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STUDIES ON MECHANICAL AND DURABILITY PROPERTIES OF ALKALI-RESISTANT GLASS FIBER REINFORCED CONCRETE

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Abstract: Alkali-Resistant Glass Fiber Reinforced Concrete (AR-GFRC) has emerged as a promising composite material that enhances the performance of conventional concrete, particularly in structural and infrastructure applications. This study investigates the influence of varying percentages of alkali-resistant glass fibers on the mechanical and durability properties of concrete. AR glass fibers are incorporated at different volume fractions to evaluate improvements in compressive strength, tensile strength, flexural behavior, and impact resistance compared to plain concrete. The research further assesses durability characteristics including water absorption, shrinkage, resistance to chloride ion penetration, and performance under cyclic wetting–drying and freeze–thaw conditioning. Experimental results indicate that the inclusion of AR glass fibers significantly improves tensile and flexural strengths, mitigating crack propagation and enhancing post-cracking behavior. Durability tests demonstrate reduced permeability and improved resistance to environmental degradation, suggesting enhanced long-term performance in aggressive conditions. The findings underscore the potential of AR-GFRC as a high-performance construction material, advocating for optimized fiber content to achieve balanced mechanical and durability benefits. This research contributes to sustainable infrastructure solutions by improving concrete resilience in severe service environments.

Keywords: Alkali-Resistant Glass Fiber, Fiber Reinforced Concrete, Mechanical Properties, Durability Performance, Compressive Strength, Flexural Strength, Tensile Strength, Crack Resistance, Chloride Penetration, Sustainable Construction Materials

I. Introduction

Concrete is the most widely used construction material due to its versatility, strength, and cost-effectiveness. However, conventional concrete requires mechanical vibration to achieve proper compaction, which can lead to issues such as honeycombing, segregation, and poor surface finish, especially in heavily reinforced sections. To overcome these limitations, Self-Compacting Concrete (SCC) was developed. SCC is a highly flowable concrete that can spread into place, fill formwork, and encapsulate reinforcement without the need for external vibration. Its use improves construction efficiency, reduces labor requirements, and enhances the quality and durability of concrete structures.

In recent years, the construction industry has focused on sustainability and the efficient use of industrial by-products. Fly ash, a by-product of thermal power plants, poses significant disposal and environmental challenges. Sintered fly ash aggregate is produced by pelletizing and sintering fly ash, resulting in lightweight aggregates with adequate strength and durability. The use of sintered fly ash aggregate in concrete reduces the consumption of natural aggregates and promotes sustainable construction practices.

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The brittle nature and low tensile strength of concrete remain major concerns, even in SCC. The incorporation of fibers is an effective method to enhance tensile strength, crack resistance, ductility, and energy absorption capacity. Fiber-Reinforced Self-Compacting Concrete (FRSCC) combines the advantages of SCC and fiber reinforcement, resulting in improved mechanical performance and durability. This study investigates the combined effect of fiber reinforcement and sintered fly ash aggregate on the fresh and hardened properties of SCC.

II. Literature Survey

Concrete reinforced with alkali-resistant glass fibers (ARGFRC) has been widely investigated as a means to enhance mechanical performance and durability of conventional concrete. Early research on glass fibers in cementitious composites highlighted the need for alkali resistance due to severe degradation of conventional glass in the highly alkaline concrete environment (pH > 12). Traditional borosilicate glass fibers suffered strength loss and surface deterioration, prompting development of AR glass fibers with high zirconia content to improve durability in concrete matrices. MDPI Ahmad et al. (2022) provided a comprehensive review of glass fiber reinforced concrete, summarizing that the inclusion of glass fibers improves mechanical properties such as compressive, flexural, and tensile strength, while also positively influencing durability parameters like chloride ion penetration resistance and reduced water absorption. However, they noted that higher fiber contents can decrease workability, necessitating careful mix design and use of admixtures. MDPISpecific experimental investigations have demonstrated similar performance enhancements. Shaik et al. (2022) conducted tests on AR glass fiber reinforced concrete with varying fiber contents and lengths, observing significant improvements in compressive and flexural strength and mitigation of alkali-silica reaction effects compared to plain concrete. These findings support the use of AR glass fibers in environments where chemical degradation is a concern. Jett Tiwari and Prakash (2025) similarly reported that optimum fiber dosages (1.0–1.5%) enhanced split tensile strength by up to 35% and reduced water absorption by 33%, indicating improved microstructural resistance to aggressive agents. Ijaresm

Durability under simulated aggressive environments has also been a focus of research. In studies published in Materiales de Construccion, GFRC samples with AR glass fibers were exposed to tropical climates, cyclic wetting/drying, and seawater immersion. Results indicated that while higher fiber contents could suffer strength loss in certain environments, AR glass fibers generally helped maintain lower permeability under cyclic conditions, suggesting nuanced performance dependent on exposure type. Directory of Open Access Journals Other studies have explored reinforcing concrete with AR glass fibers in combination with supplementary materials. For example, Sk. Sahera et al. (2023) used dunite powder in AR glass fiber reinforced mixes and reported notable improvements in compressive and split tensile strength. These hybrid approaches highlight potential synergistic effects in enhancing both strength and durability. IJRASET Despite the overall performance benefits,

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long-term durability challenges persist. Literature indicates that even alkali-resistant fibers may undergo gradual strength reduction under prolonged alkaline exposure, with degradation influenced by fiber composition, environmental conditions, and exposure duration. MDPI Therefore, current research emphasizes optimization of fiber content, concrete mix design, and protective measures to balance mechanical gains with sustainable durability performance.

III. Materials

1. Alkali-Resistant Glass Fibers

These are specially formulated glass fibers that resist the alkaline environment of concrete. They improve tensile strength, crack resistance, and durability in the concrete matrix.

2. Cement

Cement is the primary binding material used in ARGFRC. Ordinary Portland Cement (OPC), generally of 43 or 53 grade, is commonly used due to its availability and consistent performance. Cement reacts with water through the process of hydration to form a hardened matrix that binds all other materials together. In ARGFRC, cement also provides a protective environment for embedded fibers. However, cement paste is highly alkaline in nature, which can cause degradation of ordinary glass fibers. Therefore, the selection of alkali-resistant glass fibers becomes essential. The quality of cement directly influences strength development, setting time, and durability of the concrete.

3. Fine Aggregate

Fine aggregate, usually natural river sand or manufactured sand, is used in ARGFRC to provide bulk and improve workability. Unlike conventional concrete, ARGFRC typically avoids the use of coarse aggregates, especially in thin-section elements, to achieve better fiber dispersion and surface finish. Fine aggregates help in reducing shrinkage and improving the homogeneity of the concrete mix. The particle size distribution, cleanliness, and shape of sand significantly affect the strength and durability of ARGFRC. Well-graded sand ensures proper bonding between the cement matrix and glass fibers.

3. Water

Water is an essential component required for cement hydration and for achieving proper workability of the concrete mix. Clean and potable water free from harmful salts, acids, and organic impurities is

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recommended. The water–cement ratio plays a crucial role in determining the strength and durability of ARGFRC. Excess water may lead to increased porosity and reduced strength, while insufficient water affects workability and fiber dispersion. Proper control of water content ensures uniform mixing and effective bonding between cement paste and fibers.

4. Admixtures

Chemical admixtures are used in ARGFRC to improve workability, reduce water demand, and enhance performance. Superplasticizers or high-range water-reducing admixtures are commonly used to maintain flowability without increasing water content. These admixtures help in achieving better fiber dispersion and prevent fiber balling during mixing. In some cases, retarders or accelerators may be added to control setting time depending on site conditions. The use of admixtures significantly improves the fresh and hardened properties of ARGFRC.

Material	Specification	Purpose
Cement	Ordinary Portland Cement (OPC) 53 grade	Primary binder providing strength and durability
Fly Ash	Class F	Supplementary cementitious material, improves workability, reduces heat of hydration, and enhances durability
Fine Aggregate	Natural river sand, clean and well-graded	Provides bulk, improves workability, and supports matrix integrity
Coarse Aggregate	Sintered fly ash aggregate	Lightweight, sustainable replacement for conventional aggregates, reduces density and environmental impact
Fibers	Alkali-resistant fibers (12 mm length)	Enhances tensile and flexural strength, improves crack resistance and post-cracking behavior
Water	Potable	Hydration of cement and uniform mixing
Admixture	Superplasticizer	Ensures self-compacting properties, reduces water content without compromising flowability

Mix Proportions

Mix ID	Cement (kg/m³)	Fly Ash (kg/m³)	Fine Aggregate (kg/m³)	Sintered Fly Ash Aggregate (kg/m³)

SCC-Control	400	0	750	1000
FRSCC-0.5	400	50	750	950
FRSCC-1.0	400	50	750	950
FRSCC-1.5	400	50	750	950

IV. Experimental Investigation

The experimental investigation was carried out to study the mechanical and durability properties of Alkali-Resistant Glass Fiber Reinforced Concrete (ARGFRC) and to evaluate the effect of varying fiber content on concrete performance. Ordinary Portland Cement (OPC) of 53 grade, fine aggregate, alkali-resistant glass fibers, potable water, and a superplasticizer were used in the preparation of concrete mixes. Alkali-resistant glass fibers containing a high percentage of zirconium dioxide were used to ensure resistance against the alkaline environment of cement. Concrete mixes were prepared by incorporating alkali-resistant glass fibers at different percentages by volume of cement, namely 0%, 0.5%, 1.0%, and 1.5%. A control mix without fibers was also prepared for comparison. The water–cement ratio was kept constant for all mixes to maintain uniformity. Mixing was carried out in a laboratory mixer, ensuring gradual addition and uniform dispersion of fibers to avoid balling.

Standard specimens were cast for testing purposes. Cubes of size 150 mm were prepared for compressive strength tests, cylinders for split tensile strength tests, and beams for flexural strength tests. After casting, specimens were demolded after 24 hours and cured in water for 7 and 28 days. Mechanical properties such as compressive strength, split tensile strength, and flexural strength were evaluated as per relevant Indian Standard codes. Durability tests including water absorption and chemical resistance were also conducted. The experimental results showed improved crack resistance, tensile strength, and durability with the inclusion of alkali-resistant glass fibers, indicating the effectiveness of ARGFRC for structural applications.

4.1 Mix Trails Details

Table 1 Alkali-Resistant Glass Fibers of concrete mixes:

Types of Mixes	OPC	Fly Ash	Admixtures	Alkali-Resistant Glass Fibers
M1	79%	11%	10%	-
M2	78%	11%	10%	1%
M3	77%	11%	10%	2%
M4	76%	11%	10%	3%
M5	75%	11%	10%	4%

V. Results And Discussions

5.1 Workability test on fresh concrete

The test was done to measure the workability property of the concrete, the test indicates the homogeneity and uniformness of the concrete mix, the segregation and bleeding phenomena is observed by this trail investigation. By doing this experiment we can say that workability decreases due to high surface area of nano silica.

Table 2 workability of concrete test results

Types of Mixes	Slump(mm)
M1	70
M2	70

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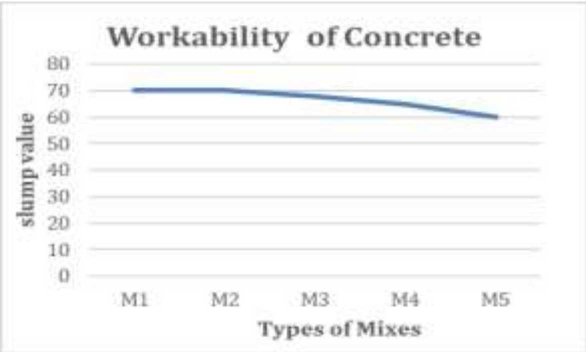
M3	68
M4	65
M5	60



Graph 1: Comparison of workability of concrete

5.2 Compressive Strength of Concrete Test

The values for the compressive strength of proportions 7 days and 28 days are calculated and represented in following graph below as per code IS: 516-1959 [25]. From results obtained by this test we can say that compressive strength increases by 10 % with reference to standard concrete.

Table 3 compressive strength of concrete test results

Mix	Compressive strength (N/mm^2)	
	7 Days	**28 days**
M1	52.9 N/mm^2	81.3 N/mm^2
M2	54.1N/mm^2	83.23 N/mm^2
M3	56.3N/mm^2	86.6 N/mm^2
M4	58.1N/mm^2	88.3 N/mm^2
M5	56.2N/mm^2	86.3 N/mm^2

Graph 2: Comparison of compressive strength of concrete

5.3 Split Tensile Strength Test

The values for the split tensile strength of proportions 7 days and 28 days are calculated and represented in following graph below as per code IS:5816-1999[26]. From results we can say that split tensile strength increase by 4% when compare with standard mix.

Table4 split tensile strength of concrete test results

Mix	Split Tensile Strength (N/mm^2)	
	7 Days	**28 Days**
M1	3.97	4.77
M4	4.138	4.93

Graph 3: Comparison of split tensile strength of concrete

5.4 Flexural Strength of Concrete Test

The values for the flexural strength of proportions 7 days and 28 days are calculated and represented in following graph below as per code IS:516-1959[25]. From results we say that flexural strength increases by 5% when compare to standard mix.

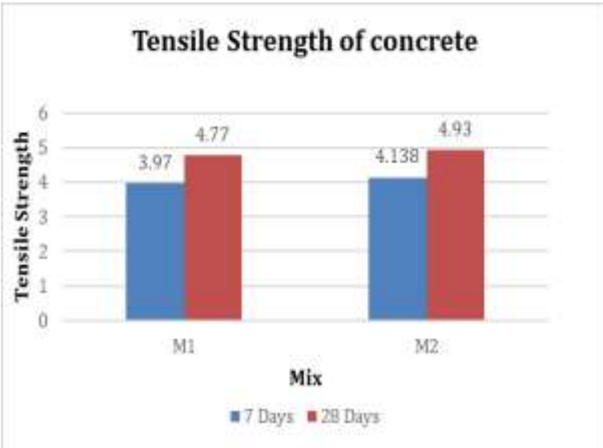
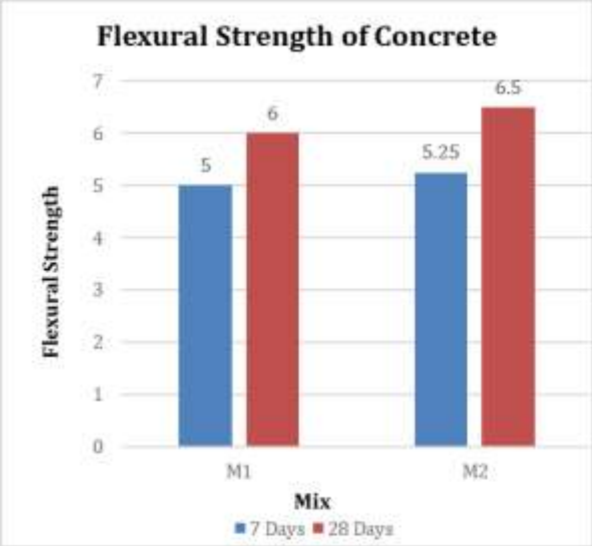


Table 5 flexural strength of concrete test results

Mix	Flexural strength (N/mm^2)	
	7Days	**28 Days**
M1	5	6
M4	5.25	6.5



Graph 4: Comparison of flexural strength of concrete

VI. Conclusions

- Alkali-Resistant Glass Fiber Reinforced Concrete (ARGFRC) shows improved performance compared to conventional concrete.
- The inclusion of alkali-resistant glass fibers effectively controls micro-cracks and reduces crack propagation.
- Compressive strength shows marginal improvement, while split tensile and flexural strengths increase significantly with fiber addition.
- AR glass fibers enhance post-cracking behavior and toughness, leading to a more ductile failure mode.
- Durability properties such as water absorption and chemical resistance are improved due to reduced permeability.
- An optimum fiber content provides the best balance between workability and strength enhancement.
- Excessive fiber content may reduce workability and cause fiber balling.
- ARGFRC is suitable for applications requiring high crack resistance, durability, and long service life.
- The use of ARGFRC contributes to sustainable construction by reducing maintenance and repair needs.
- The split tensile strength of M4 mix at 7 days and 28 days is increased by 4% as compared to the reference mix M1.
- The flexural strength of M4 mix at 7 days and 28 Days is increased by 5% as compared to the reference M1 mix.

VII. Future Work

Future research on Alkali-Resistant Glass Fiber Reinforced Concrete (ARGFRC) can be directed toward evaluating its long-term performance under various aggressive environmental conditions such as marine exposure, sulphate-rich soils, and acidic environments. Detailed studies on fatigue, impact, and cyclic loading behavior are necessary to assess its suitability for dynamic and seismic applications. The combined use of alkali-resistant glass fibers with supplementary cementitious materials like fly ash, silica fume, metakaolin, and GGBS can be explored to enhance strength, durability, and sustainability. Further investigation into optimizing fiber length, aspect ratio, and dosage is required to achieve improved mechanical properties without compromising workability. Large-scale structural testing of ARGFRC elements such as beams, slabs, and precast panels will provide better insight into its practical implementation. Additionally, life-cycle cost analysis and environmental impact assessment can support the wider adoption of ARGFRC in modern construction practices.

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