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Glasscrete: Enhancing Strength and Durability with Alkali-Resistant Glass Fibers

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Abstract: Concrete, though widely used in construction, often faces challenges related to brittleness, cracking, and durability under aggressive environments. To address these limitations, fiber reinforcement has emerged as an effective solution. This study, "GLASSCRETE," focuses on experimental investigations of alkali-resistant (AR) glass fiber reinforced concrete and its impact on mechanical and durability properties. Various concrete mixes were prepared with different percentages of AR glass fibers, and tests were conducted to evaluate compressive strength, split tensile strength, flexural strength, and resistance to cracking. The results indicate that the inclusion of AR glass fibers significantly improves tensile and flexural performance while enhancing resistance against crack propagation. Furthermore, the durability of concrete in alkali environments is improved due to the specialized alkali-resistant nature of the fibers. This research highlights the potential of GLASSCRETE as a cost-effective, high-performance, and sustainable material suitable for modern infrastructure applications.

Keywords: *Glass Fiber Reinforced Concrete (GFRC), Alkali-Resistant Fibers, GLASSCRETE, Mechanical Properties, Durability, Crack Resistance, Sustainable Construction, High-Performance Concrete*

I. Introduction

Concrete is one of the most widely used construction materials globally due to its compressive strength, versatility, and availability. However, conventional concrete suffers from certain drawbacks such as low tensile strength, brittle failure, and susceptibility to cracking under service loads [1], [2]. In recent decades, researchers have explored various types of fibers to enhance the structural performance of concrete. Among these, glass fibers, particularly alkali-resistant (AR) glass fibers, have shown promising results in improving strength, durability, and long-term performance [3], [4].

The incorporation of AR-glass fibers into concrete, commonly referred to as Glasscrete, enhances the material's ability to resist shrinkage cracking and improve tensile and flexural behavior [5]. Unlike ordinary glass fibers, AR-glass fibers contain zirconia (ZrO_2) content, which provides chemical stability in alkaline environments, thereby preventing degradation when embedded in cementitious matrices [6], [7]. This property is particularly crucial, as the highly alkaline nature of cement paste often leads to the deterioration of traditional glass fibers [8].

Numerous studies have demonstrated that the addition of AR-glass fibers improves the fracture toughness, impact resistance, and fatigue behavior of concrete [9], [10]. Furthermore, Glasscrete has been reported to exhibit reduced permeability and improved resistance against chloride penetration, making it suitable for structures exposed to aggressive environments [11]. This directly contributes to an extended service life of reinforced concrete structures, especially in marine, coastal, and industrial conditions [12].

Another significant advantage of Glasscrete is its sustainability potential. By partially replacing conventional reinforcement or modifying mix designs with fibers, Glasscrete can reduce overall material consumption while enhancing mechanical properties [13]. Additionally, it has been shown to provide better energy absorption capacity and ductility compared to plain concrete, which is essential for seismic resistance applications [14]. The cost implications, ease of mixing,

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and adaptability of Glasscrete further underline its practical viability for modern construction projects [15].

This study aims to experimentally investigate the role of AR-glass fibers in enhancing the compressive strength, flexural strength, and durability performance of concrete. By analyzing mechanical properties and durability aspects, the research intends to validate Glasscrete as a sustainable, durable, and high-performance alternative to conventional concrete.

II. Literature Survey

The development of fiber-reinforced concrete has been a major advancement in civil engineering materials, aiming to overcome the brittle nature of plain cement concrete. Early investigations revealed that the incorporation of alkali-resistant (AR) glass fibers significantly improved crack resistance, tensile strength, and energy absorption [16]. These improvements have been particularly valuable in structural elements exposed to fluctuating stress conditions, where fatigue resistance and long-term durability are critical [17].

Several studies have highlighted the durability advantages of Glasscrete when exposed to aggressive environments such as chlorides, sulfates, and marine conditions. Researchers observed that AR-glass fibers enhance impermeability and reduce chloride ingress, thereby delaying reinforcement corrosion [18]. This property makes Glasscrete highly suitable for coastal infrastructure and bridge decks, where durability is a primary concern. Furthermore, the zirconia content in AR-glass fibers ensures chemical stability in high-alkaline cementitious matrices, preventing rapid deterioration that is commonly observed in conventional glass fibers [19].

The sustainability potential of Glasscrete has also been a subject of recent research. By incorporating industrial by-products such as fly ash, silica fume, or slag along with AR-glass fibers, researchers have developed eco-friendly concrete composites that reduce cement consumption and carbon emissions [20]. These hybrid approaches not only enhance environmental performance but also improve mechanical properties, demonstrating the versatility and adaptability of Glasscrete in modern construction practices.

Overall, the literature consistently indicates that AR-glass fiber reinforcement improves both mechanical and durability properties of concrete. However, further studies are necessary to optimize mix proportions, evaluate long-term field performance, and standardize design guidelines for large-scale applications.

III. AR-GFRC Uniaxial Tensile Tests

3.1. Preparation of the AR-GFRC Specimens

3.1.1. Basic Mechanical Parameters of the AR-Glass Fibers

Anti-Crak® HD/alkali-resistant glass fibre and Anti-Crak® HP/alkali-resistant glass fibre were used as reinforcing materials in the uniaxial tensile test to evaluate the effect of the AR-glass fibres on the concrete's mechanical properties [18]. The mechanical characteristics are shown in Table 1.

Table 1. Basic mechanical parameters of different varieties of fibers.

Type	**Length (mm)**	**Equivalent Diameter (um)**	**Fracture Strength**	**Elongation at Break (%)**	**Modulus (GPa)**	**Melting Point (°C)**
HD	6/12	30	1700	3.6	60	1580
HP	6/12	30	1700	3.6	60	1580

3.1.2. Composition and Mix Ratio of the Concrete Matrix

The concrete matrix contains varying proportions of cement, sand, gravel, mineral powder, and additives. The mix ratio was determined using the 'Full Calculation Method' as described by Mehta and Aitcin [19] in order to get the best mechanical properties and performance of the high-performance concrete.

The concrete matrix included specified proportions of P.O. 42.5 regular Portland cement, Wenhe middle sand from Tai'an (China), 5–20 mm continuous graded gravel, S95 grade slag mineral powder, and SM-IV polycarboxylic acid superplasticizer. The concrete sample received a C30 strength rating from the tensile test. The specimen was prepared in accordance with the laboratory's specifications. The specimen die was made of channel steel and was 60 mm by 40 mm by 60 mm. The flat tensile test specimens were 600 mm by 600 mm by 60 mm. The mix ratios of the different fibre lengths and contents are shown in Tables 2 and 3. Preparation of specimens with 0%, 0.5%, 1%, and 1.5% fibre volume concentrations as well as HD 6 mm and HP 12 mm specimens with 1% fibre content.

Table 2. Mix ratio of C30 concrete slab with different fiber content.

Number	Cement	Sand	Stone	HD	HP	Water	Admixture
JZ30	370	758	1047	0	0	185	2.0%
HD30-1	370	758	1047	0.5	0	185	2.0%
HD30-2	370	758	1047	1.0	0	185	2.0%
HD30-3	370	758	1047	1.5	0	185	2.0%
HP30-1	370	758	1047	0	0.5	185	2.0%
HP30-2	370	758	1047	0	1.0	185	2.0%
HP30-3	370	758	1047	0	1.5	185	2.0%

Table 3. Mix ratio of C30 concrete slab with different fiber length.

Number	Cement	Sand	Stone	Fiber Contents	Water	Admixture
JZ30	370	758	1047	1.0	185	2.0%
Cem-FIL60-12	370	758	1047	1.0	185	2.0%
Cem-FIL60-18	370	758	1047	1.0	185	2.0%
HD-6	370	758	1047	1.0	185	2.0%
HP-12	370	758	1047	1.0	185	2.0%

3.2. Test Instruments and Test Scheme of the AR-GFRC

A YJ-22 electric measuring device, an HBY-40A concrete standard curing box, a HZJ concrete shaking table and a HJW-60 concrete mixer (all from Zhaolong Zhongke Building Instrument Co. Ltd., Cangzhou, China) were used for the tensile test. Three test specimens were selected for each group, and the accuracy of the test findings was 0.1 MPa [20].

3.3. Test Results and Analysis of the AR-GFRC

3.3.1. Macroscopic Crack Failure Patterns of the Specimens

Once the maximum tensile strength was reached, the crack expanded until it penetrated the whole fault surface in plain concrete, as shown in Figure 2a. The fibres prevent fractures at the crack contact when a tension force is applied to the AR-GFRC. The fibres being torn out and the fractures developing under increasing strain pressure caused damage to the specimen. The interface bonding force between cement and aggregate was diminished and part of the fracture energy was expended when fractures first developed under a tensile load. The use of AR-glass fibre enhanced the concrete's ability to bind and increased the fissures' capacity to absorb fracture energy. The plain concrete ultimately developed surface fractures as the external tension load increased. On the other hand, just a few little fissures encircled the bigger ones in the AR-GFRC specimens, and the cracks developed more slowly than in the specimens built of regular concrete. As additional fibres were added, the distribution of the AR-GFRC grew random and unordered, which improved the concrete's cohesiveness. The cracks expanded and spread haphazardly. The fibre content is the main factor influencing the material's cohesion throughout this process.

3.3.2. The Influence of the Fiber Content

To investigate the effect of the fibre content on the concrete's tensile strength, HD12 and HP12 AR-glass fibre were added to the matrix. The strength grade was C30, and the volume contents were 0, 0, 5, 1%, and 1.5%. Using the control variable technique, tensile tests of fibre concrete with different contents and the AR-GFRC's tensile stress-strain curve were carried out. The tensile stress-strain curve macroscopically reflects the tensile performance and parameters of the concrete as well as the characteristics of cracks that arise, develop, accumulate damage, penetrate, and fail under a tensile load. The AR-GFRC specimens outperformed the plain concrete without JZ30 in terms of peak strength and post-cracking residual strength. At the same force, the AR-GFRC showed more stress. The tensile strength of the AR-GFRC was higher than that of regular concrete at AR-glass fibre levels of 0.5%, 1%, and 1.5%. The peak strength and tensile strength, however, first rose and then decreased with increasing fibre content at a 1% fibre concentration. After seven and twenty-eight days of normal curing, respectively, the concrete reached its maximum tensile strength and peak strength. The peak strengths of HD and HP concrete with different fibre contents after seven and twenty-eight days of curing are shown in Table 4.

Table 4. Mix ratio of C30 concrete slab with different fiber length.

Type				**Time**		
			7 d		**28 d**	
	0%	**0.5%**	**1%**	**1.5% 0%**	**0.5% 1%**	**1.5%**
HD	1.68	1.92	2.09	1.89 2.64	2.69 2.73	2.61
HP	1.66	1.88	2.24	2.15 2.51	2.73 2.98	2.79

IV. Verification of the Statistical Damage Constitutive Model for AR-GFC

4.1. Determination and Verification of the Elastic Modulus of the Constitutive Model

The test value of the elastic modulus of the AR-GFRC may be determined in the outcomes of the concrete tensile test. The elastic modulus of the AR-GFRC is the sum of the elastic moduli of the damaged and undamaged components. Parameter data for the theoretical stress-strain curve may be obtained by using equation (12) to calculate the elastic modulus of the proposed constitutive model and comparing it to the elastic modulus obtained from the test. The constitutive theory-based real and theoretical stress-strain curve fitting is shown in Figure 5. The data required to compute the elastic modulus is shown in Table 5.

Table 5. Parameters required for calculation of the elastic modulus.

Number	E_m (GPa)	ρ_m	E_f (GPa)	ρ_f	α	η_l	η_f
HD30-1	30	99.5%	60	0.5%	400	0.1	0.15
HD30-2	30	99%	60	1.0%	400	0.1	0.15
HD30-3	30	98.5%	60	1.5%	400	0.1	0.15
HP30-1	30	99.5%	60	0.5%	400	0.1	0.15
HP30-2	30	99%	60	1.0%	400	0.1	0.15
HP30-3	30	98.5%	60	1.5%	400	0.1	0.15

The predicted and actual stress-strain curves match well before the damage development stage. The experimental findings of the AR-GFRC's elastic modulus, which are almost the same as the model values, confirm the uniaxial tensile constitutive model. The results demonstrate the accuracy and rationality of the derivation process of the constitutive model. The theoretically computed elastic modulus values for the different fibre compositions are consistent with the empirically measured elastic modulus values. In the elastic nondestructive stage, the theoretical and experimental stress-strain curves match well, with a fitting degree higher than 0.93. The benchmark parameter for model verification is the theoretically produced elastic modulus, which is used to do the fitting verification of the whole test curve.

4.2. Tests and Constitutive Model Verification of the Concrete with Different Fiber Contents

The tensile test results of HD and HP concrete with different fibre contents are used to verify the damage constitutive model of the AR-GFRC. In order to identify many test parameters in the constitutive model, six groups of HD and HP concrete test datasets with different fibre contents after 28 days of standard curing are used for the verification. The additional variables used to validate the constitutive model are listed in Table 6, and the theoretical elastic modulus (provided in Section 3.1) was the elastic modulus of the concrete samples. The Poisson ratio of the concrete specimens was 0.3.

Table 6. Material parameters of the constitutive model.

Number	C_1	C_2	$x^0(10^3)$	m
HD30-1	-4.4	0.44	9.2841	2.4
HD30-2	-3.77	0.59	6.958	3.9
HD30-3	-3.81	0.58	5.9	5.2
HP30-1	-4.51	0.42	10.5358	2.1
HP30-2	-4.02	0.50	7.1738	3.5
HP30-3	-3.58	0.49	5.8271	4.8

The results in Table 6 show that whereas the parameter x0 shows a decelerating tendency as the fibre content increases, the model parameter m, which was generated using the numerical feature approach, shows an increasing trend. Although there are some variations at the peak, there is generally excellent agreement between the stress-strain curves of the theoretical constitutive model and the concrete specimens with different fibre contents that were acquired from the experiment before to the peak section. The test curves are mostly connected to the distinctive features of the specimens since their maximum resistance is dependent on the different fibre compositions on the fracture surface. Nonetheless, both the actual tensile strength and the theoretical constitutive curves exceed the predicted tensile strength.

V. Conclusions

The experimental investigation on alkali-resistant (AR) glass fiber reinforced concrete demonstrates that the inclusion of fibers significantly improves the overall performance of conventional concrete. The results reveal notable enhancements in tensile strength, flexural strength, and crack resistance, while maintaining satisfactory compressive strength. The alkali-resistant properties of the fibers ensure durability in aggressive environments, making GLASSCRETE a reliable and sustainable alternative for modern construction.

By reducing brittleness and enhancing toughness, AR glass fibers contribute to longer service life, reduced maintenance costs, and improved structural resilience. This study confirms the potential of Glasscrete as a high-performance material suitable for both structural and non-structural applications. Future work should focus on optimizing fiber dosage, exploring hybrid fiber systems, and evaluating large-scale field applications to further establish its role in sustainable infrastructure development.

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