Analysis of Glass Fiber Reinforced Concrete

Pushpendra Kumar Gupta[1], Prof. Dinesh Kumar Jaiswal[2], Dr. D.K Jain[3], Dr. R.P Tiwari[4]

[1]*M.Tech Scholar Civil Engineering Department Rewa Engineering College, Rewa MP, 486001*
[2]*Assistant Professor Civil Engineering Department Rewa Engineering College, Rewa MP, 486001*
[3]*Professor Civil Engineering Department Rewa Engineering College, Rewa MP, 486001*
[4]*Professor & Head Civil Engineering Department Rewa Engineering College, Rewa MP, 486001*

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Abstract - The most common building material utilized worldwide is concrete. These days, more difficult engineering constructions are being built all over the world. Concrete must therefore be extremely durable and workable. By adjusting the ratios of different fibers and admixtures, researchers worldwide are creating high-performance concrete. Concrete's tensile strength, fatigue characteristics, durability, shrinkage, impact, erosion resistance, and serviceability are all improved by a variety of fibers, including as glass, carbon, polypropylene, and aramid fibers. These qualities allow fiber reinforced concrete to be used in a variety of civil engineering applications. The history of GRC is briefly summarized before going over the essential elements of this complex compound. Features are analyzed, production methods are enumerated, and fracture mechanisms unique to GRC are explained.

Glass fiber reinforced concrete, or GFRC, is a relatively recent advancement in concrete technology. The benefits of GFRC are its high compressive strength, flexural strength, and light weight. To improve long-term durability, glass fiber reinforced concrete that is resistant to alkali is also being developed. A review of the advantages that are currently available and being used by its customers is provided, along with a description of the wide variety of current GRC applications.

Key Words: Glass fiber, compressive strength, flexural strength, alkali resistant.

1.INTRODUCTION

Cement concrete's brittle failure qualities, which restrict its application, can be addressed by adding a small amount of short, randomly distributed fibers, such as steel, glass, synthetic, and natural fibers. When concrete has flaws such high shrinkage cracking, low durability, etc., this type of concrete can be employed.

Concrete's shortcomings include brittleness, high porosity, low post-cracking capacity, poor tensile strength, and susceptibility to chemical and environmental harm.

The new materials go beyond the previously described drawbacks of ordinary concrete because of unique properties that make them particularly sensitive to any environment. Fiber Among these is reinforced concrete, a relatively new composite material strengthened with short, discontinuous fibers up to 35 mm in length that are uniformly distributed. Flexural strength, shear strength, fatigue resistance, impact resistance, and the removal of temperature and shrinkage cracks are just a few of the many engineering qualities that are enhanced by this.

Fibers up to 35 mm in length are used for premix and spray applications. Glass fiber exhibits high tensile strength (2-4 GPa), high elastic modulus (70-80 GPa), negligible creep at room temperature, and brittle stress-strain characteristics (2.5-4.8% elongation at break). Glass fibers are usually straight and spherical, with diameters ranging from 0.005 to 0.015 mm. With a bundle diameter of 1.3 mm, they can be packed together.

2. BASIC CONSTITUENT MATERIALS

2.1 Binders

A hydraulic cement's suitability for creating GRC matrices depends on how well it works with the type of glass fiber that is used as reinforcement. Over the course of their usable lifespan, all common types of Portland cement produce matrices that are continually extremely alkaline. Such matrices are only used in alkali-resistant (AR) glass fibers. White Portland cement is used when more intense coloring of GRC surfaces is required. GRC matrices constructed of portland cement can have their alkalinity reduced by pozzolanic additions such as metakaolin, ground granulated blast furnace slag (GGBS), pulverized fly ash (pfa), and microsilica (silica fume). These additives reduce alkalinity and change the microstructure and properties of the hardened matrix, but they do not replace the essential alkaline binders.

2.2 Aggregates

Over time, the aggregate content of a typical mix has increased to a cement: aggregate ratio of 1:1 or greater. Spherical particles are the ideal shape, and the maximum size of the particles is normally limited to 1.2 mm (spray-up method) and 2.4 mm (premix procedure). Only 10% of the sample's weight can be made up of very minute particles, or those that can fit through a 150 µm sieve. It is usual practice to use silica sands with a SiO_2 content greater than 96%. The moisture content of the aggregate must be controlled. The majority of mix designs take into consideration the free water in the aggregate and are based on a moisture content of less than 2%.

2.3 Fibres

The tensile strength of glass in the form of incredibly thin individual fibers or filaments (dia. < 20 µm) is significantly higher than that of glass in bulk (> 3GPa). It relies on the glass fibers preserving their perfect, untouched surfaces with few, if any, imperfections. Maintaining the fibers as intact as possible during the GRC production process is the aim of both the fiber and the composite. A coating of a "size" usually tens of nanometers (10-9 m) thick is immediately applied to the newly extracted filaments for protection and to keep the fibers in a bundle. It is important to keep in mind that the overall weight (mass) of the composite is usually used to describe the percentage of glass fibers in GRC.

3. LITERATURE REVIEW

An experimental investigation into the behavior of steel and glass fiber reinforced concrete composites was carried out by **Kavita Kene et al.** Alkali-resistant glass fibers with 0% and 25% by weight of cement of 12 mm cut length and steel fibers with 0% and 0.5% volume fraction were used in the study to compare the results of fiber-reinforced concrete.

The behavior of concrete beams reinforced using glass fiber reinforced polymer flats was examined by **G. Jyothi Kumari et al.** They found that silica-coated glass fiber reinforced polymer (GFRP) flats shear reinforcement failed at higher loads. The fiber orientation and fiber to matrix ratio determine the strength of the composites, flats, or bars; the higher the fiber content, the higher the tensile strength.

Durability tests on glass fiber reinforced concrete were carried out by **Dr. P. Srinivasa Rao** and colleagues. The workability and resistance of concrete to acids, sulfates, and fast chloride permeability tests of M30, M40 were determined using alkali-resistant glass fibers, as well as regular concrete and glass fiber reinforced concrete of M50 grade. Alkali-resistant glass fibers were added to the concrete to boost its durability. According to the experimental investigation, adding glass fibers to concrete reduces bleeding. Concrete's ability to withstand acid attacks has improved since glass fibers were added.

The effectiveness of glass fiber reinforced plastic bars as reinforcing materials for concrete constructions was investigated by **S. H. Alsayed et al.** According to the study, the ultimate design theory can be used to precisely estimate the flexural capacity of concrete beams reinforced with GFRP bars. Additionally, the study found that because GFRP bars have low Long and intermediate beams reinforced with FDRP bars may be designed according to deflection criteria and modulus of elasticity.

Glass fiber reinforced concrete's performance was investigated by **Yogesh Murthy** et al. The study found that adding glass fiber to concrete not only enhances its qualities and reduces costs slightly, but it also offers a convenient disposal method, the glass as industrial waste for the environment. The results of the investigation showed that the flexural strength of the beam with 1.5% glass fiber increased by nearly 30%. Slump was shown to decrease as the amount of glass fiber increased.

Glass fiber reinforced concrete's strength was investigated by Avinash Gornale et al. According to the study, the M20, M30, and M40 grades of concrete showed increases in compressive strength, flexural strength, and split tensile strength at 3, 7, and 28. When compared to plain concrete, the number of days following the inclusion of glass fibers was 20% to 30%, 25% to 30%, and 25% to 30%, respectively.

4. PRODUCTION METHODS

4.1 Batching and mixing

Each of the matrix's fundamental components is grouped according to weight. Admixtures and additives are added precisely in tiny amounts using specialized dispensers. The accuracy of the weighing apparatus must be within ± 2% of the specified target batch weight. When the spray-up manufacturing method is employed, the quantity of glass fibers and their rate of feeding into the chopping mechanism typically regulate the input of glass fibers. A fiber output rate monitor continuously checks performance, or the machine must undergo routine testing to ensure that its delivery rates and fiber-to-slurry ratio are accurate.

4.2 Production of GRC elements

Production is important since it determines the internal structure of the composite. The degree of compaction of the new mix affects how it will behave once it hardens because GRC is a porous material by nature. A common production method that produces compaction when the mix hits the mold is spraying. However, it is common practice to apply a second compaction, usually by hand using handheld rollers. Intricate form components require special attention to the corners. In order to compact the premix GRC, the mixture is frequently trowelled or hand-packed into a freshly filled mold, which is then vibrated externally. Compaction is not necessary when a very workable, flowing self-compacting mix is used.

4.3 Production of GRC elements

It is critical to realize that the orientation of the fibers is influenced by the type of production procedure. Consequently, it establishes the level of anisotropy in the toughened GRC that is generated. The majority of the fibers are typically sprayed in a two-dimensional random pattern that is "in-plane" with the manufactured sheet or panel and parallel to the flat mold surface. The fibers' length typically greatly surpasses the GRC elements' thickness, and a random 2-D dispersion of fibers is produced as opposed to a 3-D one. By increasing the flexural strength of hardened flat, sheet-like GRC, such a distribution can be beneficial. When utilized improperly, twin-head spray guns, which were used in earlier production methods, might result in an uneven distribution of fibers "in-plane" of the sheet, which would cause an uneven 2-D distribution.

Compressed air is used to propel a freshly prepared cement/sand slurry out of the concentric spray gun's nozzle after it has been combined with chopped fiber strands. The fibers are chopped to a predetermined length, often 25–37 mm. The rate at which the fibers are chopped and pumped of the cement:sand slurry are regulated and usually set to generate GRC with 4.0–5.0% fibers by weight of the entire mixture. Using a specifically designed spray gun, the fresh premix-GRC can also be sprayed in a procedure called sprayed premix. The process works especially well for producing a lot of standard products.

4.4 Curing

GRC is mostly utilized to create parts with thin cross-sections and contains a high cement concentration. Compared to regular concrete, the curing regime for GRC requires far more precise control. In addition to minimizing early drying shrinkage and any associated distortion, it must guarantee that

the composite reaches a sufficient strength by the time it is to be handled and removed from molds or formwork.
GRC elements were cured early in the manufacturing process by being enclosed in polythene sheets or maintained in heated fog chambers. Modern production techniques get around it by altering the mix design.

4.5 Moulds and formwork
Because of GRC's exceptional ability to create products with complex geometries, extremely high-quality molds and formwork are required. Compared with conventional concrete technology, GRC has stricter performance requirements for molds and formwork. The mass of the material and the formwork are reduced.

Larger, more complex, and more often reusable molds with lower pressures are made possible by GRC. However, more accuracy and tighter dimensional tolerances are required. The design of the molds must suitably account for the anticipated volume fluctuations of the GRC element (shrinkage or temperature changes).

4.6 Surface finishes and treatments
The GRC product's first surface finish is a reflection of the mold's surface. It is crucial that the molds' surfaces be free of flaws and obvious joints. To create an even wider variety of finishes, the GRC's original surface can be treated later.

There is a vast range of textured and patterned surfaces, with or without pigments, as well as extremely smooth, glossy, and flat, matte surface finishes. Depending on the mold surface, GRC can have either a smooth or textured ex-mold finish. Texturing reduces the visibility of small flaws. A fine aggregate finish that is revealed, either with or without a texture.

4.7 Handling, transport, storage and repairs
If handled, transported, and stored improperly, thin-walled GRC panels—especially extremely large panels—are susceptible to irreversible damage. The structural design of a GRC panel should take into account how it is handled, particularly the impact of an asymmetrical lift. It is important to use lifting only.

For handling huge panels, specific lifting frames and design elements are employed. GRC elements can only be lifted using embedded fixes if they were made specifically for this use. During transportation, care must be made to limit vibration and control their movement. If the units are stacked, all of the points of support need to be in the proper positions and vertically aligned.

5. BASIC PROPERTIES

5.1. Mix design and fresh GRC
The following constituent materials are among the many factors that affect the properties of both fresh and hardened GRC:
► filaments (size/diameter, strength, modulus of elasticity, surface treatment)
► strands (number of filaments, form, length)
► matrix (type of cement, w/c, cement content, additives, and admixtures)

Additional factors are taken into account in the mix design, including:
► production process, which includes mixing, compaction, curing, distribution, and orientation of fibers/strands
► product application, which establishes the expected exposure and service environment (temperature and humidity levels and variations, including freeze/thaw cycles), chemical and biological attack, and chemical and physical fiber-matrix interactions
► development / changes in fiber-matrix interaction over the course of service life and conditions for a particular GRC mix design.

5.2 Assessment of performance
It is necessary to comprehend that there are many different elements that affect GRC properties, and that these factors are highly and variedly interrelated. The value of one or more additional factors typically determines the magnitude of the effect of a single factor on a particular attribute. Additionally, these multifactorial interactions are frequently non-linear and vary in their level of significance. Dependable,

Therefore, it is impossible to make broad generalizations from an experiment or test series if only two factors or variables are correlated without taking into account any of the others.

Table 1. Mix proportions of Sprayed Grades 18 & 18P [3]

Sprayed GRC Grade	Grade 18	Grade 18P
Aggregate/cement ratio	0.5 -1.5	0.5 -1.5
Water/cement ratio	0.30 - 0.38	0.30 - 0.38
Glassfibre content (% by weight of total mix)	4.0 - 5.5%	4.0 - 5.5%
Polymer solids content (% by weight of cement)	Nil	4 -7%

As a cement-based matrix ages, its characteristics change. Since it is not feasible to evaluate the impact of age directly, accelerated ageing tests are employed instead. In more aggressive warm/hot solutions that mimic pore solutions in a particular GRC, the lengthy natural exposure is swapped off for a shorter one.

matrix substance. Tests for accelerated aging are helpful for comparison, but performance in actual service life may rely on other elements like the history and consequences of applied pressures and any micro or macrocracking that is already present in the composite.

5.3. Mechanical properties
Typical values at the age of 28 days for current GRC are shown in Table 2

Table 2. Range of properties of a typical hardened premix or sprayed (italics) GRC [17]

Dry density (kg/m3)	Ultimate strength (MPa) at 28days in bending (MOR)	uniaxial tension	transverse tension
1900-2100 ; *1800-2000*	5-14 ; *18-30*	3-6 ; *8-12*	7-11 ; *5-8*
Modulus of Elasticity GPa 10-20 (both)	Tensile strain at MOR % 0.1- *0.8*		Impact resistance kJ/m2 7-12 ; *15-25*
Thermal movement 10-20 x10 -6 per 1 °C (both)	Drying shrinkage strain 300-1200 x10 -6 (both)		Poisson's ratio 0.24-0.25 (both)

5.4 Physical properties

5.4.1. Density
Hardened GRC's density (bulk density in kg/m3) indicates the matrix's density, which is determined by the aggregate's density and composition as well as the fresh composite's level of compaction. The density of the hardened GRC is also affected by its free water content and any trapped or entrained air. For accurate comparisons and density evaluation, the composite specimens should be oven-dried or have the same moisture content. A normal GRC has a density of 1800 kg/m3 when dry and 2000 kg/m3 when wet.

5.4.2. Permeability, water absorption and apparent porosity.
Because of its naturally low water permeability, a well-compacted GRC is regarded as waterproof and can be used in water-retaining constructions. Measured on freshly manufactured GRC samples that are 8 mm thick, the water permeability ranges from 0.02 to 0.4 ml/m2/min. Both the premix and sprayed GRC exhibit comparable levels of water absorption (5–11%) and perceived porosity (16–25%). The absorption is measured using standardized procedures, such as the iGRCA test technique or EN 1170 Pt. 6.

5.4.3. Acoustic properties
Because of its high density, a typical GRC has a good capability for noise attenuation. However, the geometry and fastening technique of the element significantly affect the acoustic performance, in addition to GRC's inherent ability to attenuate noise. When exposed to a sound pressure of 0.2 kPa, a 10 mm thick GRC sheet with a density of 2000 kg/m3 will yield a Sound Transmission Class of 5.4.4.

5.4.4. Thermal properties
A coefficient representing "unit strain" for a one-degree temperature change characterizes thermal expansion and contraction; for a typical GRC, this range is roughly 10-20 x10 -6 / o C. At both high and low relative humidity, the expansion/contraction values are at their lowest. The highest value is found between 50 and 80% RH.

The density and moisture content of the GRC determine its thermal conductivity and resistance.

►A typical GRC with a density of 1900–2100 kg/m3 has a thermal conductivity ˊ of 0.5–1.0 W/m o C. It is a property of the substance.

► The material's thickness (t) and thermal conductivity () determine its thermal resistance (R), which is equal to t / ˙.
► A building element's insulating capacity U is the inverse of its resistance R plus the heat losses from radiation and convection. Therefore, in addition to the material's thermal resistance, the value of U is dependent on external elements that reflect the building element's ambient condition.

5.4.5. Hydraulic and abrasion resistance
GRC's smooth mold-side surfaces make it suitable for parts used in a variety of hydraulic designs. The Manning formula uses the Manning roughness coefficient, which is around 0.012, to calculate a hydraulic flow in an open channel. There are no specific rules pertaining to GRC's resistance to abrasion. In circumstances when the abrasion resistance is significant (abrasion resistant aggregate is used), a process similar to that for abrasion resistant concrete may be used, even though there is much less room to modify the GRC matrix to make it more abrasion resistant (lower aggregate concentration).

6. SUMMARY OF BENEFITS

6.1. Economy through a combination of low weight and high strength.
When GRC is employed and foundation demands are decreased, the self-weight of structures lowers. Even extremely tall buildings can benefit from GRC cladding, which performs well under seismic loads.

6.2. Freedom of shape.
GRC may be readily molded into a variety of shapes, such as complex grilles, double-curved panels, and three-dimensional objects. The creation of structurally highly efficient elements is made possible by the high degree of shape freedom. It is simple to cast, and it can replicate intricate details and features of both contemporary and old structures.

6.3. Durability.
Unlike conventional reinforced concrete, GRC products are resistant to corrosion and the basic reinforcement is non-ferrous. Steel in nearby reinforced concrete is protected from corrosion by low permeability and a very slow rate of carbonation. GRC is naturally resistant to harsh environmental factors (fire, freeze/thaw, etc.).

6.4. Appearance.
There is a vast array of appealing surface treatments that can match the color and texture of the surfaces of existing buildings while meeting the strictest specifications for the aesthetic look of new construction. A range of textures and shapes can be used to create long-lasting, vibrantly colored surfaces with improved self-cleaning.

6.5. Environment.
GRC products' comparatively light weight lowers transportation-related CO2 emissions. Neither during production nor during usage does the material itself produce any volatile organic compounds (VOCs) or other contaminants.
GRC can be completely recycled into concrete and other materials. Additionally, with a negligible additional cost, the photocatalytic e GRC directly and considerably lowers the concentration of pollutants in the surrounding air, improving the quality of the environment, particularly in crowded urban centers.

7. CONCLUSIONS

Despite the high initial cost, fiber reinforced concrete's superior qualities result in a significant reduction in overall costs. The compressive, flexural, and split tensile strengths of the glass fiber reinforced concrete increased by nearly 20% to 25% in contrast to the plain concrete's 28-day compressive strength. AR glass fibers were used to increase the durability of concrete against acid attacks, and the results were positive. Therefore, dams, hydraulic structures, and blast-resistant constructions can all be made using GFRC.

Although there has been a significant amount of research and publications on concrete reinforced with metallic and other fibers, resulting in a disproportionately small number of practical applications, GRC is already a well-established building material in the GRC instance. Although GRC is widely utilized in practice, there is a dearth of research and publications to back it up. There is a compelling argument for expanding our understanding of GRC's capabilities and for the necessary research to enhance its qualities.

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