# Effect of Alkali Resistant Glass Fiber on Performance of Cement Concrete - A Review of Experimental Investigations

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***Abstract:*** ***Cement concrete, a universally accepted construction material is enough strong in compression but weak in tension with limited ductility and therefore its resistance to cracking is low attributed to the inherent presence of micro-internal cracks. In order to improve its resistance to cracking, and post peak response, alkali-resistant glass fiber (ARGF) as an additive is one of the options. This is added in certain percentage during mixing and the concrete is generally called alkali-resistant glass fiber reinforced concrete (ARGFRC). This paper presents review of the experimental research works carried out on use of type with regards to aspect ratio and quantity of ARGF in cement concrete. Type and quantity both influence the properties of fresh and hardened ARGFRC. The dosage effect with quantity of the fiber on fresh concrete such as workability, and mechanical performance, seismic vulnerability evaluation, microstructural analysis, durability aspects on hardened concrete have been reviewed. It is found that alkali-resistant glass fiber together with silica fume can be utilized to enhance the toughness and load carrying capacity and improve the stiffness of the composite concrete.***

***Keywords:*** ***Alkali Resistant Glass Fiber; Alkali Resistant Glass Fiber Reinforced Concrete; Durability; Microstructural analysis; Admixture.***

## I. INTRODUCTION

Glass fiber reinforced concrete (GFRC) is a special class of fiber-reinforced concrete. It is primarily made of ordinary Portland cement, aggregates, water, discrete alkali-resistant glass fibers, and water reducing admixture. Alkali Resistant (AR) glass fiber is accommodated into a matrix either in continuous or discontinuous (Chopped) length [1].

### A. Glass fiber reinforced concrete (GFRC):

According to International Glass Fiber Reinforced Concrete Association (IGRCA), GRC (Glassfibre Reinforced Cement) or GFRC (Glassfibre Reinforced Concrete), famous around the world by various names such as Fiber Beton, Fiber takviyeli Beton, Composite Ciment Verre or CCV and Glasfaserbeton or GFB, is a mixture of cement, sand, water, admixtures and AR glass fibres. Glassfibre Reinforced Concrete (GRC) is a material which today is making a considerable contribution to economics, to the technology and the aesthetics of the construction industry worldwide [1].

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**B. According to evaluation on GFRC panels for use in military constructions by Us Army Corps of Engineers):** The term "GFRC" applies to products manufactured using cement/aggregate reinforced entirely with glass fibers. These products include molded sheets, corrugated and plain sheets, non-pressure pipes, and industrial panels (cladding). The panels are by far the most extensively used product. Due to their versatility and low cost, architects are increasing GFRC boards at an ever-increasing rate. The usage and application of GFRC panels are most commonly seen in Japan, Europe, United Kingdom, United States, and South Africa, as well as in the Middle East [2].

The American Concrete Institute Committee 544 has divided Fiber Reinforced Concrete into four distinct categories based on fiber type [3].

(1) Steel fiber reinforced concrete (SFRC).
(2) Glass fiber reinforced concrete (GFRC).
(3) Synthetic fiber reinforced concrete (SNFRC).
(4) Natural fiber reinforced concrete (NFRC).

The committee prescribe the chemical composition and properties of A-glass (Soda lime silica glass fiber); E-glass (Borosilicate glass fiber); Cem-Fil AR glass fiber; and NEG AR-glass fiber (Nippon Electric Glass) [3].

**C. (Muhammed Iskender and Bekir Karasu):** In the 1940s, the special type of glass fiber as a building material was found out, and progress was made by adding zirconium dioxide in the 1960s for severe and offensive alkaline conditions. The glass fiber reinforced concrete so obtained named as ARGFRC was thus designed to meet different demands and satisfaction. Systematic research and experimental work on glass fiber reinforced concrete have pointed to their physical and mechanical characteristics modification concerning their quality and method of manufacturing. GFRC can be utilized anywhere where it is lightweight, durable, fire-resistant, weather-resistant, attractive, and impermeable [4].

**D. International GFRC Association (GRCA) Practical Design Guide:** According to the guide, alkali-resistant glass fiber (ARGF) is specifically designed to a high degree of resistance against alkali attack from cement (typically pH12.9) and high durability. 'E' glass fiber, as used in plastic reinforcement, gets rapidly destroyed due to a high alkaline environment. The unique ingredient of the AR glass fiber, particularly, the zirconia content, withstands against this offensive alkaline circumference. Based on the investigations, a minimum of 16% zirconia content was recommended for adequate alkali resistance. ACI Committee 544 also recommended 16% zirconia content in the glass fiber and named it alkali-resistant glass fiber [3].

**H. Taraura of Nippon Electric Glass Co., Ltd, Japan** reviewed the development of GRC and claimed that NEG started production of glass fiber in 1976 in Japan, and NEG AR fiber satisfied this requirement of zirconia for alkali resistance [5]. Prince Engineering presented the classification of glass fiber as given in Table 1 [6].

**Table 1 Classification of glass fiber [6].**

| S. No | Type of Glass Fiber | Usage |
|---|---|---|
| 1 | A-glass - Alkali glass containing soda lime silica | Apply for containers and windowpanes |
| 2 | AR-glass – Alkali Resistant glass with zirconium silicate content | For OPC cement substrates |
| 3 | C-glass – resist to corrosion and containing of calcium borosilicate | For acid corrosive environment |
| 4 | D-glass – Low dielectric glass with borosilicate content | Use for electrical appliances |
| 5 | E-glass –Free alkali glass containing alumina-calcium borosilicate | For fiber reinforced polymer composite industry |
| 6 | ECR-glass – Special type of E-glass with higher resistivity against acid corrosion made of calcium aluminosilicate | Used where strength, electrical conductivity and resistance to acid corrosion is required |
| 7 | R-glass – reinforcement glass with calcium aluminosilicate content | It is applying for high strength and resist against acid corrosion |
| 8 | S-glass – possess rich strength made with magnesium aluminosilicate content | It is use for higher strength, hardness and temperature resistance |
| 9 | S-2 glass – same as S-glass with slightly improvement in properties | where high tensile strength, compressive strength and resistant to high temperature is required |

**E. Applications:** GFRC has numerous applications, as also mentioned by ACI Committee 544. By far, the large and significant application of GFRC is the exterior panels of the building. Most of the application of entire GFRC structural and architectural components manufactured and used in the United States. Another primary employment of GFRC is in the electrical utility, agriculture components such as irrigation water troughs, feeding troughs, and sheep dips, asbestos replacement, fire protective system, marine application, low-cost building, and irrigation structures [3].

**F. Production of GFRC:** According to the International Glass Fiber Reinforced Concrete Association, GFRC is generally manufactured by either the "sprayed" method or the "premix" method [1].

The average value of properties of GFRC spray up and premix type is given by J.P.J.G. Ferreira and F.A.B. Branco [7].

## II. RESEARCH DONE ON GFRC

### A. Sizing effect of AR Glass fiber:

Shang-Lin Gao et al. [8] Studied the mechanical, surface, and bulk behavior of Alkali-Resistant glass fiber exposed to various environmental attacks, Due to the elastic and non-elastic properties at the fiber surface. They developed a non-dimensional energy index parameter to describe the extent of damage and a sensitive parameter to specify the transition between the dominated size response and the substrate-dominated response. They concluded that strength of fiber at failure was strongly surface flaw dependent.

### B. Durability property of GFRC:

Mahmoud Mazen Hilles and Mohammed M. Ziara. [9] This paper reported on mechanical properties of high strength alkali resistant glass fiber reinforced concrete. AR glass fiber of length 8 to 30mm with varying percentages of 0, 0.3, 0.6, 0.9, and 1.2% by weight of cement was used. The concrete specimens were tested for compressive, split tensile, and flexural strength after 7 and 28 days. It was reported that the maximum compressive strength was given by 1.2% of glass fiber content. Whereas, higher split tensile and flexural strength was reported as compared to compressive strength. Tejal Desai et al. [10] This paper studied the response of lean concrete and high-performance concrete reinforced with AR glass fiber. Two different type of ARGF namely high dispersion and high performance with different sizes of 6, 12, 24, and 40mm were used. The dosage of high dispersion (HD) type of ARGF was 0.6 and 5kg/m$^3$ and used to study the early age strength and plastic shrinkage of concrete. Whereas, high-performance (HP) type of ARGF from 5 to 20kg/m$^3$ was utilized to investigate the long-term strength and ductility. it was reported that the HP fiber of 12mm length gave higher compressive strength as compared to other length of fiber. At early age the fibers are responsible for its toughness. Whereas, at later age they contributed to increase the strength of the concrete. Babar Ali and Liaqat Ali Qureshi [11] The effect of ARGF and recycled coarse aggregate on strength and durability performance of concrete were studied. Alkaliproof glass fiber with 6, 12, and 18mm length were used. Three varied mixes using recycled coarse aggregate of 0, 50, and 100% and ARGF of varying percentages of 0, 0.25, 0.5, and 1% by weight of cement were utilized in each of the RCA concrete mixes. The concrete specimens were tested for compressive, split tensile, flexural strength, and sorptivity after 28 days of normal water curing.

It was reported that the fresh density of concrete declined with increasing recycled coarse aggregate and glass fiber content. Remarkable reduction in compressive strength was reported at 50% and 100% RCA. Whereas, ARGF mitigate the loss in compressive strength up to some certain limit. Flexural strength of concrete with 0.25% of glass fiber in all type of concrete mixes enhanced by 26%. Atheer H. M. Algburi et al. [12] This paper studied the response of glass, steel, and hybrid fiber used in reactive powder concrete. Both ARGF and steel fibers of 13mm length with 0.6% and 0.9% by weight of mix were used. Concrete specimens were tested for compressive, split tensile, share strength and modulus of elasticity after 7 and 28 days. It was reported that the strength of glass fiber and hybride fiber reactive powder were decreased as compared to non-fiberous concrete. Whereas, the shear strength of glass and hybrid fiber RPC were enhanced to that of control concrete. Zhifu Dong et al. [13] Alkali resistant glass fiber containing reach zirconium content, steel and macro-polypropylene fiber were utilized in concrete to examine the impact behavior of slab. The impact behavior of slab was tested using drop hammer and compared the result with macro-polypropylene fiber and steel fiber. ARGF, steel, and polypropylene fibers of 36, 60, 60mm length were used. AR glass fiber with varying percentages of 0, 0.25, 0.45, and 0.75% by volume of mix were used. Whereas steel fiber with 0.45, and polypropylene fibers with 0.45 and 0.75% were utilized. SFRC slab exhibited better performance in terms of cracking and resistance to energy absorption with comparison to glass and polypropylene fibers. With 0.45% of glass and polypropylene fiber the damaged degree of slab against first impact was similar. Whereas, with 0.45% the width and number of cracks in slab was reported less as compared to concrete slab reinforced with macro-polypropylene fiber. The level of damage with 0.45% and 0.75% of the macro-polypropylene fiber reinforced concrete slab after second impact was observed better than concrete slab reinforced with glass fiber. Ms. Shinde P.A and Ms. Gaikwad R.D [14] In general, durability can be linked to the ability of concrete to withstand the detrimental effects of its environment and service conditions until it reaches a minimum level of performance. This paper reported the effect of HCl on AR glass fiber reinforced concrete. ARGF by varying percentages of 0, 1, and 2% by weight of cement were used. It was found that the better resistance of concrete reinforced with ARGF against acid attack (HCl) was observed at 1% of fiber content. Magdy Riad et al. [15] RCC beam subjected to fire and cooling conditions. Out of the 18 beams, nine beams were cast for 35MPa, and the remaining nine beams were cast for 60MPa, with a rectangular cross-section of size 120mm (width) x 250mm (height) x 1650mm (length). AR glass fiber of 18mm length with 0%, 0.5%, and 1% by concrete weight were used. For 60MPa, silica fume, along with superplasticizer, was used. In the investigation, these eighteen beams were classified to six different groups. Each group of 3 beams, Odd parts (Part 1, Part 3, and Part 5), belonged to M35 and even part (Part 2, Part 4 and Part 6) where belongs to M60. Part 1 and Part 2 were kept as a reference beam for comparison of the result with other beams. Part 3 and Part 4 beams were loaded to one-third part of the ultimate load resulted from the reference beam and were subjected to fire up to 500 ℃ temperature and then allow to cool in the air and then increased the load to the failure stage. The same procedure was followed for beams of Part 5 and Part 6. They concluded that by adding glass fiber to the mix of concrete improved the ultimate strength over the reference specimen. But the effect of fire on the deflection was more pronounced. And also, the response of all cooled specimens after the fire was indifferent from the control sample, only a 10% reduction in compressive strength was observed. It was also inferred that 0.5% of glass fiber content in GFRC contributed more effectively than higher dosages. W.H. Kwan et al. [16] The durability of AR glass fiber reinforced concrete under offensive environment conditions, namely tropical climate, cyclic air, and seawater immersion was studied on specimens with different glass fiber percentage (0%, 0.6%, 1.2%, 1.8%, and 2.4%) of 24mm cut length by volume of the binder. Silica fume was also used as 12% of the binder. 28 days cured specimens were exposed to an aggressive environment for 3, 6, 12, and 18 months. Specimens for tropical air were cured in air temperature ranging between 23-32 ℃ and relative humidity between 65-79% and then exposed to sun radiations and rains. And specimens for cyclic wetting and drying in tropical air were cured for 14 days. For seawater immersion, specimens were subjected to seawater at 25±2 ℃ temperature. The specimens were tested for crushing strength, intrinsic permeability, chloride penetration, and also micro-structural analysis was done on a sample subjected to seawater. XRD analysis was performed to confirm seawater attacks and the presence of portlandite. SEM and EDX analyses were performed to determine the microstructure at fiber interfacial transition zone and the condition of the fiber after exposure to such environment, as shown in Fig. 1 and Fig. 2. It was reported that GFRC at 2.4% of AR glass fiber content caused to loss its compressive strength under such an aggressive environment. Chloride diffusion and air permeability of GFRC increased with increasing fiber content. For low chloride diffusivity and air permeability, the AR glass fiber content of 0.6% to 1.2%, and for optimum durability performance, AR glass fiber of 1.2% or less were recommended.


**Fig. 1 SEM image (5000× magnification) of the 2.4% glass fiber in tropical air for 18 months [16].**

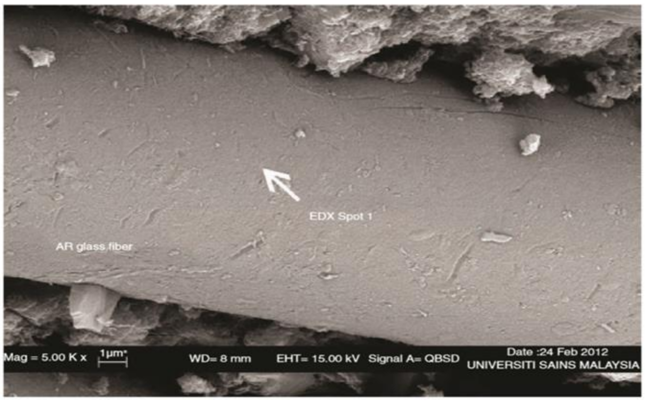


**Fig. 2 SEM image (501× magnification) of the 2.4% glass fiber in seawater for 18 months [16].**

WU Huijun, ZHAO Jing et al. [17] This paper presented the failure action of ARGF in cement-based material. To study compressive strength, flexural strength and also failure mechanism of AR glass fiber to understand the failure and damage of ARGF in cement and porosity of cement and chloride diffusivity, OPC cement mortar, ARGF cement mortar, the seed of ARGF cement mortar were used to cast 40mmx40mmx160mm specimens having DK-4 type of superplasticizer with 1.5% by cement weight. ARGF with 1.1% of the silica fume test, with its 10% substitution of cement, the seed of AR glass fiber to volume 2%, 5%, and 10% substitution of cement. During the investigation, all specimens under standard water and heat water (with a constant temperature of 60°C) curing conditions were cured for the stipulated ages of 7 and 3, 7, 14, and 28 days, respectively. SEM analysis was carried out for both standard water, and heat water curing conditions and reported that heat curing caused to accelerate the cement hydration process; thermal enlargement of cement paste developed the cracks, hence affected the solidity and concrete performance. And also, the strength of the cement mortar and slurry interface area of the fiber were closely linked. The cement mortar became hard early prior to completion of cement hydration, and the fiber surface had slight corrosion and etching. The gradual damaged of the fiber caused due to formation of portlandite at the fiber interface, and the cement solidified, which deepens with the degree of cement hydration and damages the fiber. Shashidhara Marikunte et al. [18] This paper focused on the durability of GFRC composite. The fiber in cement alkaline environment subjected to hot water curing at 500 °C for an additional 28 and 84 days. The ARGF of Cem-FIL type with 5% by weight of the composite was used. The test series contained plain mortar, control GFRC, GFRC with Metakaolin, and GFRC with Silica fume. For better workability, a superplasticizer of type Sikament 10 and Forton acrylic polymer was used, as shown in Table 2. It was reported that the improvement of flexural as well as tensile behavior of cement composite was due to presence of glass. However, with an additional dosage of silica fume content, the response of composite with aging was not improved. However, the flexural and tensile strength of old GFRC composite was improved with synthetic pozzolan.

**Table 2 Detail of test and mix proportion [18]**

| Mix | Casting Series | | | |
|---|---|---|---|---|
| | Control (kg) | GFRC (kg) | GFRC+M.K (kg) | GFRC+S.F (kg) |
| Cement | 100 | 100 | 100 | 100 |
| Sand | 100 | 100 | 100 | 100 |
| Metakaolin | - | - | 25.0 | - |
| Silica Fume | - | - | - | 25.0 |
| Water | 27.2 | 27.2 | 44.0 | 45.9 |
| Polymer | 9.8 | 9.8 | 12.3 | 12.3 |
| Superplasticizer | 1.8 | 1.8 | 3.0 | 3.0 |
| Glass fibers | - | 5% by weight of the composite | 5% by weight of the composite | 5% by weight of the composite |

A. Peled et al. [19] This paper presented the influence of matrix modification on the durability of AR glass fiber reinforced cement composite. The aimed of this paper was to investigate the influences of dimension-stabilizing admixture (NSR) and blast furnace slag with and without acrylic polymer. NSR is a type of admixture developed for use in precast concrete products to control the shrinkage. In the experimental investigation, GFRC panels were cast with and without acrylic polymer and tested for flexure and tension, and results were compared with the control GFRC specimen. The alkali-resistant glass fiber content was 5% by weight of concrete. The specimens were cured for 28 days and then immersed in hot water at the temperature of 50 °C for 84 days and then tested. It was reported that shrinkage controller admixture (NSR) with furnace slag gave a remarkable improvement in terms of the aging of GFRC composite. NSR and slag with acrylic polymer gave the greatest improvement in terms of strength and toughness. These improvements were attributed to the absence of $Ca(OH)_2$ in the NSR admixture. X. Qian et al. [20] This paper aimed to monitor the influence of polyvinyl alcohol (PVA) fibers in raising the durability properties of the ARGFRC sheet. The durability of ARGFRC was assessed by conducting a tensile strength test. ARG and PVA fibers of length 12mm and 6mm respectively were used. PVA fiber of 2% and ARGF of 2% and 4% by weight of binder were added to the concrete mix. ARGF reinforced concrete sheet of size 75x250x6mm were prepared and tested. It was found that the employment of PVA fibers in the GFRC sheet enhanced mechanical properties and changed the mode of failure of the sheet from brittle to ductile. Arabi Nourredine [21] Effect of curing condition on the durability of ARGF cement matrix was studied in this work using AR glass fiber of length 12mm. To reduce the alkali attack, silica fume from 1 to 3% by weight of cement was used. It was found that the 3% addition of silica fume did not impart considerable protection to the chemical attack caused by the portlandite environment present in the cement matrix. Rose Mary Georg et al. [22] This paper studied the durability aspect of GFRC. ARGF of length 12mm with 0.5, 1, and 1.5% by weight of cement were utilized. The effect of ARGF on the bond strength between concrete and steel was investigated.

Also, the combined effect of various pH levels and the marine environment on the final bond strength and retention of compressive strength of GFRC were studied. It was found that the addition of ARGF had minimal effect on the compressive strength of GFRC. Ultimate bond strength improved with the addition dosage of ARGF. The increase in bond strength between ARGF and concrete was stabilized by SEM analysis.

### C. Effect of Size and Dosage of ARGF on Workability of Fresh Concrete

According to the ACI Committee, 544 [3], the addition of unprocessed natural fibers to concrete tends to reduce workability due to higher surface area and water absorption of fibers. Too stiff or dry mix leads to an insufficient compacted product, which is likely to contain voids and honeycombs. On the other hand, the too wet mix tends to develop less strength or strength reduction. In GFRC, balling should be minimized in the mixture of concrete. The term balling refers to the fiber that is entangled into large clumps or ball in a mix. This balling may be attributed to the type, length of fibers, volume fraction of fibers, and the maximum size of aggregate. Clumps or balling cause a deleterious and harmful effect on the strength of concrete. To reduce the effect of balling, the gradual addition of fibers at the end of the mixing process, after mixing other materials, reduces the effect of balling. It was found that a high dosage of water reducer (Superplasticizer) admixture can help to increase the workability without adversely affecting the strength. It was recommended that the inverted slump cone test [23] or the Vee-Bee test [24] can be used to assess the workability of fresh fiber reinforced concrete mixtures. S. U. Kannan et al. [25] This paper studied the effect of alkali-resistant glass fiber in self-compacting concrete. The fibers added at a certain percentage varying 0.2% to 1% by weight of cement with a 12mm cut length. Based on the test result, it was found that 0.2% of ARGF content gave a better result for workability and gained higher compressive strength. The slump values for different percentage of glass fiber as 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1% was recorded as 145mm, 140mm, 130mm, 120mm, 70mm and 40mm respectively. S. Jagan et al. [26] This paper reported the effect of chopped alkali-resistant glass fiber on the strength and durability of concrete. AR glass fiber used in certain percentage of 0.25%, 0.5%, 0.75% and 1% by weight of concrete. For proper workability, a superplasticizer was utilized in the study by varying percentage of 0.5%, 1%, 1.5%, 2%, 2.5% and 3% by weight of cement. Based on the result done for workability, it was found that an increase in fiber content will cause to decrease the workability and strength of concrete, and a superplasticizer of 2.5% gave the better result for workability (slump= 120mm). B.S. Krishnamurthy et al. [27] This work conducted to study ARGFRC. Glass fiber used in varying percentages of 0.2%, 0.4%, 0.6%, and 1% by weight of concrete. Based on the experimental test conducted for the workability, it was concluded that at 0.6% addition of ARGF in GFRC has the lowest workability by 74.44% with respect to M35 grade of concrete mix (Slump=38mm). Yuwaraj M. Ghugal et al. [28] This paper presented to study the performance of ARGF reinforced concrete. AR glass fiber was used with a 12mm cut length. In the experimental investigation, concrete of grade M20 was studied for workability, density, and various strength. ARGF with varied percentage of 0%, 0.5%, 1%, 1.5%, 2%, 2.5%, 3%, 3.5%, 4% and 4.5% were used. The researcher reported that workability decreased by 44.44% at 4.5% glass fiber content as compared to the control specimen. Hanuma Kasagani et al. [29] In this present paper mono graded glass fiber (3mm, 6mm, 12mm, and 20mm), short graded glass fibers (3mm+6mm fiber length), long graded glass fibers (12mm+20mm fiber length) and the combination of both called combined graded fibers (3mm+6mm+12mm+20mm) were studied. Glass fiber content with varied percentage of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% for concrete of grade M30 was studied. Based on the research work, it was concluded that different volumes of fiber and length had a different effect on the slump. The measured slump for conventional concrete was reported as 160mm. When the volume of fiber increased from 0.1% to 0.5%, the slump decreased from 126mm to 39mm as compared to conventional concrete. However, 0.4% and 0.5% of fiber content led to clumps, and therefore reduction in workability is observed in the mix of concrete. As per the researcher report for mono graded fiber, when the length of fiber increased from 3mm to 20mm, the slump decreased from 126mm to 106mm. Generally, 3mm and 6mm length of fiber showed a higher slump. For short graded fiber, SGF-1, SGF-2, SGF-3, SGF-4 and SGF-5 at 0.3% of glass fiber content the slump values were reported as 92mm, 126mm, 116mm, 109mm and 90mm respectively. In short graded only SGF-2 showed the highest slump. For long graded fiber LGF-1, LGF-2, LGF-3, LGF-4 and LGF-5 the slumps were 81mm, 112mm, 103mm, 79mm and 90mm respectively. In long graded fiber, only LGF-2 showed the highest result for a slump. N. Arabi [30] This paper conducted to study the influence of short AR glass fiber randomly oriented of a reinforced cement-based composite on the mechanical behavior. Glass fiber with varied percentage of 0%, 0.5%, 1%, 1.5%, 2% and 2.5% by weight of cement and fiber with varied length of 3mm, 6mm and 12mm was replaced by an equivalent volume of sand. It was concluded that superplasticizer up to 1% by weight of cement imparted adequate workability to the mix of concrete. Sujit V. Patil., N. J. Pathak et al. [31] This paper studied compressive strength using ARGF and partial substitution of cement with ground granulated blast furnace slag with the effect of magnetic water. AR glass fiber with varying percentage of 0%, 0.2%, 0.3%, 0.4% and 0.5% were used. A slump test was performed for various content of fiber both for normal water and magnetic water. The slump for normal water recorded as 67.5mm, 59mm, 42.5mm, 35mm, and 23.5mm. And for magnetic water recorded as 90mm, 76mm, 60.5mm, 46mm, and 38mm. Erhan Guneyisi et al. [32] Glass fiber reinforced self-compacting concrete made with nano-silica and fly ash for fresh and rheological properties was studied. All concrete mixes for slump flow, V-funnel, and L-Box were studied. Fifteen self-compacted mixture with a fixed water-cement ratio of 0.35 was prepared. Various replacement levels of nano-silica were 0, 2, and 4%, and for glass fiber were 0, 0.7, 1, and 1.5% and 25% for fly ash by weight of cement were used.

It was concluded that SCC with 2% and 4% of nano-silica and maximum dosage of glass fiber showed lower workability.

**D. Effect of ARGF on Concrete Strength:**

S. A. Yildizel et al. [33] In this investigation waste alkali resistant glass fiber was used in concrete and tested for compressive and flexural strength after 7 and 28 days. Alkali resistant glass fiber of length 10mm with varying percentages of 1, 1.5, and 2% by weight of cement was utilized. It was reported that the compressive strength decreased with increasing glass fiber content. Whereas, 28 days result for flexural strength at 2% glass fiber content was reported similar to that of control concrete. Dayalan J [34] This studied mechanical properties of high-performance concrete reinforced with ARGF. Alkali resistant glass fiber of 12mm cut length with varying percentages of 0.03, 0.06, and 0.1% by weight of concrete was used. Compressive, split tensile, and flexural strength were tested after 7 and 28 days. B. Rath et al. [35] This paper investigated plastic and hardened state of concrete reinforced with ARGF. Glass fiber of 12mm length with constant dosage of 0.1% by volume of concrete. The cement was substituted by fly ash by 20% and 40%. Whereas, sand was replaced by pond ash by 10% and 20%. Concrete specimens were tested for shrinkage, electrical resistivity, scan electron microscope analysis, and UPV after 7, 28, 56, and 119 days. It was reported that the glass fiber at 0.1% reduced the shrinkage by 40% and enhanced the ultrasonic pulse velocity and electrical resistivity by 5% and 40%, respectively. Fly ash by 40% replacement ratio decreased the electrical resistivity by 50%, shrinkage declined by 23%, UPV enhanced by 6.3% and compressive strength lower by 23%. Also, long term curing significantly improved the electrical resistivity, UPV, and compressive strength for both fiber and non-fiber concrete. S. Ghouse Basha and P. Polu Raju [36] This paper investigated to compare the effect of steel and glass fiber on performance of concrete. Steel and AR glass fiber of length 60mm and 6mm with varying percentages of 0, 0.5, and 3% by weight of concrete were utilized. Compressive strength was carried out after 3, 7, and 28 days. Whereas, flexural strength was carried out after 28 days. It was reported that the performance of steel fiber in terms of strength was better than glass fiber. Deshmukh S.H et al. [37] The glass fiber type of Cem-FIL with 12mm cut length was used in this experimental investigation. The quantity influence of ARGF on compressive, split tensile, and flexural strength of AGFRC was investigated. GF with varied percentage of 0%, 0.03%, 0.06% and 0.1% by weight of concrete were utilized in the mix of concrete. They concluded that 0.1% of glass fiber gave better results in terms of compressive, split tensile, and flexural strength after 28 days. Liaqat Ali Qureshi et al. [38] This research paper studied the strength properties of GFRC. In the investigation AR glass fiber with varied percentage of 0%, 0.5%, 1%, 1.5%, 2%, 2.5%, 3% and 3.5% with 12mm cut length were used in concrete mix. The experimental tests were performed for compressive, splitting tensile and flexural strength and as well as for ultra-sonic pulse velocity. It was reported that the glass fiber content of 1.5% imparted the significant result for split tensile and flexural strength over the ordinary concrete. The researcher also pointed out that the workability of GFRC decreased with increase in glass fiber content. Yeol Choia and Robert L. Yuan [39] this paper studied the correlation between split tensile and compressive strength of GFRC and PFRC concrete. Both fibers were varied from 1% to 1.5% by weight of concrete mass with 19mm cut length. The specimens were tested for 7, 28, and 90 days, it was reported that the inclusion of glass and polypropylene fibers content developed the split tensile strength of both GFRC and PFRC concrete approximately from 20% to 50%, and the splitting tensile strength of glass fiber reinforced concrete and polypropylene fiber reinforced concrete ranged from 9-13% of its compressive strength. it was concluded that the relation between split tensile and compressive strength governed by a 0.5 power relationship and use for estimating the tensile strength of GFRC and PFRC. S. Jagan et al. [40] this paper reported the strength and durability improvement of concrete using glass fiber with varying percentages of 0.25, 0.5, 0.75 & 1% by weight of concrete. The consistency of the concrete was maintained using polycarboxylate (ether-based superplasticizer) with 0.5, 1, 1.5, 2, and 2.5% by volume of cement. varied test such as compressive, split tensile, and flexural strength, as well as durability test like acid attack and fire-resistant were performed for 7 and 28 days. It was found that the maximum compressive, split tensile, and flexural strength was given by 1% of glass fiber content. The reduction in compressive strength after the fire was observed, and it can be attributed to the less susceptibility of glass fiber to fire attack. V.R.Rathi et al. [41] This paper reported the flexural strength of deep T-beam of varied depth (150, 200, 200, and 300mm) with a span to depth ratio of 2, 2.4, 3, and 4 made of GFRC. AR glass fiber of 12mm length with varied percentage of 0.25, 0.5, 0.75, and 1% by weight of cement were used. The maximum flexural strength under one-third span loading for the span to depth ratio of 3 with 0.75% of glass fiber content was reported. Also, the maximum ultimate load-carrying capacity of the beam with span to depth ratio of 2.4 and 2 was given by 0.75% of the glass fiber content. The shear strength, which helps to reduce stirrups requirement, was found with 0.75% of the fiber. Widodo Kushartomo et al. [42] This paper studied the effect of glass fiber on compressive, split tensile, and flexural strength of concrete without coarse aggregate known as reactive powder concrete. Usually, steel fiber used as reinforcement in the RPC mixture. In this research paper, the influence of steel fiber as well as glass fiber ranging from 1-2% by weight of concrete with cut length varied from 11-13mm was investigated. Curing was carried out by steam for 28 days. And the tests were performed for compressive, split tensile and flexural strength. The optimum strength with 2% of glass fiber content and 1.5% for steel fiber content was reported. P. Sangeetha [43] This paper reported compressive and impact strength of GFRC using various admixtures. Eighty specimens were cast for both compression and impact tests. Impact tests were carried out by drop weight method to observe the impact behavior of the GFRC. Glass fiber with varied percentage of 0.1%, 0.2% and 0.3% by weight of concrete were used in the concrete mixture.

Various combinations of admixtures were superplasticizer + air-entraining agent + accelerator, superplasticizer + Air entraining agent + retarder, superplasticizer + air-entraining agent + waterproofing compound used for investigation. It was reported that the different combinations of admixture increase compressive strength by 10% and impact strength by 100%. B.S. Krishnamurthy et al. [44] This paper reported the influence of Alkali resistant glass fiber on concrete strength. Glass fiber of cut length 12mm was added to the mix of concrete as reinforcement in a certain percentage of 0.2%, 0.4%, 0.6%, and 1% by weight of concrete. compressive, split tensile and flexural strength, and as well as temperature tests were carried out. The researcher concluded that the fiber content of 0.6% imparted a satisfactory result in GFRC, and 1% of Alkali resistant glass fiber content by weight of concrete showed zero workability. Yuwaraj M. Ghugal et al. [45] This paper studied the performance of ARGF reinforced concrete. Alkali resistant glass fiber was used in this study. In the experimental investigation, concrete of grade M20 was investigated for workability, density, and strength. ARGF with varied percentage of 0%, 0.5%, 1%, 1.5%, 2%, 2.5%, 3%, 3.5%, 4% and 4.5% by weight of cement with 12mm cut length were utilized. All the concrete specimens were tested for 28 days. Based on the experimental study, it was found that 4% content of ARGF imparted maximum strength to the concrete. It was also reported that workability (measured by slump test) decreased by 44.44% at 4.5% of glass fiber content as compared to control concrete specimens. Alexey Kharitonov et al. [46] This paper reported physical and mechanical properties of GFRC as a function of reinforcement level and binder composition for durable underground construction. AR glass fiber was utilized in concrete mix as reinforcement in a certain percentage of 0.5%, 1%, 1.5%, 2% and 2.5% by weight of concrete mix with 10mm cut length. It was concluded that 2.5% of AR glass fiber content by concrete weight caused to increase ultimate strength twice as compare to control concrete specimens. Shrinkage and creep were decreased twice. To achieve durable GFRC, it is mandatory to use ARGF with metakaolin. Hanuma Kasagani et al. [47] This paper studied the effect of ARGF of various cut lengths on the stress-strain behavior of GFRC in tension. Having known the fact that short length fibers prevent micro cracks and enhance ultimate strength capacity whereas, long length fibers control the macro cracks and helping to minimize post crack deformation of concrete, test series contained of mono graded glass fibers (3mm, 6mm, 12mm and 20mm), short graded glass fibers (3mm+6mm), long graded glass fibers (12mm+20mm) and their combination called combined graded fibers (3mm+6mm+12mm+20mm) with varied percentage of 0.1, 0.2, 0.3, 0.4, and 0.5% by weight of cement were used. Dog-bone GFRC samples were cast and subjected to uniaxial tension. Strength deformation and energy absorption capacity were found better for GFRC with AR graded glass fiber as compared to GFRC with AR mono graded fiber with higher workability. Short length graded fiber (3mm+6mm) improved strength as compared to long length graded fiber. Long length graded fiber (12mm and 20mm) improved the deformation capacity of GFRC.

K.I.M Ibrahim [48] This paper reported on the strength of concrete reinforced with ARGF. Alkali-resistant glass fiber with various percentages of 0%, 0.1%, 0.3% and 0.5% by weigh of concrete were used. The optimum flexural and split tensile strength at 28 days was reported for 0.5% of glass fiber content. Komal Chawla etal. [49]. The effect of ARGF and its properties on the strength of concrete was studied. ARGF of 12mm length with varying percentages of 0, 0.33, 0.67, and 1% by weight of concrete were used and compressive, split tensile, flexural strength, and toughness of the concrete were investigated at 28 days. It was reported that the optimum crushing and flexural strength were observed at 0.33% and 1% of glass fiber content, respectively. Kiran Kumar Poloju et al. [50] The strength and stress-strain response of various grades of ARGF reinforced concrete were studied. ARGF of length 6 and 12mm with 0, 0.03, 0.06 and 0.09% by weight of concrete were used. Cube specimens of size 150x150x150mm and prisms of size 100x100x500mm were cast for compressive and flexural strength at 28 days. It was concluded that the compressive strength, as well as the stress-strain response of GFRC, significantly improved with 0.09% of glass fiber content. Janani. S et al. [51] Strength properties of concrete reinforced with Alkali proof glass fiber were studied for 7 and 28 days. ARGF with 0.05, 0.1, 0.15, and 0.2% by volume of concrete was investigated. It was concluded that 0.1% of glass fiber content imparted higher strength over the conventional concrete. Avinash Gornale et al. [52] This paper studied the mechanical properties of GFRC. ARGF of length 12mm with 0.03% by volume of concrete was used. Concrete of various grades of M20, M30, and M40 were tested for compressive, split tensile, and flexural strength at 3, 7, and 28 days. It was found that flexural and split tensile strength for concrete of grade M20, M30 and M40 at 28 days increased by 20 to 30%, 25 to 30% and 25 to 30% as compared to plain concrete. J. A. Purkiss et al. [53] This paper studied various strength of GFRC at higher temperatures. AR glass fiber of type Cem Fill with 25mm length and with 0.75% and 1.5% by weight of cement were used. Compressive, flexural strength, ultrasonic pulse velocity, and dynamic modulus of elasticity of GFRC under the temperature of 350-850°C were investigated. It was found that there was very little difference in the reduction in the compressive strength of GFRC and plain concrete. It was reported that the most significant loss in the reduction of flexural strength was observed to the specimen under 300-650°C, with 1.5% of fiber content. A suitable correlation of compressive, flexural strength and dynamic modulus of elasticity with UPV was observed. T.Subramani and A.Mumtaj [54] This experimental work carried out on partial substitution of sand with glass fiber. E-glass fiber was replaced by 5, 10, and 15% by weight. EGFRC was tested for compressive, split tensile, and flexural strength at 7, 14, and 28 days. It was found that 10% of E-glass fiber content gave the highest strength as compared to concrete without glass fiber. Manjit Singh and Mridul Garg [55] This paper studied the influence of E-glass fiber on the mechanical properties of the water-resistant gypsum board. The boards were manufactured by ground granulated slag, OPC cement, and organic retarder with calcined phosphor-gypsum in a ball mill.

E-glass fiber water-resistant board of size 250x250x12mm was cast and cured in relatively high humidity and kept in a special box for 28 days and then dried at 42℃ for an additional two days and tested for flexural, split tensile, and impact strength. E-glass fiber at 4% content and 50mm long were added to the mixture. It was found that the flexural, split tensile, and impact strength of the water-resistant gypsum board was increased with a longer length and optimum fiber content. Ahmet B. Kizilkanat et al. [56] Basalt, as well as glass fiber, were used as fiber reinforcement, and their effect on the strength of concrete was studied. Basalt and glass fiber of 12mm length with various percentages of 0.25, 0.5, 0.75, and 1% by weight of cement were utilized. In this study, compressive, split tensile, and flexural strength was investigated. It was found that basalt and glass fiber contents higher than 0.25% resulted in an inconsiderable increase in crushing strength. It was also concluded that 0.5% content of basalt fiber displayed the highest compressive strength, whereas, GFRC with 0.75% of glass fiber content imparted better compressive strength. S.T. Tassew and A.S. Lubell [57] This paper reported on the mechanical and rheological properties of ceramic-based cement concrete made with chopped AR glass fiber. AR glass fiber of length 13 and 19mm with 0% and 2% by weight of cement was used. It was found that the addition of glass fiber incorporated into ceramic-based concrete had a negligible effect on compression and modulus of elasticity however made considerable increase in flexural and direct shear strength. It was also concluded that the compressive, flexure, and shear toughness of the GFRC increased with a higher dosage of fiber content with lower workability. Mehmet Emin Arslan [58] Basalt and chopped glass fiber of length 24mm with 0.5, 1, 2, and 3kg/m3 were used to make GFRC. For determination of fracture energy of control, basalt fiber, and glass fiber reinforced concrete, 27 notched beams of size 50x100x480mm were cast and tested by a three-point bending test as shown in Fig. 3. It was found that the effect of fibers was significant on energy fracture of notched beams and also improved its split tensile. Fracture energy of the concrete by using basalt and glass fiber investigated in this paper also improved with increasing fiber content, whereas a small drop was observed in flexural strength with a higher dosage of fiber content.

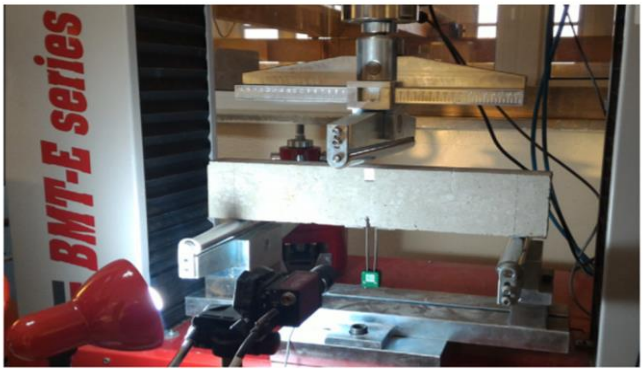


**Fig. 3 Bending test set-up [58]**

Dinesh et al. [59] This paper studied GFRC with partial substitution of sand by quarry dust. Quarry dust and AR glass fiber with 0, 15, 25, 35, and 45% by weight of concrete and 0, 0.4, 0.8, 1.2, and 1.6% by weight of cement were used. Compressive, split tensile, and flexural strength of glass fiber quarry dust concrete were tested at 28 days. It was reported that the compressive, split tensile, and flexural strength of GFQDC increased with a 35% replacement level of fine aggregate by quarry dust as compared to conventional concrete. A. Upendra Varma and A.D. Kumar [60] This paper reported on compressive, split tensile, and flexural strength of ARGFRC of grade M20, M40, and M60. AR glass fiber with 0.03% by weight of concrete was utilized. Compressive, split tensile, and flexural strength was carried out at 28 days. It was reported that the increase in compressive, split tensile, and flexural strength at 28 days of all grades was observed from 10 to 20%. Nitin Verma and Dr. A.K. Jain [61] This paper reported on the mechanical properties of concrete reinforced with steel and AR glass fiber. Steel and AR glass fiber with 0, 0.4, 0.45, 0.5, and 0.55% by weight of concrete and AR glass fiber with 0, 0.2, 0.25, 0.3, 0.35 by weight of cement were used. Compressive, split tensile, and flexural strength was tested for 7 and 28 days. It was found that the maximum compressive, split tensile, and flexural strength was imparted for 0.3% AR glass fiber and 0.5% of steel fiber. J.D.Chaitanya Kumar et al. [62] This paper reported the effect of E-glass fiber on the mechanical properties of concrete. E-glass fiber with 0.5, 1, 2, and 3% by weight of cement were used. Compressive, split tensile and flexural strength of concrete of grade M20 at 7 and 28 days were tested. It was found that the maximum strengths were observed for 1% of E-glass fiber content. Kavita S Kene et al. [63] This paper studied the response of steel and ARGF on the strength of concrete. Steel fiber of length 50 and 35mm with 0.5% by weight of cement and ARGF of length 12mm with 0.25% by weight of cement were used. Compressive and split tensile strength tests were conducted for 7 and 28 days. It was found that the maximum compressive strength, as well as split tensile strength, were given by 0.5% and 0.25% of steel and glass fiber content, respectively. Karthik BS [64] This paper studied non-destructive and serviceability tests on GFRC. Fly ash and silica fume were replaced with cement at 15% and 10%, respectively. Bottom ash replaced with fine aggregate at various percentages of 0, 10, 20, 30, and 40%. ARGF of length 12mm at various percentages of 0.3, 0.66, and 1% by weight of concrete were used. Compressive strength, rebound hammer, and ultrasonic pulse velocity tests were carried out for 28, 56, and 90 days. It was found that the compressive strength increased at 56 and 90 days for a 40% replacement level of fly ash and optimum dosage of glass fiber. UPV value decreased as the bottom ash content increased. T. Sai Kiran et al. [65] This paper reported on the strength of concrete, reinforced with AR glass fiber. AR glass fiber with 0, 5, 6, and 7% by weight of cement were utilized. Compressive, split tensile, and flexural strength was tested for 1, 3, 7, 28, and 56 days. It was found that 7% of glass fiber content gave maximum compressive strength. Whereas, 6% of glass fiber content imparted optimum split tensile and flexural strength as compared to conventional concrete.

### E. Effect of AR glass fiber, marble and granite dust in concrete

Anandaraj et al. [66] This study investigated the distress in GFRC made with marble and granite dust subject to various loading and exposure to harsh environment replacing with 20, 40, 60, and 80% by volume of river sand. AR Cem Fil type glass fiber of 25mm length with percentages of 0.5, 1, 1.5, and 2% as an additive to the concrete was used. Compressive, split tensile, flexural strength, and durability tests were carried out. It was found that 20% marble or granite dust and 1% glass fiber improved the strength of concrete. It was also found that the performance of marble or granite dust based GFRC in an aggressive environment played a better role as compared to control concrete.

### F. GFRC with TRC

J. Orlowsky and M. Raupach [67] This paper studied the loss of strength of AR glass fiber in textile reinforced concrete (TRC) reconcile to material and weathering conditions. In this study, the effect of humidity, temperature, pH-value, glass composition, and load on the strength loss on the AR glass fiber was studied. It was found that the long-term decline of strength in ARGF in the TRC component was caused due to arbitrary complex weathering. Marko Butler et al. [68] This paper studied the time-related mechanical performance of textile reinforced concrete (TRC) made with ARGF. The effect of composites was studied by hydration kinetic and alkalinity of the binder mix. TRC composites were tested for tensile, pull out test as well as microstructure analysis. It was concluded that the tensile strength and strain capacity of TRC decreased with the presence of Alkaline.

Sai Liu et al. [69] The performance of the TRC made with the modified alkali matrix compound was mostly unaffected by the exposure to accelerated aging. This paper studied basal and glass textile reinforced concrete beam exposed to temperature and different strain rate. Basalt and alkali resistant glass textile wrapping mesh of size 5x5mm were used. Quasi static three-point bending test was carried out. Six specimens of size 15x40x250mm were tested under constant loading rate of 2.5mm/min. dynamic flexural test was conducted by drop weight impact tester machine with 37.5kg weight with a specified height from 0.03 to 1.1m with varying impact velocities of 1, 2,3, 4, and 4.5m/s.

The impact velocity of 3m/s was considered to determine the flexural response of beam subjected to varying temperatures of -50, 0, 25, 50, and 100°C. The test set up is shown in Fig.2 and the flexural stress-strain curve of BTRC and GTRC samples are shown in Fig.4, Fig.5, and Fig. 6. At initial strain rate from 3.33x10-5 to 18s-1, a remarkable improvement in flexural strength was observed. Ultimate strain and toughness were reduced then increased with increasing initial rate of strain. For both BTRC and GTRC the response of flexural in terms of strength, modulus, ultimate strain, and toughness reduced with the higher rate of temperature.

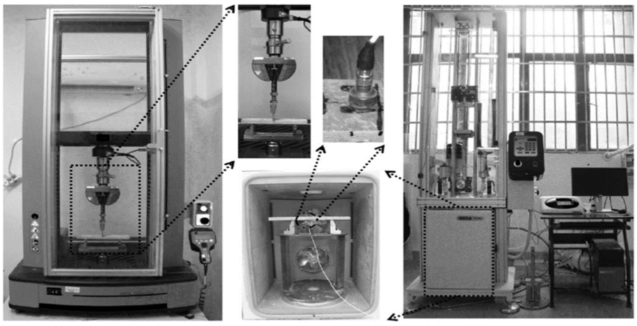

**Fig. 4. Universal testing set up [69]**

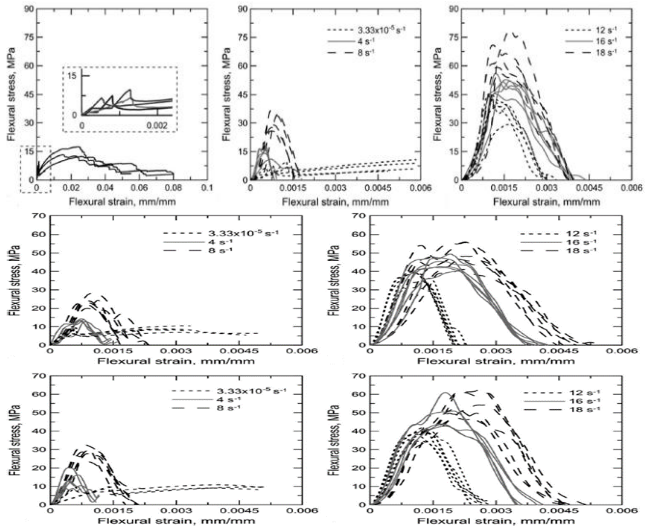


**Fig. 5. Showing flexural stress-strain response of BTRC at various strain rate subjected to 25°C [69]**

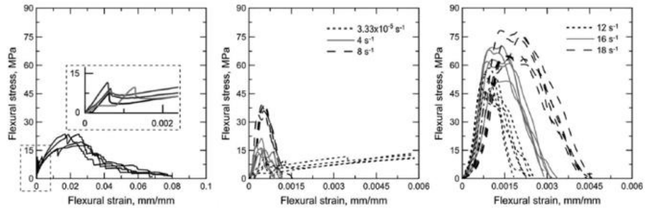


**Fig. 6. Showing flexural stress-strain response of beam at various strain rate subjected to 25°C [69]**

### G. GFRC with waste tire rubber and pull out the response of GFRC

J.M. Pastor et al. [70] Glass fiber reinforced concrete panels with waste rubber tires were investigated in this study. Recycled rubber tires of weight 5/10 kg replaced with an equal amount of sieved sand of particle size less than 2mm. AR glass fiber of 3% by weight of cement was employed in the concrete mix. These materials were utilized in concrete panels of size 50x80cm. It was reported that the presence of rubber in concrete panels imparted lower density and a negligible increase in porosity to GFRC. It was also concluded that improved flexibility and impact resistance, along with the acoustic behavior of the GFRC made with a rubber-based concrete panel, could be a suitable member to manufacture safety barriers with enhanced resistance to traffic noise. Christina Scheffler et al. [71] This paper investigated pull out response under quasi-static and high-speed loading for AR glass fiber composite and cement matrix.

The fibers were embedded in the concrete mix to various lengths of 500-2000µm at 23°C and 50% relative humidity. The quasi-static, pull out test was performed at a pull-out rate of 0.01µm/s. Fifteen specimens were tested for each embedded length and pull out rate level. It was found that the interface between AR glass fiber and concrete mix responded usually. It was also concluded that the decrease in post debonding interfacial frictional stress at high rate pull out test attributed to smoothening of surface properties upon debonding, which caused lower mechanical interlocking.

### H. Flexural strength of GFRC beams

Ata El-Kareim S.Soliman and Mostafa Abdel-megied Osman [72] This paper studied the efficiency of discrete glass fiber on the shear behavior of the RCC beam following the test procedure of Egyptian standard. RCC beam was cast to evaluate the shear behavior as well as elastic behavior in the flexural zone. Stirrups with the varied spacing of 50mm, 75mm, and 100mm were placed throughout the beam section. RCC beam with a cross-section of 150mm x 150mm with 900mm length was studied. Glass fiber with different percentages of 0%, 0.75%, and 1.5% by weight of cement with a 15mm cut length was used. In the experimental work, the span to depth ratio was varied from 2.5 to 5. As per the experimental result, it was found that glass fiber of 1.5% with a span to depth ratio of 2.5 increased the shear behavior of beam by 77%. It was also concluded that glass fiber, along with stirrups, increased the ductility and failure load of the RCC beam. M. A. Asgari et al. [73] This paper studied experimental and numerical programs to reinforced concrete beam with AR glass fiber to obtain deflection hardening behavior. In the research work, 270 specimens were tested for strength property. AR glass fiber with different percentage of 1%, 1.5%, and 2% by weight of cement with a 12mm cut length was used. Based on the experimental result, it was found that using the GFRC layer for strengthening concrete beam through section enlargement method significantly improved the load-carrying capacity and ultimate deflection. It was also concluded that using GFRC to reinforce the beam, resulted in increasing the load and mid-span deflection up to 3.5 to 4 times, and 2.5 to 3 times compared to un-strengthened beams. Luigi fenu et al. [74] This paper investigated the static and dynamic response of cement mortar reinforced with AR glass fiber and basalt fiber. In the research work, the influence of both fibers examined at high strain-rate to determine the energy absorption and tensile strength and then compared the performance of glass fiber with basalt fiber. Both fibers used with the same diameter and length of 14µm and 12mm. Both fibers with percentages of 3% and 5% were used. In the experimental investigation, static and dynamic tests were carried out. Static analysis was performed for compressive, split tensile, and flexural strength and dynamic tests performed through the Hopkinson bar. The dynamic test was carried out at a high strain rate to obtain how glass and basalt fibers affected energy absorption and tensile strength. In the research work, dynamic increase factor (DIF) was studied, and the result showed that DIF did not significantly change by the addition dosage of glass and basalt fibers, while energy absorption capacity at high strain rate was increased considerably by the addition of glass fiber and slightly increased by the addition of basalt fiber. It was also found that the flexural strength of the mortar increased for both glass and basalt fiber. A. Venkatesh and K. Kannan [75] This paper studied GFRC with precast sifcon laminate. In this study, the cube of size 150x150x150mm and a concrete beam of size 100x100x500mm were investigated for compressive and flexural strength at the age of 28 days. E-glass fiber with 0.05 and 0.1% by weight of concrete was utilized. It was concluded that the maximum compressive strength of concrete made of glass fibers increased by 4% as compared to conventional concrete. It can also be mentioned that 0.1% of E-glass fiber content with sifcon laminations increased the ultimate load capacity of the beam. N. Arabi [76] This paper presented the effect of AR glass fiber on static and cyclic performance of cementitious composites. AR glass fiber with varying percentages of 0%, 0.5%, 1%, 1.5%, 2%, and 2.5% was replaced by an equal volume of sand with a cut length of 3mm, 6mm, and 12mm. Water reducer admixture of sikament FF86 type with 1% by weight of cement was utilized. Tests were carried out for compressive and flexural strength. Glass fiber with a 12mm length and 2% replacement level gave better results for flexural strength. The fatigue behavior determined by Wohler plots shown in Fig. 7 was derived in this study. This plot showed a high dissipation that attributed to many causes initiating this damage. Brittle features of these materials, with low-amplitude cycles of loading, made to report negative recommendations for adaptation of these materials.

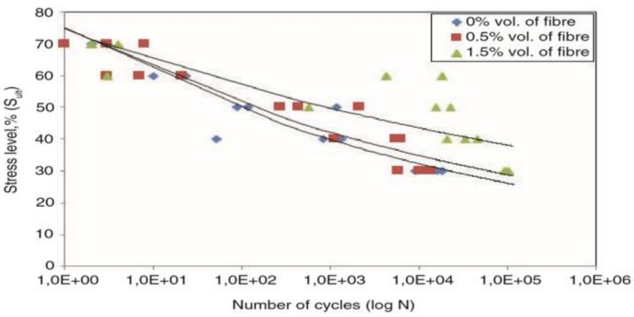


**Fig. 7 S-N diagrams identifying Wohler curves [76]**

Yan Lv et al. [77] This paper reported on sixty-three GFRC beams of size 100x100x400mm tested under four-point loading. ARGF with 36mm lenght was employed in concrete at 0.6, 0.8, and 1% by weight of concrete. The coefficient of fatigue equation corresponding to various survival probabilities was derived to predict the flexural fatigue of resistance for the desired level of survival probability. It was found that the fatigue performance of GFRC was better than conventional concrete. V. Genov´es et al. [78] This paper reported on bending strength and ultrasonic pulse velocity values of concrete mortar, reinforced with AR glass fiber. ARGF of length 12mm with 3% and 5% by weight of mortar was used. The bending strength test of GFRC mortar was performed through a specimen of size 325x50x20mm under four-point loading. The bending test of GFRC mortar was monitored by ultrasonic pulse velocity and was compared in the time scale. It was found that within the elastic range, there was no significant change in the UPV values, energy, attenuation, and non-linearities. Whereas at the beginning of the plastic state, some differences were observed for UPV, energy, attenuation, and non-linearities. Michaela Kostelecká et al. [79] This paper reported on GFRC subjected to a high temperature of 200, 300, 400, and 500℃ for 24 hours. ARGF with 5% by weight of mixture was utilized. GFRC specimens of size 14x40x160mm were used in this study. The samples were heated at various temperatures of 200, 300, 400, and 500℃ for 24 hours. After this period, the same specimens were subjected to three-point bending test, as shown in Fig. 8. For the exact response and change in the mass of GFRC compositions subjected to high temperature, Differential thermal analysis (GT-DTA) was performed. The reference sample and sample subjected to 500℃ for 24 hours were analysis with the GT-DTA analysis procedure. GT-DTA measuring was performed with temperature ranging from 20 to 1200℃ at an increasing rate of 5℃/min. From the GT-DTA analysis, it was found that there was a separation of portlandite in a sample exposed to thermal. It can be one of the reasons that were decreasing the strength of materials.

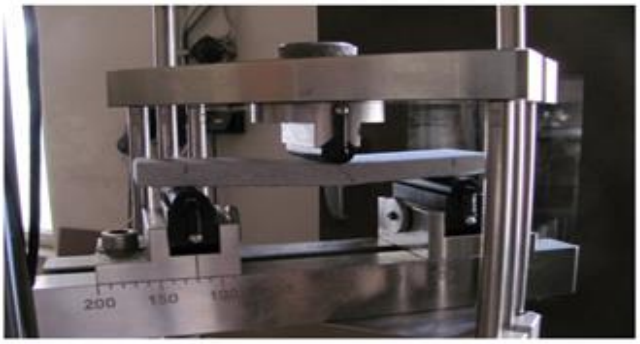

**Fig. 8 Test arrangement of three-point bending [79]**

Guodong Xu and D. J. Hannant [80] This paper investigated flexural response of combined ARGF and polypropylene based concrete. ARGF of 24mm length in the form of strand and roving was used. Six different series of mixes covered a total of 32 flat sheets of size 550x550mm with 7 to 9mm thickness were casted and tested for flexural strength after 28 days. after 28 days of normal curing these sheets were cut about 150mm length and 50mm wide for flexural test. It was reported that the polypropylene and glass strand significantly enhanced the LOP and flexural behavior of sheets at post-cracking zone. G.B. Kim et al. [81] This paper reported on thin structural GFRC members reinforced with glass fiber reinforced polymer bars used as permanent formwork. ARGF with 2% and 3% by weight of cement were used. For validation of design, glass fiber reinforced concrete panels of size 3m long were provided with 8mm2 GFRP bars for experimental testing as shown in Fig. 9. These panels over a span of 2.88m were tested by two concentrated line loads as shown in Fig. 10. Pull out test was conducted to study the bond strength between GFRC and GFRP bars. It was reported that the bond strength between GFRC and GFRP bars was enhanced by 60% as compared to GFRP bars embedded alone in the control concrete.

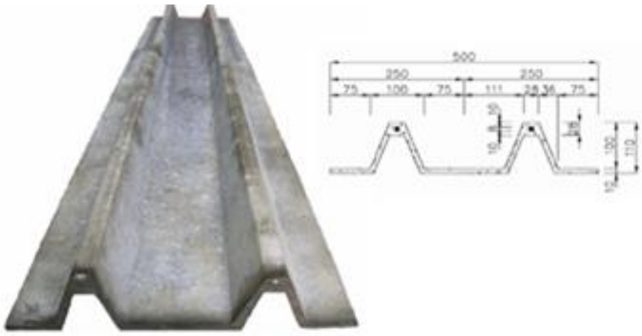

**Fig. 10. Thin structural panels under two concentrated line load testing scheme [81]**

Fares E. Tannous and Hamid Saadatmanesh [82] This paper reported the durability of ARGF based polyester and vinyl ester bars used in concrete beams. In this study a total of 160bars were used for 10 concrete beams. These bars were pultruded with AR glass fiber in polyester or vinyl ester resin matrix. Each concrete beam of size 200x405mm cross section with 2.4mm length reinforced with 2Φ10mm of AR glass polyester and vinyl ester bars. These beams were immersed in deicing salt solution and tested for flexural. It was reported that the response of both AR glass polyester and vinyl ester bars did not exhibit significant improvement in the alkali environment present in concrete. Considerable decline in compressive strength was reported when alkali resistant glass FRP bars subjected to marine environment. Antonio Conforti et al. [83] This paper reported to control the cracking response of concrete beam under flexure reinforced with glass, steel, and polymer fibers. Glass, steel, and polypropylene fibers of 36, 60, and 60mm length were used. Glass fiber with 0.22% and 0.44%, steel fiber with 0.32% and 0.64%, and polypropylene fiber with 0.55% and 1.1% by weight of concrete mix were utilized. It was reported that the crack width at serviceability limit state decreased by using steel fiber from 30% to 50% and glass fiber from 25% to 30%, while for macro-polypropylene fiber the dosage suggested lower than 10%.

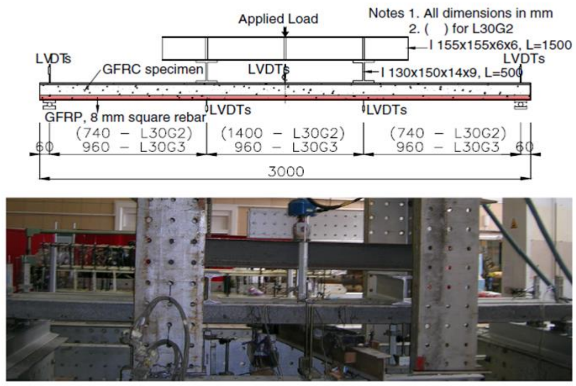


**Fig. 9. Showing scheme of testing panel [81]**

### I. Supplementary cementitious material

Hifzurrahman et al. [84] E-glass fiber reinforced concrete with partial substitution of cement with fly ash by 20%, 30%, and 40%, and with varying fiber content from 1-2% by weight of cement was made and tested for compressive and split tensile strength at 28 days.

Maximum split tensile strength was given by 20% replacement level of fly ash with 2% E-glass fiber content. Morteza Madhkhan and Roozbeh Katirai [85] In this study, AR glass fiber of length 25mm was used to improve mechanical properties (Tensile and flexural strength) of concrete. But at a later age, it was still suffering from some corrosion activities. To mitigate and prevent the corrosion on glass fiber in the concrete environment, 10% silica fume with 1.5% and 2.5% AR fiber and 15% metakaolin with 4% and 6% AR fiber by weight of cement was used following premix and spray-up procedures. For compressive strength, cube specimens of 100x100x100mm, and prism specimens of size 15x50x350mm were used for bending and toughness index. It was found that glass fiber increased toughness indices. It was also found that pozzolanic materials were found suitable to prevent the decline in modulus of rupture and concrete toughness with aging both for premix and spray-up procedures, as shown in Table 3 & Table 4.

**Table 3 Toughness index of the premix specimens [85]**

| Mix design | 7 days | | | 28 days | | | 90 days | | |
|---|---|---|---|---|---|---|---|---|---|
| | Toughness index | | | Toughness index | | | Toughness index | | |
| | $I_5$ | $I_{10}$ | $I_{20}$ | $I_5$ | $I_{10}$ | $I_{20}$ | $I_5$ | $I_{10}$ | $I_{20}$ |
| PC | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| GF1.5 | 4.44 | 5.85 | 7.92 | 4.02 | 5.73 | 6.59 | 3.75 | 4.62 | 4.89 |
| GF1.5-SF10 | 5.10 | 6.70 | 8.07 | 5.30 | 6.15 | 7.62 | 4.90 | 5.62 | 5.78 |
| GF1.5-SF15 | 4.93 | 6.79 | 7.60 | 5.22 | 6.40 | 6.98 | 4.95 | 6.12 | 6.48 |
| GF1.5-MK10 | 5.28 | 7.24 | 9.10 | 4.86 | 6.67 | 7.65 | 4.90 | 6.44 | 7.14 |
| GF1.5-MK15 | 5.40 | 8.03 | 9.89 | 5.22 | 7.48 | 8.70 | 5.09 | 6.48 | 6.97 |
| GF1.5-NS0.75 | 4.40 | 5.57 | 6.63 | 3.66 | 5.15 | 5.94 | 3.60 | 4.56 | 5.35 |
| GF1.5-NS1.5 | 4.28 | 5.26 | 5.91 | 4.05 | 5.04 | 6.12 | 4.02 | 4.61 | 5.38 |
| GF2.5 | 4.35 | 6.65 | 8.05 | 4.36 | 5.54 | 6.95 | 4.19 | 5.20 | 6.07 |
| GF2.5-SF10 | 4.95 | 7.01 | 8.20 | 4.72 | 6.30 | 6.62 | 4.23 | 5.47 | 6.12 |
| GF2.5-SF15 | 5.53 | 7.60 | 8.79 | 4.83 | 6.53 | 7.04 | 4.24 | 5.62 | 6.33 |
| GF2.5-MK10 | 5.30 | 8.63 | 10.29 | 5.40 | 7.63 | 8.24 | 5.20 | 7.29 | 7.65 |
| GF2.5-MK15 | 5.60 | 8.44 | 10.14 | 5.30 | 7.87 | 8.55 | 5.10 | 6.92 | 7.38 |
| GF2.5-NS0.75 | 4.83 | 5.87 | 5.98 | 4.15 | 5.76 | 5.96 | 3.98 | 5.06 | 5.37 |
| GF2.5-NS1.5 | 4.28 | 5.10 | 5.94 | 3.77 | 4.30 | 4.70 | 3.55 | 4.06 | 4.28 |

**Table 4 Toughness index of the spray-up specimens [85]**

| Mix design | 7 days | | | 28 days | | | 90 days | | |
|---|---|---|---|---|---|---|---|---|---|
| | Toughness index | | | Toughness index | | | Toughness index | | |
| | $I_5$ | $I_{10}$ | $I_{20}$ | $I_5$ | $I_{10}$ | $I_{20}$ | $I_5$ | $I_{10}$ | $I_{20}$ |
| GF4 | 5.54 | 12.44 | 23.94 | 6.01 | 12.10 | 22.30 | 6.10 | 12.11 | 22.77 |
| GF4-SF10 | 6.13 | 12.91 | 28.77 | 6.43 | 12.57 | 28.50 | 6.14 | 12.40 | 25.48 |
| GF4-SF15 | 6.08 | 13.45 | 30.96 | 6.45 | 14.07 | 27.19 | 6.16 | 12.44 | 26.55 |
| GF4-MK10 | 5.83 | 13.52 | 31.57 | 5.97 | 13.77 | 31.03 | 6.12 | 13.57 | 28.60 |
| GF4-MK15 | 5.78 | 13.68 | 31.85 | 6.38 | 13.50 | 28.86 | 6.45 | 13.47 | 27.86 |
| GF4-NS0.75 | 5.64 | 12.26 | 25.21 | 5.36 | 11.53 | 24.04 | 5.60 | 11.55 | 22.78 |
| GF4-NS1.5 | 5.46 | 12.24 | 23.40 | 5.44 | 11.01 | 20.49 | 5.75 | 10.85 | 19.85 |
| GF6 | 5.93 | 12.55 | 27.08 | 5.95 | 13.30 | 25.33 | 6.09 | 13.12 | 27.54 |
| GF6-SF10 | 5.84 | 12.73 | 28.14 | 5.85 | 13.56 | 26.01 | 5.86 | 13.41 | 25.14 |
| GF6-SF15 | 5.80 | 13.15 | 31.00 | 5.99 | 14.08 | 28.53 | 6.16 | 13.11 | 27.54 |
| GF6-MK10 | 6.09 | 14.10 | 31.28 | 6.17 | 13.90 | 28.75 | 6.42 | 13.82 | 28.20 |
| GF6-MK15 | 6.17 | 13.78 | 30.53 | 6.57 | 14.57 | 28.48 | 6.61 | 14.15 | 28.03 |
| GF6-NS0.75 | 5.39 | 12.27 | 24.83 | 5.34 | 11.78 | 23.72 | 5.56 | 11.62 | 20.21 |
| GF6-NS1.5 | 5.25 | 12.36 | 23.82 | 5.30 | 12.14 | 19.54 | 5.62 | 11.68 | 19.30 |

Sujit V. Patil and N. J. Pathak [86] In this paper, the compressive strength was investigated using alkali-resistant glass fibers and partial substitution of cement with ground granulated blast furnace slag with the effect of magnetic water. Magnetic water treatment is a method that passes through a magnetic field as a non-chemical alternative to softening water and reducing the effects of the hardness of the water. Specimens of 150mm size were made with 50% cement replacement with GGBS using AR glass fiber with different percentages of 0.2%, 0.3%, 0.4%, and 0.5% for 7 and 28 days. The researcher found that samples with 50% GGBS and 0.3% alkaliproof glass fiber imparted satisfactory results to the compressive strength. It was also concluded that the effect of treated water for curing and mixing, the compressive strength increased by 32% for 7 days and 20% for 28 days as compared to conventional tap water. Arnon Bentur [87] In this paper, the treatment of silica fume as a tool to enhance the durability of glass fiber reinforced cementitious composites was investigated. Two different treatment modalities were evaluated. The first treatment (fiber treatment) was performed by immersing the reinforcing filaments in the slurry and the second by matrix modification by 10% silica fume replacement of cement. The first treatment alone was beneficial, resulting in 50% or more of its toughness after 5 to 9 months of accelerating aging. Additional matrix modification resulted in better performance, although the toughness retention was over 50%. Further adjustment of the matrix led to better performance, with the toughness retention exceeding 50%. Matrix modification alone did not make any significant progress. The different type of cementitious materials is shown in Fig. 11.

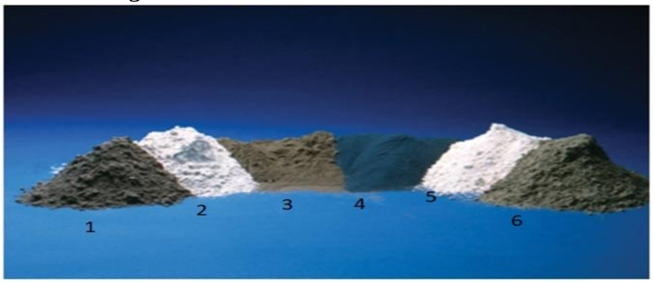


**Fig. 11 Cementitious materials. (1) Calcined shale; (2) Slag; (3) Fly ash (Class F); (4) Silica fume; (5) Metakaolin; (6) Fly ash (Class C) (www.sbm-co.com) [87].**

Chuchai Sujivorakul et al. [88] This paper investigated the use of fly ash, rice husk ash, and palm oil fuel ash in the GFRC. These alternatives were used to replace Ordinary Portland Cement with different percentages of 0%, 10%, 20%, 30%, and 40%. 95% of these substitutes passed through the standard size of screening No. 325. GFRC, with 5% of AR glass fibers with 35mm cutting length by weight of cement, was used to produce standard panels through external spray machine. All panels were tested for water absorption, bending strength, bending strain, and toughness at 7, 28, 56, and 180 days following BS-E 1170-5 standard. It was found that GFRC panels with and without replacement of cement by FA, RHA, and POFA increased the limit of proportionality with increasing curing age. Whereas, the modulus of rupture increased initially and then gradually fell. It was also concluded that 20% of fly ash, rice husk ash, and palm oil ash could be used to replace OPC cement without disturbing the physical properties of glass fiber reinforced concrete, which include the benefits of reducing costs and helping to reduce CO2 emissions. Antonina Ryabova et al. [89] This paper reported on mechanical properties of GFRC through time. Alkali proof glass fiber of Cem Fill trademark with 10mm length and with 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, and 3% by weight of concrete were used. Metakaolin and micro-silica were employed as additive with 2, 5, and 8% by weight of cement. GFRC beams were casted and tested for bending and compression. The tests were carried out for 28 and 180 days. The coefficient of micro silica and metakaolin on bending strength through time is shown in Fig. 12. It was found that the employment of metakaolin in the GFRC beam resulted in an increase in deformation capacity. It was also be concluded that the combined use of metakaolin with micro silica as additives, positively affects the bending strength of the GFRC.

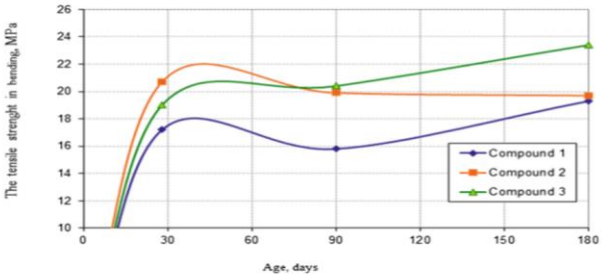


**Fig. 12 Co-efficient of micro silica and metakaolin on bonding strength through time [89].**

**B**. Subhan Ramji and M. Sri Lakshmi [90] This paper studied GRFC with partly substitution of coarse aggregate with pumice stone and cement with fly ash. Coarse aggregate was partially replaced by 5, 10, 15, and 20%. AR glass fiber of 12mm length and fly ash with 1.5% and 5% was used in this study. The maximum compressive and split tensile strength of concrete was gained with 5% fly ash, 5% pumice stone, and 1.5% of glass fiber content. It was also concluded that the workability decreased with a higher dosage of pumice stone.

### J. Effect of Glass Fiber on Fresh and Hardened Properties of Self Compacted Concrete

R Bharathi Murugan et al. [91] Self-compacted GFRC concrete properties on fresh and hardened state were investigated. Glass fiber was utilized to determine the optimum fiber dose level to give better results for GFRC resistance. Glass fiber with 0%, 0.1%, 0.3% , 0.5%, and 0.6% by weight of cement was used to replace fly ash with 30% of its weight. In the fresh state, concrete tested for slump flow, V-funnel, and L-box. In hardened state, compressive, split tensile, flexural strength, and modulus of elasticity was carried out for 28 days. It was found that the strength of GFRC increased with the addition of glass fiber (0.6%) content. It was also concluded that 0.6% of glass fiber could be a better replacement level to utilized in self-compacting concrete. Mr. Manohar KN et al. [92] This paper investigated the workability and strength characteristics of glass fiber reinforced self-compacted concrete (GFRSCC) of grade M40 using fly ash with silica fume. The cement was replaced with 20% fly ash and 12% silica fume by weight. AR glass fiber with varied percentage of 0%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7% and 0.8% by weight of concrete was used to make GFRSCC. Tests were performed for 7 and 28 days. It was reported that the maximum compressive strength, split tensile, and flexural strength was given by 0.3, 0.4, and 0.7% of the ARGF replacement level. Subhan Ahmad and Arshad Umar [93] This paper reported on mechanical performance of SCC concrete reinforced with ARGF and polyvinyl alcohol fibers. Cem-fill AR glass fiber and PVA fiber of length 12mm with 0.1, 0.2, and 0.3% by weight of concrete were used. Concrete specimens were tested for compressive, split tensile, flexural strength, and ultrasonic pulse velocity after 7 and 28 days. The maximum compressive strength was given by 0.2% of glass and PVA fibers. Split tensile and flexural strength increased with 0.3% of both fibers.

### K. Seismic Vulnerability Evaluation of Strengthened GFRC

Liaqat Ali Qureshi et al. [94] This work reported the utilization of carbon-reinforced polymer as a reinforcing material on the seismic response of PCC and GFRC. AR glass fibers with 12 mm cutting length and 1.5% by weight of cement were used. Research work held in two steps. In the first step, cylindrical specimens were cast for PCC and GFRC. In the second step, the specimens were wrapped by CFRP in 3 different patterns, namely full and partially covered, as shown in Fig. 13. All specimens were tested for compressive loading at 28 days. The test results used in the non-linear static cyclic analysis of reinforced concrete frames modeled in a finite element based analytical procedure. Through seismic vulnerability evaluation, the analytical curve for frames was developed using a modified capacity spectral method. Based on the result, it was reported that the frames wrapped by CFRP were significantly improved its seismic performance. There was a 20.73% increment in the Collapse hazard level of unconfined GFRC structure with comparison to unconfined plain cement concrete structure. Whereas, 21% to 28% improvement in the collapse hazard level was observed in confined PCC structures compared to its unconfined counterpart. However, GFRC confined structure resulted in an 8% increment in collapse hazard level over the unconfined GFRC structures.

**Fig. 13 Wrapped specimens with CFRP [94].**

E. Tore et al. [95] This paper reported the seismic retrofitting technique for columns. This retrofitted method was utilized with basalt mesh together with reinforced sprayed GFRC jacket, as shown in Fig. 14. GFRC and basalt mesh contained cement-based matrix and textile reinforcement materials, respectively. AR chopped glass fiber of 24mm length, with 3.5% by weight of cement, was used. Retrofitted members were tested for compressive and bending tests for 28 days. It was found that this technique has prominent features in terms of application, performance against high temperature, and low cost.


**Fig. 14 Retrofitting process of the members [95]**

A.O. Ates et al. [96] This paper reported the retrofitting technique used for rectangular columns, sprayed with GFRC and basalt textile reinforcement.

Columns of square section (200x200mm) and rectangular section (200x300mm) were subjected to various loading. AR glass fiber of length 24mm with 3.5% by weight of cement was used. Retrofitted members were tested for compressive and flexural strength at 28 days. It was found that GFRC basalt reinforced textile spray is an adequate strengthening method for the external confinement of low strength concrete members due to its enhanced compressive strength and deformability. It was also concluded that confinement effectiveness decreased as the aspect ratio (h/b) of the columns increased.

### L. Effects of Barite Sand on Mechanical Behavior of GFRC

Sadık Alper Yıldızel [97] This paper studied the mechanical behavior of GFRC by using Barite sand replacement of silica sand by a varied percentage of 5%, 10% and 15% by weight. AR glass fiber with a constant ratio of 3% by weight of cement was used. In this experimental work, flexural strength and freeze-thaw resistant of the concrete was studied. The test was performed for 7, 15, and 28 days following TS EN 1170-4, 5. It was found that replacing silica sand with barite at the 15% replacement level, increased the flexural strength, freeze & thaw (F&T) resistance properties.

### M. Effect of nano and micro silica on various strength of glass fiber reinforced concrete

K.I.M.Ibrahim [98] This paper reported the influence of fibers on nanosilica based concrete. Polypropylene and glass fibers of length 12mm and 18mm with varying percentages of 0, 0.2, 0.4, and 0.6% by weight of concrete were used. Whereas, steel fiber with 50mm length of 0, 0.4, 0.8, and 1.2% was utilized. Cement was replaced by 1.55 of nano silica content. Compressive and split tensile strength were tested after 28 days. It was reported that the effect of nano silica on strength of concrete was less. Compressive and split tensile strength of nano silica concrete reduced with the addition dosage of glass fiber. Arya P Nair and Mohamed Asim [99] This paper investigated to study the influence of nano silica based self-compacting concrete reinforced with alkali resistant glass fiber. ARGF with 13mm length and 0.1% by weight of cement was added to the concrete. Cement was replaced by nano silica with varying percentages of 0.5, 1.5, 2.5, and 3.5%. compressive, split tensile, flexural strength, and acid attack tests were performed after 3, 7, 28, and 56 days. Workability of SCC reduced with the addition dosage of glass fiber and nano silica content. ARGF and nano silica with 0.1% and 2.5% imparted better results to the compressive strength. Erhan Güneyisi et al. [100] In this paper nano silica together with fly ash were utilized to study ARGF based self-compacting concrete. AR glass fiber of 12mm length with varying percentages of 0.35, 0.7, 1, and 1.5% by weight of concrete was added. Cement was replaced by nano silica with 2% and 4%. Whereas, fly ash was utilized by weight of cement with fix ratio of 25%. Concrete was tested for workability as well as torque. The addition of nano silica and glass fiber resulted in higher slump. Glass fiber from 0 to 1.5% improved the torque. Hamid Reza Tavakoli et al. [101] In this research work nanosilica together with steel, polypropylene, and glass fiber were utilized to study the performance of self-compacting concrete. Steel fiber with varying percentages of 0.2, 0.3, and 0.5%, polypropylene fiber of 0.1, 0.15, and 0.2%, and AR glass fiber with 0.15, 0.2, and 0.3 were used. Cement was replaced by nanosilica with varying percentages of 2, 4, and 6% by weight. Concrete was tested for compressive, split tensile, and flexural strength after 28 days. Nanosilica of 4% enhanced the compressive, split tensile, and flexural strength. Glass fiber imparted higher compressive strength than steel and polypropylene fiber.

## III. CONCLUSION

This paper presented a review on research work published on the properties of fresh and hard ARGFRC prepared using NEG and CEM-FIL alkali resistant glass fiber as an additive of cement. Based on the critical study the following conclusion can be drawn:

1. Different quantity of the fiber with varying length affected the workability of the GFRC and higher percentage of the fiber (0.4 to 0.5%) resulted in balling thereby making the concrete harsh with reduced workability. The measured slump for conventional concrete was reported as 160mm decreased to 126mm with 0.1% of the fiber which further decreased to 39mm with 0.5% of the fiber. In general, the length of fiber of 3mm and 6mm showed a greater slump, however the increase in the length of the fiber up to 20mm decrease in slump was not significant.
2. The presence of alkali-resistant glass fibers in concrete did not increase its compressive strength. However, it enhanced the value of its toughness indices. The presence of pozzolanic materials in GFRC specimens partially reduced compressive strength over a short period of time. The maximum increase in the compressive strength of GFRC was perceived in the presence of metakaolin. Basalt fiber had been found superior for imparting compressive strength to concrete than AR glass fiber.
3. High strength concrete with AR glass fiber exposed to simulated environment attack was not found suitable in terms of compressive strength. Premature fracture of fiber filament was found to be the reason for drop in compressive strength.
4. AR Glass fiber to the mix of concrete made a limited positive effect on the ultimate strength deflection due to fire was more pronounced, and showed in different behavior after cooling except 10% reduction in strength. The GFRC with 0.5% of glass fiber contributed more effectively than higher dosages.
5. Higher percentage of AR glass fiber content in GFRC is detrimental to its compressive strength under aggressive chloride environment because of higher diffusion and air permeability of GFRC. For low chloride diffusivity and air permeability, the AR glass fiber content of 0.6% to 1.2%, and for optimum durability performance, AR glass fiber of 1.2% or less were recommended.
6. Polyvinyl alcohol powder found useful in improving glass fiber and matrix interfaces. GFRC modified with PVA powder enhanced its tensile strength and ductility significantly due to migration of water soluble PVA to the glass fiber surface.
7. GFRC basalt reinforced textile spray was found to be considered as strengthening technique for the external confinement of low strength concrete members due to its enhanced compressive strength and deformability.
8. The additional content of glass and polypropylene fibers content enhanced the split tensile strength of both GFRC and PFRC concrete approximately from 20% to 50%, and the splitting tensile strength of GFRC and PFRC ranged from 9-13% of its compressive strength.
9. Glass fiber used as reinforcing material to strengthen the plain concrete beam significantly increased the load capacity and deflection at mid-span, and developed more cracks as compared to un-strengthened beam.
10. The use of micro silica as an active mineral additive resulted in maximum bending strength of concrete at 28 days. However, with later ages, the strength decreased, indicating the ineffectiveness of silica fume in terms of the protective effect against alkali.
11. Treatment of alkaliproof glass fibers with silica fume found to be more significant in maintaining the composite toughness more than 50% for the aging acceleration period of 5 to 9 months.
12. GFRC panels with and without replacement of cement by FA, RHA, and POFA increased the limit of proportionality with increasing curing age. The modulus of rupture increased initially and then gradually fell. Fly ash, rice husk ash, and palm oil ash utilized to replace OPC cement by 20% without disturbing the physical properties of GFRC.
13. ARGFRC with CFRP as a reinforcing agent significantly improved the seismic performance of the frame. Unconfined GFRC frame showed higher level of collapse than unconfined plain concrete frame. Also confined GFRC frame with CFRP showed higher increased in collapse hazard level as compared to unconfined GFRC frame.

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