Glass Fiber Reinforced Concrete Exclusive Assets and Applications in Construction

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ABSTRACT

Glass Fiber Reinforced Concrete or (GFRC) is a composite that has glass fibers instead of steel strands for its reinforcement. Removing the steel reinforcement not only weakened, but also omitted steel erosion, corrosion, and their future repair costs, steel reinforcement costs, optimal coverage, and etc.
In this research, several sources were studied to determine and clarify GFRC's applications in order to compare its featured properties with other fibers. Different figures and tables provided that show and compare physical and mechanical properties of GFRC and other fiber reinforcement.
GFRC can be used wherever a light, strong, weather resistant, attractive, fire resistant, impermeable material is required. It has remarkable physical and mechanical assets. GFRC properties are dependent on the quality of materials and accuracy of production method. Despite its wide range applications in architecture the chief goal is to show and introduce important structural purposes, for instance: anti rust characteristics of GFRC made it a good replacement for water and sewer pipes and tanks, a thin protective layer of GFRC on concrete beams and columns can increase their durability in fire as well as low temperatures and generally it is a good replacement for susceptible materials in difficult environments.

Key Words: (Fiber Reinforcement, Glass Fiber, GFRC, Composite, Lightweight Concrete, Durable).

I. Introduction

Undoubtedly one of the most important materials in worldwide construction industry that is vastly in use is **concrete**.

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[Figure 1.a], Concrete

[Figure 1.b], Concrete block

Conventional concrete is composed of aggregates (sand, gravel…), cement, water and admixtures where it is necessary.
Concrete with a uniform structure, good plasticity and the ability of deformation by form, sound and thermal insulation and the capability of quality development by admixtures, is getting more and more popular in structural industries every day.

Other advantages of an ordinary concrete can be noticed is relatively good durability in different weather conditions, high-load bearing after its optimal set and gradual increase in strength during the passage of concrete's life.

Considering all the concrete benefits, we cannot deny its weaknesses. The first fundamental problem of concrete is low tensile strength which is approximately 10%-15% of its compressive strength nevertheless this crucial problem can be solved by the reinforcement. By the way, standard concrete coverage on steel should be contemplated according to the regulations and constructional codes.
In addition, reinforcement must be calculated to prevent brittle failure in order to have plastic behavior, the maximum standards must be respected to prevent corrosion of reinforcement, admixtures or the new term of mixtures have to be used to increase ordinary concrete's impermeability.
To prevent erosion and corrosion due to freeze-thaw cycles, acid rains and various weather conditions, sulphates attacks; and all in all, to use concrete in particular environment or condition such as:
Marine structures, coastal structures and water and wastewater industries, different costs to repair and optimization should be payed.
In this paper, it is intended to introduce a vital type of concrete based on researches and investigations that have specific characteristics and today developed construction industries are working to find out more effective and noticeable assets of this type of concrete.

[Reinforcing a matrix with fibers is not new. Nature has good signs of fiber reinforcement for example: beavers pack mud into intertwined branches to build their amazingly strong houses and dams or robins and other birds build strong little mud nests reinforced with straw or twigs. Early man may have noted these benefits of reinforcement materials when he mixed straw into his sun-baked clay bricks or houses].**[*Ref. 1].**Even there are still houses made of mud-straw in rural areas.

[Figure 2.a], Beaver

[Figure 2.b],Robin

Strengthening cement by adding fibers dates back to 1908, when asbestos-cement entered the market.**[*Ref.1]**

[Figure 2.c], Asbestos-cement

The potential for using glass fiber reinforced concrete system was recognized by Russians in the 1940s and has been developing for years especially in the USA, Canada and England.

Glass Fiber Reinforced Concrete or (GFRC) is a composite that has glass fibers instead of steel strands for its reinforcement. Removing the steel reinforcement not only weakened, but also omitted steel erosion, corrosion, steel reinforcement costs, optimal coverage and etc.

[Figure 3.a], GFRC, www.Stonewear.com

[The important feature of GFRC is tensile strength or the ability to have strength when stretched .This tensile characteristic also creates remarkable enhanced impact strength .It shares equally the two primary assets of conventional concrete, which are compressive strength and longevity].**[*Ref. 2]. [**As it is mentioned GFRC do not rust and therefore require no minimum cover. It is easy to incorporate and do not protrude from the surface after demolding.].**[*Ref. 2]**

[Figure 3.b], Steel oxidization, Photo by author

II. Composition of GFRC

-GFRC is composed of:
-Concrete-typically Portland cement, type I.
-Aggregates, (crushed stone or silica sand).
- Glass fibers-to provide tensile and flexural strength.
-Polymers in some cases-to improve toughness.
-Plasticizers to enhance workability of concrete where it is necessary.

Generally, higher cement ratios are used in GFRC mixtures and concretes that contain glass fiber reinforcement. In fact, the more the fibers, the more the cement.

Normally used fiber lengths are 0.5, 1, 1.5 and 2 inches. Because using shorter fibers make distribution easier but experiences show that the 1 inch length provides optimum strength. In spray head mixing which results better physical and mechanical properties often 1.5-inch fibers are used. Mixing longer fibers in concrete or cement bother the process of consolidation and decrease density and subsequently mechanical strength. **[*Ref. 1&16]**

In most glass fibers products the content of glass fibers differ from 3 to 7 percent by weight however, when the fiber ratio goes up density declines and this is because of poor compaction.

Samples made of ordinary glass fibers are initially strong but a loss of strength is shown when they age, and it causes from high alkaline environment of Portland cement. In special cases if using typical glass fibers are required due to lower cost or accessibility it is possible to replace micro silica or nano silica by cement weight to reduce alkaline effects but when the issue of difficult environment is imposed it's highly recommended to use AR glass fibers.

Samples were made of ordinary glass fibers were initially strong but the strength dropped off as the samples aged because the highly alkaline environment of Portland cement attacked surfaces of glass fibers.

AR Glass Fibers

Table-1-Chemical composition of AR glass fibers, percent by weight

Component	AR-glass
SiO_2	61-62
Na_2O	14.8-15
CaO	-
MgO	-
K_2O	0-2
Al_2O_3	0-0.8
Fe_2O_3	-
B_2O_3	-
ZrO_2	16.7-20
TiO_2	0-0.1
Li_2O	0-1

[*Ref. 4]

Most commercial glasses have approximately similar chemical compositions of:

70% - 74% SiO_2 (silica) 12% - 16% Na_2O (sodium oxide) 5% - 11% CaO (calcium oxide) 1% - 3% MgO (magnesium oxide) 1% - 3% Al_2O_3 (aluminium oxide)

Table-2-Mechanical properties of AR glass fibers

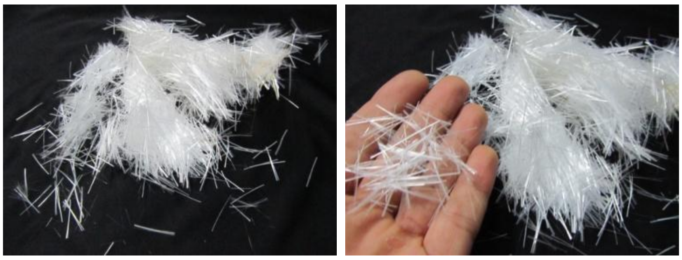
Property	AR-glass
Specific Gravity	2.70-2.74
Tensile Strength, MPa, Kg/mm^2	1700[173.35]
Modulus of Elasticity, GPa, Kg/mm^2	72[7342]
Strain at Break,%	2.0
Effect of Temperature(Cem-FIL® corporation)	Non-Combustible, Softening Point 860°C

[*Ref. 4]

AR glass fibers are available in these forms that can be used in concrete.

1. Chopped strands 2. Continuous rovings 3.Meshes

1. AR Glass Fiber Chopped Strands,[Figure-4]



[Figure 4], GFRC chopped strands. 24 mm. Photo by author

2. Continuous AR Glass Fibers,[Figure-5a,b]

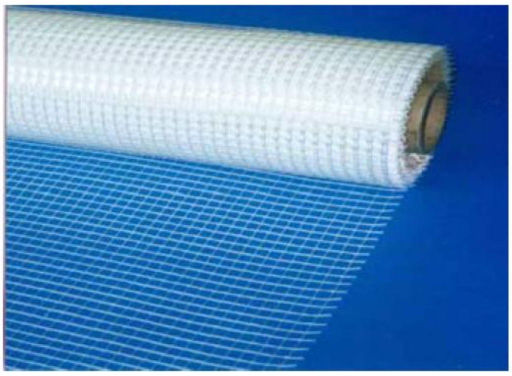
[Figure 5.a], Bundle, Wikipedia.com

[Figure 5.b], GFRC continuous strand roving,bloorintar.com

3. Glass Fiber Meshes

[Alkali-resistant glass fiber mesh [figure 5.c] can be used to reduce the need for the coating].[*Ref. 4] We can compare them with Welded Wire Fabric [WWF],but glass fiber meshes are thinner in size and lighter in weight in comparison to WWF-[figure 5.d].

[The AR mesh has recently been used in a new system for seismic improvement of mansory walls].[*Ref .4]



[Figure 5.c], GFRC Mesh

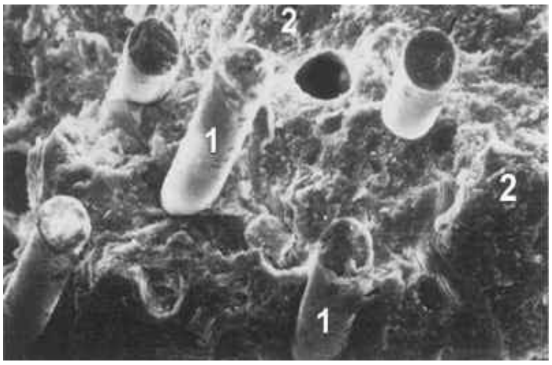
[Figure 5.d], Steel Mesh

Moreover, it seems very unique to reinforce rural buildings (typically made of clay and bricks or mud and straw) with glass fiber meshes to increase their flexural strength and durability. This solution is an innovative idea to rebuild and repair masonry buildings especially in rural museums and heritages or even in true cases because buildings must be stable in harsh environments and stand different stresses. This idea came to our mind to reinforce mud-rice straw paste with AR chopped glass fibers to improve its durability, tensile strength, compressive strength and flexural strength and permeability as well as all above. Despite all structural benefits of this solution it has several architectural benefits for example the buildings can maintain their original external view but stronger and thinner than before.

III. Physical and Mechanical

Properties of GFRC

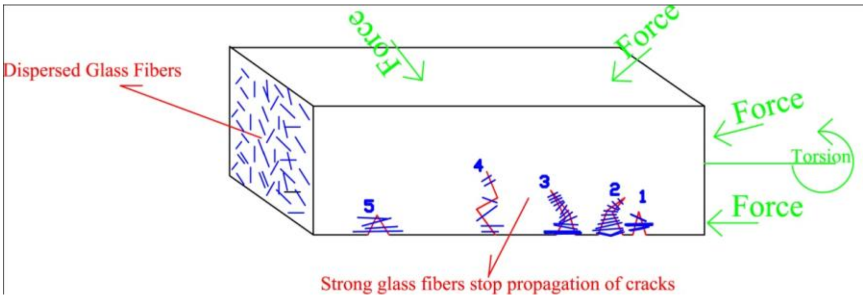
GFRC does not fail immediately under load but yields gradually nevertheless in cement and concrete tensile failure begins with micro cracks and they propagate quickly and cause destruction. The key of this accepted behavior of GFRC is due to randomly distribution of tiny glass fibers in it, uniformed distributed fibers expand the loads in a wide range and let the matrix to behave cohesive.[Figure 6.a&b] shows randomly distribution of AR glass fibers in the matrix in a large scale.



[Figure 6.b], Glass Fibers,Stonewear.com

[Figure 6.a], Glass Fibers, Stonewear.com

The existence of glass fibers provides crack arresting system for example we can imagine a concrete beam with numerous ties or reinforcement in different directions. It is clear when the first crack occurs in the beam the strong fibers pick the loads so that this characteristic allows the beam to withstand more loads. More loading impose, only new cracks appear rather than causing first cracks to develop which occurs in steel reinforced concrete especially in the tension area. Therefore, failure in GFRC develops as a gradual plastic-like yielding and in the end, fracture happens when fibers are broken. The schematic diagram below shows the process of crack arresting. [Figure 6.c]



[Figure 6.c], Glass Fibers failure trend, by author

GFRC has a higher tensile strength than steel. [Generally, the higher the fiber content, the higher the strength. A typical mix with 5% glass fiber has a compressive strength of 6000 to 8000 [psi] or 4.21 to 5.62 [Kg/mm ^{2}].] [***Ref. 12]**

In many environments, when they exposed to salt or high moisture (marine environment), the GFRC can be expected to perform better, as there is no steel reinforcement to corrode. [The use of glass fibers for reinforcement rather than steel means it would not rust and can even be used under salt water and marine environments.] [***Ref. 12].**Other important characteristics of glass fiber reinforced composites are their high damping capacity and *low coefficient of thermal expansion*. Table 3 and Table 4

[Table 3], Coefficient of Thermal Expansion of materials

Material	Coefficient of Thermal Expansion (Volumetric)- (10^{-6}/°C)-Room Temp.
Steel	33□ 39
Concrete	36
Carbon steel	32.4
Glass	25.5
GFRC	10.8□ 16.2
Borosilicate Glass	9.9

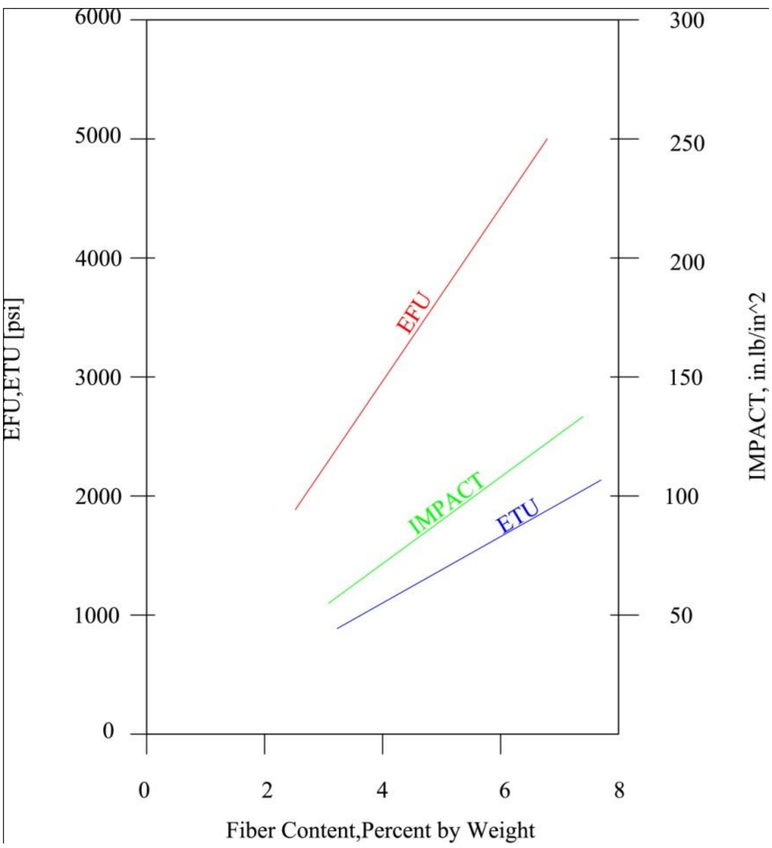
[Table 4], Thermal Conductivity of materials

Material	Thermal Conductivity [W/(m·K)]
Stainless Steel	12.11□ 45
Concrete, stone	1.7
Soil	1.5
Glass	1.1
GFRC	0.505□ 1.04
Air	0.25

IV. Factors affecting properties

[The principal factors affecting properties of GFRC are fiber content, water-cement ration or W/C, porosity, composite density, inter filler content, fiber orientation, fiber length, and type of cure.Density and porosity are also functions of the degree of compaction.

Fiber content,length, and orientaion primarily affect early tensile ultimate strength(ETU), early flexural ultimate strength (EFU) and impact strength. The relation of fiber content to these properties is show in [Figure 7].] **[*Ref. 2]**



[Figure 7],Effect of fiber content on early tensile ultimate strength(ETU) Early flexural ultimate strength (EFU) and impact strength.[*Ref.2]

[Higher fiber contents tend to entrap air into the composite and reduce density. A minimum fiber content of 4% by weight is recommended to ensure adequate ultimate strength. Fiber length also plays role in composite ultimate strength.] **[*Ref. 2]**

Modulus of Elasticity

Table [5] shows modulus of elasticity of different materials.

Material	Modulus of Elasticity , Kg/mm^2
Steel	≈20394
Carbon Fiber Reinforced Plastic	≈18457
AR Glass Fiber	≈7342
Glass Fiber Reinforced Plastic	≈4400
Concrete	≈3570

Result= $E_{Steel} > E_{Glass\ Fiber}$

It could be concluded from table 5 that however the E value of glass fiber is lower than steel but high quantity of tiny glass fibers in concrete will restitute lack of elasticity. We must not separate steel and fibers from each other but we can combine them to provide a strong product as a matter of fact glass fibers can be a good cover for columns and beams and they can increase mechanical properties of members.

Table [6] -Typical properties of sprayed GFRC, [*Ref. 4]

Property	**28-day**	**Aged***
Dry Density, t/cu.m.	1.9-2.1	1.9-2.1
Compressive, MPa	50-82	70-82
Flexural:MPa Yield,(FY) Ultimate strength, (FU) Modulus of elasticity, GPa	6-10 14-24 7-21	7-11 9-17 18-28
Direct Tension, MPa Yield, (TY) Ultimate strength, (TU) Strain to failure %	5-7 7-11 0.6-1.2	5-7 5-8 0.03-0.08
Shear: MPa Interlaminar	3-6	3-6

In-plane	7-11	5-8
Coefficient of thermal expansion, /ºC	$10\text{-}20 \times 10^{-6}$	$10\text{-}20 \times 10^{-6}$
Thermal conductivity,W/mºC	0.5-1	0.5-1

***GFRC specimens immersed in 50 to 80ºC water .It could be estimated above 50 years.**

Note: Marked numbers show there were no changes in figures due to passage of GFRC's age. Compressive strength and E value and Flexural yield increase when the GFRC is aged.

IX. GFRC versus other Fiber Reinforcement

-Iron and steel reinforcing in concrete:

Iron and steel rods cause potential corrosion and durability problems, however embedded steel is generally very durable, as it is protected from corrosion by the alkaline environment of the concrete but highly aggressive environments, the protection given by the concrete is often insufficient. The protective layer is broken down and corrosion begins, the initial signs being cracking and spalling of the concrete. Expensive remedial work is needed to repair this damage if the structure is to achieve its serviceability. **[*Ref. 8]**

-Fiber Reinforced Polymers:

[FRP rods have low compressing strength in comparison to their tensile capacities. Fire will be a design consideration for some types of structures.]**[Ref. 8]**Consequently resins show low durability under elevated temperature and will be disabled under harsh environment like hot temperature or alkaline environment of cement. The other problem of FRPs is their straight line response to failure with no plasticity. This behavior is very dangerous in concrete structures the fact that engineers try to cross out from their calculations and strive to design more durable structures and use reinforcement with higher plasticity to reduce immediate failure of members in hazards like earthquake and let habitants to escape from the buildings.

X. Comparison of Glass and other fiber properties, Table [7], [*Ref. 10]

Material	Tensile Modulus,Msi	Tensile Strength,Kg/mm^2	Density, g/cm^3	Fiber Diameter, Micron	Cost, Dollar/#
Carbon(PAN)	30-50	246-703	1.75-1.9	4-8	20-100
Carbon(Pitch)	25-110	140-316	1.9-2.15	8-11	40-200
Carbon(Rayon)	6	105	1.6	8-9	5-25
Glass	10-12.5	309-471	2.48-2.62	30	5-40
Aramid	20	288	1.44	-	25-75
Boron	58	513-703	2.3-2.6	100-200	100-250
Steel (Bar)*	29	204	**7.7**	9500	-

*Steel bars are available in different sizes; in this table 9.5mm size is considered.

The table brightly shows, glass fiber's tensile strength is much higher than steel bar and even ordinary carbon fiber and aramid but less than boron. Boron is an expensive fiber however; its diameter is bigger than glass fiber.

Tensile modulus of glass fiber is lower among the most fibers but we must consider that anti-corrosion, thermal resistance and small diameter of glass fiber can cover this problem.

XI. Applications of GFRC

1-Architectural panels, because of GFRC's light weight it can easily be transported. Weathering is a destructive factor and imposes different remedial repair costs; GFRC products are good weather resistant products and can save repairing and even transportation costs.

[Figure 12.a], GFRC architectural panels and decorative elements

2-Sound Walls

Because GFRC products are easy to transfer and can be produced in desire shapes are good noise and sound barriers. They are widely used in urban areas and roads to reduce noise pollution in addition, different and interesting shapes and colors could be eye catching.

[Figure 12.b&c], Sound barriers, Spain

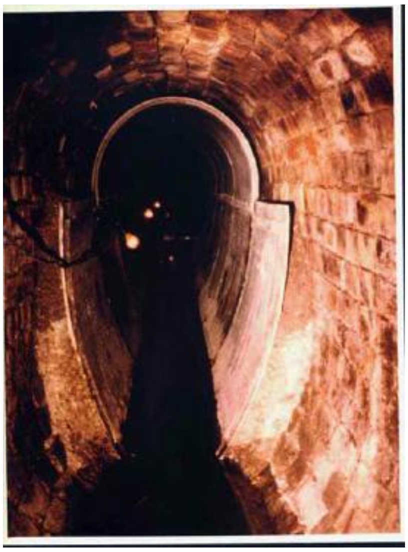
3. Ducts and Channels

It is applicable in drainage and transporting liquids or cable and pipe ducts troughs.

[Figure 12.d], Cable trough, Redland Precast Company, Hong Kong

4. Sewer lining

GFRC has stable resistance in contraction with acid, salt, lime and water so that, they are suitable choices for sewer lining, septic tanks and generally water and wastewater companies. The main problems of sewer linings are corrosion due to chemicals existed in waste water, temperature of water, problem of freezing in cold seasons and problem of humid weather condition and wet underground condition for example in our region (north of Iran).Having a good durability and permeability of GFRC create it a safe composite and solved many environmental issues related to concrete and its low strength and features in bad conditions. We believe GFRC pipes could be designed in different desired shapes and could be a good replacement for old and traditional piping systems. The picture below shows coverage of sewer canal with GFRC.



[Figure 13.a], Sewer lining, GFRC walls are installed to resist in aggressive,[*Ref. 4]

6. Pipes

As we discussed in sewer lining, these kinds of pipes could be used under soil, marine structures and etc.

7. Seismic retrofitting

As glass fibers and generally GFRC is very lighter in weight than steel reinforced concrete and also have high tensile strength they seem to be very applicable in structural purposes because they reduce building's weight and consequently lateral loads of earthquake and structural drift. We must consider that GFRC cannot be replaced by reinforced concrete because it is not load bearing but combination of FRC or fiber reinforced concrete and SRC or steel reinforced concrete is an ideal idea to reduce special surface of steel and reduce structure's weight respectively.

8. Rehabilitation of structures

Light and strong GFRC allows engineers to repair structures. Also masonry buildings are very susceptible to natural disasters and require a standard method for their strengthening. Application of glass fibers in rural buildings and masonry building were initially described in this article.

XII-Conclusion

GFRC can be used wherever a light, strong, weather resistant, attractive, fire retardant, impermeable material is required. It has many physical and mechanical remarkable assets. The high tensile strength that is higher than that of steel. Modulus of elasticity commonly is higher in steel bars but low modulus dispersed glass fibers stretch and allow concrete to crack, when the concrete cracks strong glass fibers play their role and do not allow the crack to propagate hence, a new crack in different position appears. GFRC properties are dependent on the quality of materials and accuracy of production method. Steels are removed in the GFRC so that, no corrosion will occur and no minimum cover is needed.AR glass fiber can stand acid, alkaline and salt, the main factors of erosion. Accelerated ageing test developed and proved GFRC products durability and stability in different weather conditions during the long years.[Results showed that the passage of time and effects of different weather conditions and freeze-thaw cycles had very little effects on tensile ultimate strength and flexural ultimate strength]**[*Ref. 5].** GFRC products have been used for architectural purposes for many years but the development and innovation of GFRC industries suggest many new applications like: water storage tanks, septic tanks, coastal and marine structures, water and wastewater pipelines and etc.

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