of steel fibers to high-strength concrete (HSC) significantly improves the fracture behavior of HSC. Literature [37] explored the effects of steel fibers (ST) and synthetic fibers (SYN) on the overall performance of HPFRC, emphasizing that ST, due to its rigidity and mechanical connectivity, can enhance tensile strength, fracture toughness, and post-cracking performance, while synthetic fibers can reduce micro-cracks caused by shrinkage and improve ductility. Literature [38] developed a novel multi-scale fiber-reinforced ultra-high-performance concrete using polyethylene fibers, steel fibers, and carbon fibers mixed with lightweight aggregates, achieving higher strength and toughness. Literature [39] investigated the incorporation of straight steel fibers of different lengths into ultra-high-performance concrete, revealing that a combination of 0.5% medium-length fibers and 1.5% long fibers exhibited better bending performance. Reference [40] explored the bond performance of steel embedded in HPFRC, casting 13 SHPFRC push-pull test specimens to reveal the varying degrees of influence of parameters such as splitting failure and bond anchorage failure on average bond strength. Reference [41] introduced a hybrid fiber composed of steel fibers and glass fibers to enhance the toughness and deformation resistance of rubber concrete, providing foundational information on the fracture characteristics and mechanisms of hybrid fiber-reinforced concrete. Literature [42] investigated the bending behavior of reinforced concrete beams reinforced with ultra-high-performance fiber-reinforced concrete (UHPFRC). The results indicated that UHPFRC increased the stiffness of the beams, reduced crack formation, and improved the strength and durability of the repaired beams. Literature [43] introduced the application of digital image correlation (DIC) technology in analyzing cracks in UHPFRC. Based on fiber distribution characteristics and DIC data, the fiber bridging force per unit area of individual crack regions in different zones was analyzed, revealing that the volume fraction of steel fibers has a limited effect on tensile strain at fracture and complete debonding of fibers. Literature [44] analyzed the effects of fiber type and content on the mechanical properties and failure mechanisms of fiber-reinforced concrete, particularly steel fibers and carbon fibers, with the aim of optimizing concrete performance. The results indicated that, compared to ordinary concrete, fibers promoted more pronounced initial pore compression characteristics. Reference [45] investigated the fracture toughness and fracture energy of UHPFRC under static and impact rates using double-notched tensile specimens. The results indicated that UHPFRC exhibits extremely high fracture strength under impact rates. The above studies elucidate the development and applications of high-performance fiber-reinforced concrete and experimentally validate that the addition of fibers effectively enhances the overall performance of concrete, reduces its fracture behavior, and improves durability.

Regarding the assessment of the fracture mechanism of UHMWPE high-performance fibers, this paper systematically reviews the latest domestic and international research findings on this material, providing an in-depth overview of the surface characteristics, fiber preparation methods, micro- and macro-structures of UHMWPE fibers, as well as the preparation and performance of UHMWPE fiber-reinforced concrete composite materials. Based on this, different grades of high-strength concrete were selected as the research subjects. Using the influence of fibers on concrete performance, drying shrinkage, and early crack resistance as crack resistance indicators, a series of comparative experiments were conducted to investigate the fracture behavior and crack resistance mechanisms of high-performance fiber-reinforced concrete.

II. Overview of high-performance UHMWPE fibers

Concrete, as a common building material, is widely used in various building structures such as bridges, buildings, and water conservancy projects. However, concrete's inherent brittle nature results in relatively low tensile strength and strain capacity, making it nearly incapable of resisting cracking. Concrete cracking often reduces the structural integrity and durability of a structure over its service life. To improve concrete's crack resistance, fiber materials have been introduced into concrete mixtures.

UHMWPE fibers have garnered significant attention due to their excellent properties, including low density, high strength, corrosion resistance, and wear resistance. However, issues such as their smooth surface, chemical inertness, and insufficient interfacial adhesion have limited their application scope in the construction field. To overcome these limitations, researchers analyzed the chemical structure and physical morphology of UHMWPE fibers through microscopic structural characterization. They then subjected the fiber surfaces to physical treatment or chemical modification, effectively enhancing the surface roughness, wettability, and interfacial performance of UHMWPE fibers, making them suitable for designing various fiber-reinforced concrete composite materials.

II. A. Method for preparing UHMWPE fibers

The primary methods for preparing UHMWPE fibers include melt spinning, gel spinning, and electrospinning. Among these, gel spinning is currently the primary method for industrial-scale production of UHMWPE fibers. Depending on the solvent used, gel spinning is divided into two types: dry gel spinning and wet gel spinning. Gel spinning is typically used to produce fine fibers or composite fibers, while melt spinning is more suitable for producing coarser UHMWPE fibers. Electrospinning, on the other hand, is primarily used to produce microfibers or nanofibers. To produce UHMWPE fiber products that meet the requirements for fiber concrete production, appropriate preparation methods are selected based on the required fiber specifications and performance for customized processing, thereby designing high-performance UHMWPE fibers to ensure they meet the stringent standards for fiber concrete production [46].

II. B. Chemical structure of UHMWPE fibers

UHMWPE material is formed through free radical polymerization reactions of linear ethylene monomers. Its chemical structure (-[CH_2-CH_2-]_n) is simple, with a tightly packed crystalline structure, featuring extremely high molecular weight and extremely long polymer chains. Fibers made from UHMWPE material exhibit outstanding properties such as high strength, high toughness, low friction coefficient, and excellent wear resistance, making them widely used in defense, military, biomedical, and bridge engineering applications. However, the molecular chain structure of UHMWPE fibers has a low content of side chains and lacks active functional groups, resulting in weak intermolecular forces and a chemically inert surface. The molecular chain structure of UHMWPE material is shown in Figure 1.

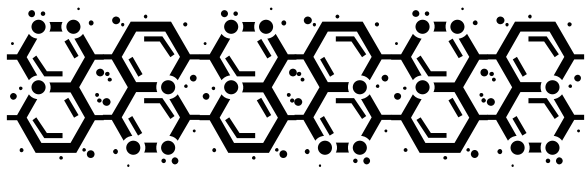


Figure 1: Molecular chain structure of UHMWPE material

II. C. UHMWPE fiber surface treatment technology

UHMWPE fibers have a smooth surface, but due to their hydrophobic fiber structure, the interfacial affinity and physical friction between the fibers and the cement-based matrix are poor, preventing the full utilization of the tensile strength of UHMWPE fibers. When using UHMWPE fibers to directly prepare concrete composite materials, it is necessary to improve the interfacial bonding performance between the fibers and the matrix. To address this critical challenge, various methods have been employed to activate and modify the fiber surface, such as treatment with strong oxidizing agents, surface activation treatment, and plasma treatment.

II. D. Research progress on UHMWPE fiber-reinforced concrete composite materials

The key challenges in the development of modern concrete technology primarily focus on three areas: enhancing the mechanical strength, tensile ductility, and durability of concrete under harsh environmental conditions. ① High-strength concrete provides structural safety margins. ② High-ductility concrete absorbs energy under extreme loads, preventing structural collapse. ③ High-durability concrete extends the lifespan of infrastructure, reduces maintenance costs, and enhances sustainability. Additionally, these three aspects can serve as important criteria for evaluating the performance of UHMWPE fiber-reinforced concrete composite materials. Considering material costs, UHMWPE fibers are typically used as fiber reinforcement materials in the preparation of ultra-high-performance concrete (UHPC), high-strength engineering cement-based reinforced composites/strain-hardening cementitious composites (ECC/SHCC), and other special functional composites. Leveraging the unique mechanical properties of UHMWPE fibers, the formation and propagation of cracks within concrete can be effectively controlled, thereby significantly enhancing the performance of concrete [47].

II. E. UHMWPE Fiber Properties

UHMWPE fibers exhibit exceptional comprehensive performance due to their extremely high molecular weight, highly entangled main chains, low density, and high orientation and crystallinity, offering advantages unmatched by other fibers. UHMWPE fibers are currently the lightest high-performance fibers in the world, with a relative molecular weight ranging from 100 to 500 million, allowing the molecular chains to fully extend. UHMWPE fibers exhibit high levels of strength and modulus, with strength exceeding 20 cN/dtex and modulus exceeding 464 cN/dtex. Under the same mass, their tensile strength far exceeds that of ordinary fibers and high-quality steel by more than tenfold, second only to ultra-high-performance carbon fibers. The theoretical ultimate strength value can reach 345 cN/dtex, and the theoretical ultimate modulus value can reach 3,500 cN/dtex.

III. UHMWPE fiber experimental plan and data processing methods

The objective of this study is to obtain a comprehensive understanding of the static and dynamic mechanical properties of UHMWPE fiber-reinforced concrete, analyze the influence of fiber volume content on concrete performance, and investigate the patterns of change relative to plain concrete. The research content includes the drying shrinkage and early crack resistance of fiber-reinforced concrete. To this end, the following series of tests are required:

Compressive strength tests on concrete with different fiber content and different types of fiber concrete (steel fibers and fiber chains). To meet the research objectives of this study, which involve investigating the static and dynamic mechanical properties of UHMWPE fiber concrete with different fiber content and comparing them with plain concrete, the experimental design will utilize concrete with different fiber volume ratios. According to the "Standard Test Methods for Mechanical Properties of Ordinary Concrete," the tensile and compressive strengths of concrete are generally obtained by splitting and uniaxial compression tests on cubic specimens, and the compressive deformation performance indicators need to be obtained through prismatic uniaxial compression tests to study the true stress-strain relationship. Dynamic compression performance tests based on the separated Hopkinson bar generally use short cylinders.

The fiber-reinforced concrete studied in this paper consists of various grades of high-strength concrete (C70, C25, etc.), with splitting tensile strength approximately one order of magnitude lower than compressive strength, thus requiring high precision testing equipment. The maximum dimensions of the compressed bearing surface are 150 mm × 150 mm. During loading, more elastic deformation energy accumulates, and upon reaching peak strain, a high energy release causes sudden specimen failure. Therefore, this study requires the use of high-precision, wide-range, and high-stiffness testing instruments for measurement. Both static splitting tensile and uniaxial compression mechanical property tests were conducted using the INSTRON 1346 electro-hydraulic servo universal testing machine produced by INSTRON Corporation of the United States, with the following main performance specifications: Maximum static load for tension and compression: ±2000 kN; maximum lateral pressure: 50 MPa; maximum temperature: 500°C; peak triaxial confining pressure: 140 MPa; maximum pore pressure: 140 MPa; load measurement accuracy: ±0.5%. The stiffness of conventional testing machines ranges from 1000 kN/mm to 8000 kN/mm, while the INSTRON 1346 achieves a stiffness of up to 10,000 kN/mm. Therefore, this testing machine meets the requirements for measurement range and accuracy, enabling more precise experimental results to be obtained [48].

IV. Discussion on the crack resistance mechanism of UHMWPE fiber concrete

IV. A. Effect of fibers on the working properties of concrete

This study investigated the effects of single and composite reinforcement with steel fibers and 12 mm-long ultra-high molecular weight polyethylene (UHMWPE) fibers on the crack resistance of concrete through early cracking shrinkage tests and plate crack resistance tests. The study aimed to reveal the mechanism of action of UHMWPE fibers on concrete and propose effective crack prevention measures.

Single and composite UHMWPE fibers and steel fibers were used to study the drying shrinkage and early crack resistance of concrete at different ages. The types and volume fractions of fibers in each group of concrete are shown in Table 1.

Table 1: The type and volume of fiber in each group of concrete

N	Steel fiber/%	UHMWPE/%	N	Steel fiber/%	UHMWPE/%
A-0	0	0	D-2	0.06	0.06
B-1	0	0.11	D-3	0.09	0.04
B-2	0	0.16	E-1	0.06	0.12
B-3	0	0.24	E-2	0.084	0.084
C-1	0.11	0	E-3	0.12	0.06
C-2	0.16	0	F-1	0.08	0.15
C-3	0.24	0	F-2	0.12	0.12
D-1	0.04	0.09	F-3	0.16	0.09

The slump of concrete significantly decreases after adding fibers. To ensure normal construction operations, the dosage of UHMWPE fibers is adjusted to control the total fiber content within 0.25%, ensuring good flowability of the concrete. The measured slump values of the concrete are shown in Table 2. As shown in the table, the slump of concrete with UHMWPE fibers is greater than that of steel fiber concrete with the same fiber content. The cohesion and water retention of UHMWPE fiber concrete are superior to those of steel fiber concrete. When the fiber content is 0.24%, the slump of UHMWPE fiber concrete is greater than that of steel fiber concrete. The slump of concrete with multiple fiber admixtures is not significantly different from that of single-admixture concrete, and the effect is even inferior to that of single-admixture UHMWPE fiber concrete.

IV. B. Effect of fibers on drying shrinkage of concrete

The results of the effects of single-blended and mixed-blended fibers with different blending ratios on the drying shrinkage rate of concrete are shown in Figure 2.

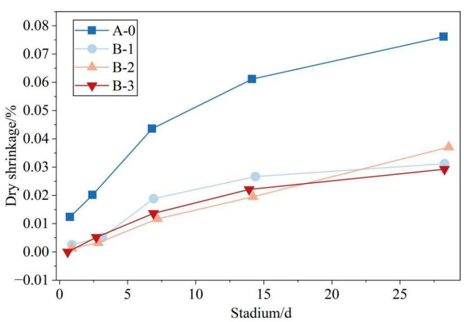
(1) When UHMWPE fibers were used as a single additive at a dosage of 0.24%, the drying shrinkage rate was reduced by up to 51.28% compared to the control group without fiber addition. The use of UHMWPE fibers as a single additive

significantly suppressed cracking shrinkage in concrete. UHMWPE fibers have a high degree of adhesion to the matrix, and the UHMWPE fibers are uniformly distributed within the concrete, forming a disordered network structure system that improves the internal structure of the concrete and effectively inhibits cracking shrinkage.

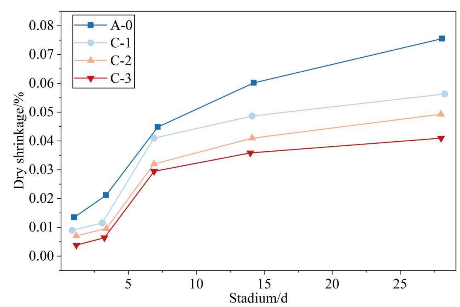
Table 2: The slump of concrete in each group

Serial number	A-0	B-1	B-2	B-3	C-1
Slumps	198	174	150	111	164
Serial number	C-2	C-3	E-1	E-2	E-3
Slumps	125	98	157	143	139

(2) When steel fibers were added at a dosage of 0.24%, the drying shrinkage rate was reduced by up to 34.75% compared to the control group, indicating that the addition of steel fibers also significantly inhibited the drying shrinkage of concrete. The addition of steel fibers improves the internal pore structure of concrete. The bond strength and mechanical interlocking force between the fibers and the matrix work in concert to significantly constrain the drying shrinkage deformation of the cementitious materials within the mortar. As shown in the figure, when two types of fibers are blended, the overall reduction rate is lower than that of concrete with single-blended UHMWPE fibers. During changes in fiber content, the influence of composite fibers on concrete drying shrinkage does not align with that of single-type fibers, and even exhibits an inverse mixing phenomenon. When using composite fibers in concrete, it is essential to strictly control the fiber content to prevent the occurrence of the inverse mixing effect.



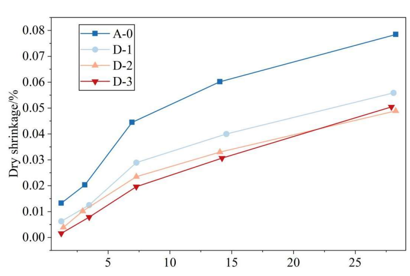
(a) Doped hmwpe fiber



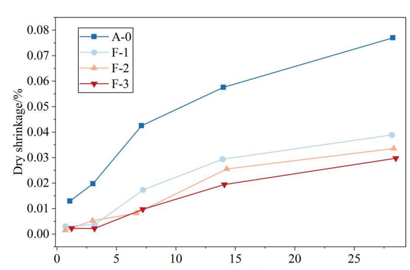
(b) Single blended steel dimension

Figure 2: Effect of single doped fiber on dry shrinkage of concrete

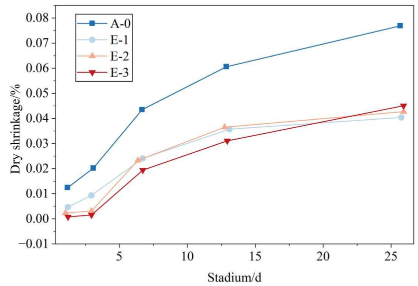
The effect of blended fibers on the drying shrinkage rate of concrete is shown in Figure 3. When two types of fibers are blended, with a total fiber content of 0.30% and steel fibers accounting for 70%, the overall reduction rate is lower than that of concrete with single-blended UHMWPE fibers. During changes in fiber content, the influence of composite fibers on concrete drying shrinkage does not align with that of single-type fibers, and even exhibits an inverse mixing phenomenon. When using composite fibers in concrete, it is essential to strictly control the fiber content to prevent the occurrence of the inverse mixing effect.



(a) 0.12%



(b) 0.18%



(c) 0.22%

Figure 3: The shrinkage of the concrete drying

IV. C. Effect of fibers on the early crack resistance of concrete

(1) When UHMWPE fibers are added at a dosage of 0.12%, 0.18%, and 0.22%, the total crack area at 7 days of age was reduced by more than 99% compared to the control group. The addition of UHMWPE fibers significantly inhibits the cracking performance of concrete, and concrete containing UHMWPE fibers exhibits virtually no cracking. UHMWPE fibers can increase the tensile strength within the concrete, better prevent the matrix from cracking, uniformly distribute the internal stress field of the concrete, prevent the presence of concentrated stress, and reduce the likelihood of concrete cracking. The effect of fibers on the early crack resistance of concrete is shown in Table 3.

(2) When steel fibers were added at a dosage of 0.12%, 0.18%, and 0.22%, the total crack area at 7 days was reduced by over 90% compared to the control group, demonstrating the significant crack-resistant effect of steel fiber-reinforced concrete. Concrete with single UHMWPE fiber addition exhibits superior crack resistance compared to concrete with single steel fiber addition. Fibers play a role in preventing stress concentration, achieving stress dispersion, making early-age drying shrinkage cracks in fiber-reinforced concrete finer, and thereby enhancing its crack resistance.

Table 3: The effect of fiber on the early anti-fracture performance of concrete

Numbering	Number of cracks/N	Crack maximum width/mm	Crack maximum length/mm	Fracture average area(mm^2/N)	Fracture area/mm^2
A-0	15	0.64	100	27.13	406.95
B-1	2	0.15	30	3.94	7.88
B-2	0	0.02	0.02	0.02	0
B-3	0	0.02	0.02	0.03	0
C-1	8	0.38	82	5.11	40.88
C-2	3	0.58	73	6.89	20.67
C-3	2	0.40	54	18.16	36.32
D-1	4	0.45	52	4.15	16.6
D-2	3	0.36	52	3.26	9.78
D-3	2	0.40	38	6.25	12.5
E-1	3	038	40	6.15	18.45
E-2	2	0.32	35	10.23	20.46
E-3	1	0.29	18	4.56	4.56
F-1	2	0.14	11	1.49	2.98
F-2	0	0.02	1	0	0
F-3	1	0.03	0	1	1

IV. D. Case Study

There are also application cases in water transport engineering, such as in the expansion project of the Beijing-Hangzhou Grand Canal's Zaohe Third Line Lock Project. To enhance the concrete's crack resistance, a trial section of C25 concrete was poured with a UHMWPE fiber volume content of 1% (in the concrete mix design, the UHMWPE fiber dosage was 12 kg/m^3).

The strength grade of concrete, UHMWPE fiber content, and fiber performance parameters vary across different projects. To maximize concrete's crack resistance, determining the optimal UHMWPE fiber content requires further research. In current hydropower engineering projects, when using UHMWPE fibers to enhance concrete crack resistance, regardless of whether it is normal concrete, pumped concrete, or roller-compacted concrete, the dosage is set at 0.93 kg/m^3, which is based on the commonly used dosage of polypropylene fibers. The density of polypropylene fibers is 0.93 g/cm^3, and when converted based on a 0.1% volume dosage, the mass dosage in concrete is 0.93 kg/m³. However, the density of UHMWPE fibers is 1.4 g/cm³, and using the same mass dosage as polypropylene fibers raises questions about its rationality.

Concrete containing untreated UHMWPE fibers at volume dosages of 0.12%, 0.25%, 0.375%, and 0.55% was subjected to drying shrinkage tests, with results shown in Table 4. Regardless of the time range (0–8 days or 30–115 days), the dry shrinkage of concrete with UHMWPE fibers was higher than that of the reference concrete, indicating that within the dosage range of 0.12% to 0.55%, the dosage had no significant effect on dry shrinkage. In the concrete test section of the Zaohe Third Line Ship Lock, a volume dosage of 1% was also used for the purpose of improving concrete crack resistance.

In previous studies on the engineering applications of UHMWPE fibers in crack-resistant concrete, research has primarily focused on the macro-level performance aspects such as plastic shrinkage, dry shrinkage, self-induced volume deformation, ultimate tensile strength, and elastic modulus to investigate the improvement of concrete crack resistance by UHMWPE fibers. However, the influence of basic performance parameters such as fiber length, equivalent diameter, and elastic modulus on concrete crack resistance has been studied less, and the microscopic mechanisms and fundamental theories underlying the impact of UHMWPE fiber properties on concrete crack resistance have not received sufficient attention.

Table 4: Application examples of pva fibers in concrete anti-cracking

Project name	Strength grade	Fiber parameter	length	equivalent	density	Tensile strength	Elastic modulus	Project name
Hydropower project	C9 050	0.9	14		1.30	1574	38.4	8.4
Brocade	C1 8040	0.9						
Hilogo	C1 8040	0.9			1.30	1652	37.4	6.8
Homing dam	C1 8025/C 9030	0.9				1695	41.4	
Soap line	C256	12.4	10	22	1.32	1306	37.05	7.3

The UHMWPE fiber concrete slurry was poured into molds and placed outdoors under average temperature conditions of 37°C and humidity of 70%. The development of concrete cracks was observed at 7 days, 14 days, 28 days, and 60 days, with the number of cracks and average crack length recorded. Based on the concrete cracking conditions and data analysis, it can be concluded that: concrete cracking primarily occurs during the early stages, often due to early shrinkage; As the fiber content increases, the number and size of cracks in the concrete decrease significantly. Fiber bead chain concrete exhibits the best crack resistance. This is because the uniformly distributed fibers in the concrete restrict early cracking. After the concrete hardens, if the matrix remains in a constrained state, the fibers can still prevent or reduce crack formation. The fiber bead chain allows the crack-resistant effect of the fibers to be fully utilized, thus proving that the fiber bead chain can effectively prevent concrete cracking.

In summary, the maximum impact of fiber addition on various concrete properties is shown in Table 5. Based on the data in the table, fiber-reinforced concrete exhibits the best overall performance. When the UHMWPE fiber content is 0.5 kg/m³, the workability of the concrete decreases slightly, with an 9.8% reduction in spreadability. However, the mechanical properties of the concrete significantly improve, with a 24.2% increase in flexural strength and a 1.6% increase in compressive strength. The durability of the concrete is improved, with a 20% decrease in shrinkage rate, a 36.3% reduction in mass loss after freeze-thaw cycles, and a 22.5% increase in dynamic elastic modulus. Ultimately, the crack resistance of the concrete is significantly enhanced, with a 92.8% reduction in the number of cracks and a 58.5% decrease in crack length.

Table 5: Maximum influence of fibers and bead chains on concrete performance

Adding method	Working performance		Mechanical property		Frost resistance			Crack resistance	
	Slump	Expansion	Flexural strength	Compressive strength	Shrinkage resistance	Mass loss	Elastic modulus	N	Length
Fiber	-13.4%	-14.3%	15.0%	-0.4%	-14.6%	-32.4%	15.9%	-89.3%	-58.5%
Bead chain	-8.3%	-9.8%	24.2%	1.6%	-20.0%	-36.3%	22.5%	-92.8%	-58.5%

V. Conclusion

To investigate the fracture behavior and crack-resistant mechanisms of high-performance UHMWPE fibers in concrete, this study tested the drying shrinkage rate and early crack-resistant performance of concrete under two fiber content levels and single/mixed fiber addition methods. Practical research was also conducted in water transport engineering applications. The results indicate:

(1) When the fiber content was 0.25%, the slump of concrete with UHMWPE fibers was greater than that of steel fiber concrete with the same fiber content.

(2) In terms of early drying shrinkage rate, single-blended UHMWPE fibers performed best, with a reduced drying shrinkage rate compared to the control group without fiber blending. UHMWPE fibers can prevent cracking of the matrix, uniformly distribute internal stress fields within the concrete, and enhance its crack resistance performance.

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