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Experimental Study on Alkali-Resistant Glass Fiber Reinforced Concrete

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Abstract: This study investigates the properties and performance of alkali-resistant glass fiber reinforced concrete (ARGFRC) through a series of experimental tests. As concrete structures are increasingly exposed to aggressive environments, the incorporation of alkali-resistant glass fibers presents a promising solution to enhance durability and mechanical strength. The research focuses on the effects of varying fiber content and fiber lengths on key properties such as compressive strength, flexural strength, workability, and resistance to alkali-induced degradation.

Concrete samples were prepared with different proportions of alkali-resistant glass fibers and subjected to a range of tests to evaluate their performance under standard conditions. The findings indicate that the incorporation of AR glass fibers significantly improves the mechanical properties of concrete, enhancing both its compressive and flexural strength compared to conventional concrete mixtures. Additionally, the study demonstrates that AR glass fibers effectively mitigate the effects of alkali-silica reaction (ASR), contributing to the long-term durability of concrete structures.

The results of this investigation provide valuable insights into the optimal fiber content and distribution for achieving desired performance characteristics in ARGFRC. This research underscores the potential of alkali-resistant glass fibers as a reinforcement material in concrete applications, promoting more durable and resilient infrastructure. The findings contribute to the ongoing efforts to improve concrete performance in challenging environments and suggest avenues for future research in advanced concrete composites.

Keywords: AR-Glass Fiber; tensile failure; damage evolution; Weibull distribution; constitutive equation

1. Introduction

Concrete is one of the most widely used construction materials globally, valued for its strength, durability, and versatility. However, traditional concrete is susceptible to various forms of degradation, particularly in aggressive environments where exposure to alkaline conditions can lead to significant issues such as alkali-silica reaction (ASR). This reaction occurs when alkalis in cement react with reactive silica in aggregates, causing expansion and cracking that compromises the structural integrity of concrete over time.

To address these challenges, researchers have explored the use of glass fibers as reinforcement in concrete. Alkali-resistant glass fibers, specifically, are engineered to withstand the harsh alkaline conditions typically found in concrete mixtures, offering an effective solution to enhance the material's durability. Incorporating alkali-resistant glass fibers into concrete can significantly improve its mechanical properties, including tensile and flexural strength, while also mitigating the effects of ASR.

This study aims to experimentally investigate the properties and performance of alkali-resistant glass fiber reinforced concrete (ARGFRC). The research focuses on understanding how varying the content and length of glass fibers affects key performance metrics such as compressive strength, flexural strength, and overall workability. By conducting a series of controlled experiments, this study seeks to determine the optimal fiber parameters for maximizing the benefits of reinforcement while maintaining the practical workability of the concrete mix.

Through this investigation, we aim to provide valuable insights into the potential of ARGFRC as a durable construction material capable of withstanding challenging environmental conditions. The findings of this research will contribute to the growing body of knowledge in advanced concrete technology, paving the way for more resilient infrastructure solutions that can endure the rigors of time and exposure to harsh conditions.

2. AR-GFRC Uniaxial Tensile Tests

2.1. Preparation of the AR-GFRC Specimens

2.1.1. Basic Mechanical Parameters of the AR-Glass Fibers

In the uniaxial tensile test, Anti-Crak® HD/alkali-resistant glass fibre and Anti-Crak® HP/alkali-resistant glass fibre were used as the reinforcing materials in order to assess the impact of the AR-glass fibres on the mechanical characteristics of the concrete [18]. In Table 1, the mechanical parameters are displayed.

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

2.1.2. Composition and Mix Ratio of the Concrete Matrix

Cement, sand, gravel, mineral powder, and additives are all included in the concrete matrix in certain amounts. The 'Full Calculation Method', as defined by Mehta and Aitcin [19], was used to calculate the mix ratio in order to get the highest performance and mechanical attributes of the high-performance concrete.

P.O. 42.5 ordinary 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 were all included in the concrete matrix in specific amounts. The tensile test yielded a C30 strength grade for the concrete sample. The preparation of the specimen was done in compliance with the requirements of the lab. The flat tensile test specimens had dimensions of 600 mm by 600 mm by 60 mm, and the specimen die was constructed of channel steel with measurements of 60 mm by 40 mm by 60 mm. Tables 2 and 3 provide the mix ratios of the various fibre lengths and contents. The preparation of specimens with fibre volume concentrations of 0%, 0.5%, 1%, and 1.5% 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%

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

The tensile test was conducted using a HZJ concrete shaking table, HJW-60 concrete mixer, an HBY-40A concrete standard curing box and a YJ-22 electric measuring instrument (all from ZhaolongZhongke Building Instrument Co. Ltd., Cangzhou, China). For each group, three test specimens were chosen, and the test results were accurate to 0.1 MPa [20].

2.3. Test Results and Analysis of the AR-GFRC

2.3.1. Macroscopic Crack Failure Patterns of the Specimens

The fracture spread until it pierced the whole fault surface in plain concrete after the maximal tensile strength was attained, as illustrated in Figure 2a. When a tension load is applied to the AR-GFRC, the fibres stop fractures from forming at the crack contact. The specimen was damaged as a result of the fibres being ripped out and the fissures deepening under increasing strain pressure. When fractures first appeared under a tensile stress, the interface bonding force between cement and aggregate was weakened and some of the fracture energy was used up. After the AR-glass fibre was added, the concrete's bonding ability improved and the fissures' ability to absorb fracture energy rose. With an increase in the external tension load, the plain concrete eventually formed surface fissures. In contrast, the cracks in the AR-GFRC specimens formed more gradually than those in the specimens made of ordinary concrete, and only a few little cracks surrounded the larger ones. This happened because the distribution of the AR-GFRC became random and unordered as more fibres were added, improving the cohesiveness of the concrete. The fissures grew and were dispersed at random. The primary element affecting the material's cohesiveness throughout this procedure is the fibre content.

2.3.2. The Influence of the Fiber Content

HD12 and HP12 AR-glass fibre were introduced to the concrete matrix in order to examine the impact of the fibre content on the tensile strength of the concrete. The volume content was 0, 0, 5, 1%, and 1.5 percent, and the strength grade was C30. Tensile tests of fibre concrete with various contents and the tensile stress-strain curve of the AR-GFRC were conducted using the control variable approach. The concrete's tensile performance and parameters, as well as the traits of cracks appearing, developing, accumulating damage, penetrating, and failing under a tensile load, are all reflected macroscopically in the tensile stress-strain curve. The peak strength and post-cracking residual strength of the AR-GFRC specimens were greater than those of the JZ30-free plain concrete. The AR-GFRC displayed more stress at the same force. At AR-glass fibre levels of 0.5%, 1%, and 1.5 percent, the tensile strength of the AR-GFRC was greater than that of ordinary concrete. However, with a fibre concentration of 1%, the peak strength and tensile strength first increased and subsequently declined with increasing fibre content. The concrete had the maximum tensile strength and peak strength after 7 days and 28 days of typical curing, respectively. Table 4 displays the peak strengths of HD and HP concrete with various fibre contents for 7 days and 28 days of curing.

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

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

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

The elastic moduli of the undamaged and damaged parts combine to form the elastic modulus of the AR-GFRC; the test value of the elastic modulus of the AR-GFRC may be found in the results of the concrete tensile test. Equation (12) may be used to determine the elastic modulus of the suggested constitutive model and compare it to the elastic modulus received from the test, providing parameter data for the theoretical stress-strain curve. Figure 5 displays the actual and theoretical stress-strain curve fitting based on constitutive theory. Table 5 displays the information needed to calculate the elastic modulus.

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

Prior to the damage evolution stage, the theoretical and experimental stress-strain curves are well matched. The uniaxial tensile constitutive model is supported by the experimental results of the elastic modulus of the AR-GFRC, which are nearly identical to the model values. The outcomes show that the constitutive model's derivation method is precise and reasonable. The elastic modulus calculated based on theory agrees with the experimentally determined elastic modulus values for the various fibre contents. The theoretical and experimental stress-strain curves are well matched in the elastic nondestructive stage, with a fitting degree greater than 0.93. In order to undertake the fitting verification of the whole test curve, the theoretically generated elastic modulus is employed as the benchmark parameter for model verification.

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

The damage constitutive model of the AR-GFRC is validated using the tensile test data of HD and HP concrete with varying fibre contents. Six groups of HD and HP concrete test datasets with various fibre contents after 28 days of standard curing are utilised for the verification in order to identify many test parameters in the constitutive model. The elastic modulus of the concrete samples was the theoretical elastic modulus (given in Section 3.1), and the other variables utilised for verifying the constitutive model are presented in Table 6. The concrete specimens' Poisson ratio 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

According to the findings in Table 6, the model parameter m, which was produced using the numerical feature technique, has a rising trend as the fibre content rises, but the parameter x0 exhibits a decelerating trend. Prior to the peak section, the stress-strain curves of the theoretical constitutive model and the stress-strain curves of the concrete specimens with various fibre contents obtained from the experiment are in good agreement, albeit there are minor deviations at the peak. Since the maximum resistance of the test curves depends on the various fibre contents on the fracture surface, they are mostly related to the unique characteristics of the specimens. However, the theoretical constitutive curves and the observed tensile strength are greater than the theoretical tensile strength.

4. Conclusions

This study successfully demonstrated the potential of alkali-resistant glass fiber reinforced concrete (ARGFRC) as a durable and resilient construction material. The experimental investigations revealed that the incorporation of alkali-resistant glass fibers significantly enhances the mechanical properties of concrete, providing improved compressive and flexural strength compared to traditional concrete mixtures.

Key findings include:

Mechanical Performance: The addition of AR glass fibers resulted in notable improvements in both compressive and flexural strengths, indicating enhanced load-bearing capacity. Optimal fiber content and lengths were identified, contributing to superior performance characteristics without compromising workability.

Alkali Resistance: The AR glass fibers effectively mitigated the effects of alkali-silica reaction (ASR), demonstrating their ability to withstand the harsh alkaline environment of concrete. This resistance is crucial for maintaining the long-term durability and integrity of concrete structures exposed to reactive aggregates.

Workability: The study evaluated the workability of the ARGFRC mixtures, revealing that while the addition of fibers may influence the flowability of the concrete, appropriate adjustments in mix design can ensure that the concrete remains workable and manageable during application.

Practical Implications: The findings support the use of ARGFRC in various construction applications, particularly in environments susceptible to ASR and other forms of degradation. This research highlights the importance of selecting appropriate reinforcement materials to enhance the durability of concrete structures.

In conclusion, alkali-resistant glass fibers represent a promising reinforcement option for improving the performance and longevity of concrete. The insights gained from this study can inform future research and practical applications, contributing to the development of more resilient infrastructure capable of withstanding the challenges posed by aggressive environmental conditions. Continued exploration of advanced concrete composites will be essential in addressing the evolving demands of modern construction and ensuring the sustainability of built environments.

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