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High volume fly ash-based glass fibre reinforced concrete

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ABSTRACT

My dissertation work has been divided into 8 chapters, Chapter 1: Introduction: In this chapter, a general introduction of my dissertation work has been given. The materials used in my projects such as coarse aggregate, fine aggregate, glass fibre, fly ash and other constituents of fly ash-based glass fibre reinforced concrete have been focused. The properties of the construction materials have also been stated in brief along with advantage and disadvantage of glass fibre concrete. Chapter 2: Objectives and Aims: In India, all old glass materials are considered as waste materials. It is disposed to the disposal ground just like other waste materials. The old glass materials can be recycled in factories. These recycled glass materials become an important ingredient for making GFRC. The primary aim of using glass fibre is to examine the strength of concrete made with glass fibre in comparison to plain concrete. The secondary aim is to examine the economy of GFRC for which an economic analysis provided in Chapter 7. Chapter 3: Literature Review: This chapter contains relevant information in regard to glass fiber reinforced based concrete. For this, I had to go for different websites to get knowledge of the above subject and put my opinions. All references which required to complete my dissertation work has been given in a separate page stating references as mentioned in the content of my thesis. Chapter 4: Desired characteristics for Glass Fibre Reinforced Concrete (GFRC): The characteristics of glass fibre have considerable influence on the design, efficiency, output and particularly the reliability and durability of the glass fiber-based concrete. The glass fibre characteristics play a vital role in the atmospheric pollution of concrete industries. Chapter 5: Methods and materials: In this chapter, the description of all the materials with the specifications which I used for my experiments have been elaborated. The apparatus and the instruments which were used for performing my experiment have also been mentioned. Chapter 6: Results and discussions: In this chapter, all the test results for all kind of specimen have been stated. The efficacy of the test results has also been discussed. Particulars in regards to design mix, especially its calculation have been annexed in Appendix – A and B after chapter 5 – Materials and Methods. Chapter 7: Economic analysis of Glass fibre reinforced concrete: Glass fibre reinforced concrete is considered to be a very useful item needed for the present concrete industries. The comparative cost of GFRC and conventional concrete has been stated in this chapter. It was found that the percentage of saving per cubic meter of fly ash-based glass fiber reinforced concrete is to the tune of 3% compared to conventional concrete. Chapter 8: Conclusion: The salient points of my dissertation thesis have been given in this chapter. It was highlighted in chapter 8 (Conclusion) that the service life of GFRC is higher than that of traditional concrete due to reasons indicated in the chapter. That's why GFRC is widely used in architecture, building, other concerned engineering applications.

Keywords*— Glass fibre reinforced concrete, GRC, Construction*

1. INTRODUCTION

1.1 Glass Fibre Reinforced Concrete

Glass Fibre Reinforced Concrete (GFRC) is a cementations composite product reinforced with discrete glass fibres of varying length and size. The glass fibre used is alkaline resistant as glass fibre is susceptible to alkali which decreases the durability of GFRC. Glass strands are utilized for the most part for outside claddings, veneer plates and different components where their reinforcing impacts are required during construction. GFRC is stiff in the fresh state has a lower slump and hence less workable, therefore water reducing admixtures are used. Further, the properties of GFRC depend on various parameters like the method of producing the product. It can be done by various methods like spraying, casting, extrusion techniques etc. Cement type is also found to have a considerable effect on the GFRC. The length of the fibre, sand/filler type, cement ratio methods and duration of curing also affect the properties of GFRC.

1.2 Applications

The main area of FRC applications are: [5]

- Runway, Aircraft parking, and Pavements
- Tunnel Lining and Slope Stabilization

- Blast Resistant Structures
- Thin Shell, Walls, Pipes, and Manholes
- Dams and Hydraulic Structure
- GFRC is also used for machine tool frames, lighting poles, and water and oil tanks and also for concrete repairs.

1.3 Advantages and Disadvantages of using Glass Fibres in Concrete

1.3.1 Advantages

- It is a great material for the restoration of the old building and is used for the exterior of the buildings. It is also being used extensively for walls and ceilings. Landscape artists have come on board and discovered the versatility of GFRC.
- GFRC is lightweight and is about 75% lighter than traditional concrete. The lighter weight of GFRC brings economy to compare to conventional concrete while it is used in RCC multi-storey frame structures with the advantage of reducing the sections of slabs, beams and columns including the sub-structures viz. foundations.
- The flexural strength gives it a high strength to weight ratio.
- The reinforcement for this concrete is internal and does not need additional reinforcements.
- Heavy duty or expensive equipment is not necessary when pouring or spraying GFRC.
- It is easy to cut and is very difficult to crack.
- GFRC is very adaptable in that it can be poured or sprayed.
- When sprayed, the surface finish has no pits or bug-holes. If it is poured, it is easily shimmied to remove all pits and bug-holes prior to hardening.
- The wires used as one of the constituents of fibre reinforce concrete help the concreting of superstructures such as walls and ceiling and substructures such as foundations to adhere concrete better than the conventional concrete and have a stronger and durable finish.

1.3.2 Disadvantages

- There is no ductility. Ductility is a solid material's ability to deform under stress.
- The cost of GFRC is higher than traditional concrete. Due to the fibreglass being inside the concrete and the addition of additives and acrylic copolymer the price is steeper.
- GFRC is difficult to self-mix. Generally, a contractor will mix and pour or spray this type of concrete.
- While the mix can be pretty versatile it can fall apart if not properly applied or poured. [6]

2. OBJECTIVES

In India all old glass materials are considered as waste materials. It is disposed to the disposal ground just like other waste materials. But if the old glass materials are recycled, two objectives can be met with.

- Residual waste can be reduced and easily disposed of.
- The old glass materials which are thrown as waste can be recycled in factories and can be transformed into small discrete glass fibre specimen as shown below. These are used in GFRC. Recycling glass materials are in practice in western countries but in India, the practice of recycling glass materials is still restricted. Recycle glass materials are an important ingredient for making GFRC. So, in India, its use has not been widened as other western countries. However, an attempt is being made to use GFRC in Indian cities for architecturally finished materials.

Fig. 1: Glass Fibre (Length 36 mm –as per IRC 15 – 2011)

2.1 Purpose

- Study the mix design aspects of the GRC.
- Understand the various applications involving GRC.
- Compare GRC with alternatives such as stone, aluminium, wood, glass, steel, marble, and granite.
- Perform laboratory tests that are related to compressive, tensile, and flexure by the use of glass fibre in the concrete pour.
- 2.3 Concept of GFRC: Glass fibre reinforced concrete or GFRC is categorised as one type of fibre-reinforced concrete [Steel fibre is one]. The product "Glass fibre reinforced concrete" is called GRC in British English.

2.2 Uses

Glass fibre concrete products are mainly used in exterior building façade panels and as architectural precast concrete. As per the United States Green Building Councils, (USGBC) definition of Green construction materials are those materials composed of renewable, recyclable or reusable resources which can be used indefinitely without negatively impacting on the environment. If we strictly keep to this wording, GRC may not be that green. The main problem is the high content of cement. Unfortunately, it has never been easy to profile cement as a green material as it is energy intensive and has high carbon dioxide emissions, and cement kilns are a source of mercury emissions. Cement production accounts for over 5% of the world's carbon emissions although a proportion is ultimately reabsorbed by the cement over time (that is. by the process of carbonation which is beneficial to GRC).

The reality is that most building materials consume lots of natural resources and we cannot simply stop using them as they are part of our lives. However, we can improve the greenness of GRC by careful selection of raw materials, proper design and more advanced production technologies etc. Furthermore, to justify whether a building material is green we need to compare it with its counterparts since none of them can claim to be 100% green. [7]

2.3 Aim

My primary aim would be to examine the strength of the concrete made with glass fibre in comparison to plain concrete. My secondary aim is also to examine the economy of uses of GFRC, for which I have made an economic analysis as enumerated in Chapter 7. For that purpose, I prepared cubes of size 150mm×150mm×150mm and Glass fibre reinforced concrete beams of sizes 100mm×100mm×500mm &150mm×150mm×700mm in the concrete laboratory situated in the basement of Techno India College, Salt Lake Campus. I will examine to what extent this concrete is cost effective.

3. REVIEW OF LITERATURE

This literature review deals with the experimental work carried out by different researchers in developing low-cost concrete. It is divided into 2 subsections:

(a) Materials
- Fly ash
- Glass Fibre (Length 36 mm –as per IRC 15 – 2011)

(b) Applications
- Rigid Pavement: Rural road/National Highway

The detailed review study for fly ash and glass fibre is carried out chronologically [year wise] so as to examine the design methodologies and outcome of different researchers. [8]

3.1 Fly ash

Giaccio GM et.al (1988) concluded that high-volume fly ash concrete had excellent mechanical properties and satisfactory resistance to repeated cycles of freezing and thawing. The use of ASTM Type in cement appeared to be essential when high strengths at early ages were required. For concretes made with ASTM Type I cement, the use of beneficiated fly ash and condensed silica fume, did little to enhance the properties of concrete compared with "as received" fly ash. For concrete made with ASTM Type II cement, the benefits of using beneficiated Class F fly ash and condensed silica fume were not clear.

Antonio Eduardo et al (2013) In Brazil, only 6.4% of electricity comes from power plants and only 1.6% of this amount use coal as fuel. Coal ash tested is lighter and finer than cement and seems to to be pozzolans. However, when tested in concrete mixtures replacing cement, results do not were well once air entrainment increased and compressive and tensile strength almost does not change. Best results were obtained for water absorption by capillarity and for water rise once for 0.55 w/c ratio concretes decreases up to 37% were observed.

Magudeaswaran P et.al (2013) observed that for the increase in the percentage of fly ash and silica fume there was a steady increase in the water absorption and alkalinity which significantly indicates the markable change in strength and durability characteristics of concrete. An acceptable strength and durability characteristics could be achieved by using fly ash and silica fume. The use of fly ash and silica fume which were to cause environmental pollution when dumped as waste could be reused for strengthening the concrete gave a double fold advantage.

3.2 Glass fibre (Length 36 mm – as per IRC 15-2011)

Hau-yan Leung et al (2003) studied the effects polypropylene fibres on workability. And the effects of Quality Assured Processed Fly Ash also known as Pulverised Fuel Ash (PFA) and Silica Fume (SF) on the properties of polypropylene Fibre Reinforced Concrete (FRC) in the fresh state were investigated experimentally under the same conditions. According to the experimental investigation, the Vebe time test is a more appropriate method than tire slump test to measure the low workability of FRC and the workability of FRC with pozzolana. 10 % substitution of cement with PF A in the fibre concrete mixes generally had positive effects on the workability of the fresh mix as represented by the Vebe time test.

Jagannadha Rao K et al (2009) aimed to determine the suitability of glass fibres for use in structural RAC of high strength. The fresh and hardened state properties of partially replaced recycled aggregate concrete, with varying percentages of glass fibres, were compared with the corresponding conventional aggregate concrete. The compressive, split tensile and flexural strengths of M50 grade concrete with 0% RCA and 50% RCA increased as the fibre content increased. The maximum values of all these strengths were obtained at 0.03% of fibre content for both the concrete of 0% RCA and 50% RCA. Large deflections of beams before failure indicated improved ductility with the addition of fibres.

Liaqat A. Qureshi et al (2013) in this paper, the effect of using glass fibres on strength properties of concrete has been discussed. Different GFRC mixes were cast using different percentages of glass fibres by weight of cement at constant mix and water-cement ratios. The results show that the workability of GFRC decreases by increasing glass fibre content. It was also observed that long term compressive strength of GFRC was marginally improved. However significant improvement in tensile and flexural strength of GFRC at 1.5% glass fibre content was observed as compared to ordinary concrete.

3.3 Rigid Pavement: Rural Road/National Highway

Narasimha V.L et al (2004) Lime addition did not influence the compressive strength of fly ash in concrete, but gypsum addition improved the compressive strength. The optimum gypsum dose was 6-12% of the total binder content. Fly ash concrete with added gypsum had the potential for use as the base or sub-base course material in road pavements.

Kumar P. et al (2008) As per IRC-SP: 20--2002 the sub-base material should have minimum soaked CBR of 15 per cent in case of rural roads. Fly ash with 0.2 per cent fibre content has CBR value 19.5 per cent. Therefore, fly ash with 0.2 per cent fibre content is suitable for rural road sub-bases. After mixing 25 per cent soil with fly ash 0.1 per cent fibre content is sufficient. In the case of Geosynthetics reinforced fly ash all Geosynthetics used in his investigation are suitable for rural road sub-bases. For rural roads with higher traffic IRC: 37-2001 is to be followed which states the CBR requirement of 20 per cent and 30 per cent, depending upon the traffic. Fibre reinforcement of 0.3 per cent and 0.4 per cent will make the fly ash suitable for these conditions.

S L Patil et al (2013) concluded that Deep Nagar flies ash could be successfully used in the cement concrete road pavements. Though it lowers the rate of hydration as well as final strength, it makes the section economical. Hence it is a safe and environmentally consistent method of disposal of fly ash.

3.4 Minimizing the environmental impact of fly ash usage in road construction

(a) While using fly ash for road construction, potential impacts to ground water and soil must be considered and studied.
(b) While determining the possible degree of leaching, it is necessary to have an understanding of the hydrological conditions and the permeability of materials and soil.
(c) The pavement structure and its designed thickness is an important parameter when evaluating the harmful effects of fly ash on the environment.
(d) We should take care when using or disposing of any construction material in a hydro-geologically vulnerable area.
(e) We should follow proper engineering requirements when using encapsulated fly ash.
(f) Dust control and erosion prevention measures are essential during the construction phase.
(g) The scientific proportion of fly ash in the construction materials should be practised.
(h) The amount of leachate produced should be controlled by assuring adequate compaction, grading to promote surface runoff, and daily proof-rolling of the finished subgrade to impede infiltration.
(i) When construction is finished, a properly seeded soil cover will reduce infiltration. For highway embankments, the pavement may be an effective barrier to infiltration.
(j) Occupational issues include the handling of dry ash prior to or during its inclusion in a concrete mix or exposures during the demolition of concrete structures. In such cases, work inhalation and skin contact precautions should be observed.

4. WHAT IS FLY ASH?

Fly ash is the residue that is left from burning coal, and this is formed when the gaseous releases of the coal are efficiently cooled. It is somewhat like a glass powder that is fine in nature. However, the chemical constituents of this residue might vary from one other. Fly ash has several industrial applications and is widely found in power plant chimneys. The material is also used as substitute cement by mixing it with lime and water. The material is embedded with myriad beneficial features and so is being utilized as a significant building material for the construction purposes. This type of concrete is much dense and smooth. Below listed are few of the advantages and disadvantages of fly ash concrete.

Fig. 2: Fly ash vs. Cement

Fly ash is used in many countries because of its advantages. There are also some disadvantages of using fly ash in concrete. These pros and cons are described in brief below.

4.1 The advantages of using fly ash in concrete includes the followings

(a) Fly ash in the concrete mix efficiently replaces Portland cement that in turn can aid in making big savings in concrete material prices.
(b) It is also an environmentally-friendly solution, which meets the performance specifications. It can also contribute to LEED points.
(c) It improves the strength over time and thus, it offers greater strength to the building.
(d) Increased density and also the long-term strengthening action of flash that ties up with free lime and thus, results in lower bleed channels and also decreases the permeability.
(e) The reduced permeability of concrete by using fly ash also aids to keep aggressive composites on the surface where the damaging action is reduced. It is also highly resistant to attack by mild acid, water and sulfate.
(f) It effectively combines with alkalis from cement, which thereby prevents the destructive expansion.

(g) It is also helpful in reducing the heat of hydration. The pozzolanic reaction in between lime and fly ash will significantly generate less heat and thus, prevents thermal cracking.
(h) It chemically and effectively binds salts and free lime, which can create efflorescence. The lower permeability of fly ash concrete can efficiently reduce the effects of efflorescence. [9]

4.2 The disadvantages of using fly ash in concrete

There are also some disadvantages of using fly ash that should be considered.
(a) The quality of fly ash to be utilized is very vital. Poor quality often has a negative impact on the concrete.
(b) The poor quality can increase the permeability and thus damaging the building.
(c) Some fly ash, those are produced in power plant is usually compatible with concrete, while some other needs to be beneficiated, and few other types cannot actually be improved for use in concrete. Thus, it is very much vital to use only high-quality fly ash to prevent negative effects on the structure of the building.

The aforesaid is a few advantages and disadvantages of fly ash concrete. This type of concrete offers many advantages and as mentioned above it also has some disadvantages. There are various other advantages of utilizing fly ash concrete such as it is much easier to place with reduced effort and it is also able to have improved finishing to the structure with such type of concrete. Fly ash concrete can certainly add greater strength to the building. [9]

5. DESIRED CHARACTERISTICS FOR FLY ASH-BASED GLASS FIBRE REINFORCED CONCRETE (GFRC)

5.1 Structural Properties of GFRC

The properties of fibre reinforced cementitious materials are dependent on the structure of the composite. Therefore, in order to analyse these composites, and to predict their performance in various loading conditions, their internal structure must be characterized. The three components to be considered are:

- **The structure of the bulk cementitious matrix:** The bulk cementitious matrix can be divided into two types depending on the particulate filler (aggregate) which it contains: paste/mortar (cement/sand–water mix) and concrete (cement–sand– coarse aggregate–water mix). Glass fibre reinforced concrete pastes or mortars are usually applied in thin sheet which is employed mainly for cladding. In these applications, the fibres act as the primary reinforcement and their content is usually in the range of 5–15 % by volume. Special production methods need to be applied for manufacturing such composites.
- **The shape and distribution of the fibres:** There are generally two distinctly different types of fibre–reinforcing arrays: continuous reinforcement in the form of long fibres which are incorporated in the matrix by techniques such as filament winding or by the lay–up of layers of fibre mats; and discrete short fibres, usually less than 36 mm long, which are incorporated in the matrix by methods such as spraying and mixing. The reinforcing array can be further classified according to the dispersion of the fibres in the matrix, as random 2D or 3D.
- The first is random, three–dimensional (3D) reinforcing. This occurs when fibres are mixed into the concrete and the concrete is poured into forms. Because of the random and 3D orientation, very few of the fibres actually are able to resist tensile loads that develop in a specific direction. This level of fibre reinforcing is very inefficient, requiring very high loads of fibres. Typically, only about 15 % of the fibres are oriented correctly.
- The second level is random, two–dimensional (2D) reinforcing. This is what is in a spray–up GFRC. The fibres are oriented randomly within a thin plane. As the fibres are sprayed into the forms, they lay flat, conforming to the shape of the form. Typically, 30 to 50 % of the fibres are optimally oriented.
- **The structure of the fibre–matrix interface:** Cementitious composites are characterized by an interfacial transition zone in the vicinity of the reinforcing inclusion, in which the microstructure of the paste matrix is considerably different from that of the bulk paste, away from the interface. The nature and size of this transition zone depend on the type of fibre and the production technology; in some instances, it can change considerably with time. When considering the development of the microstructure in the transition zone, a bundled filament should be made and with bundled filaments, only the external filaments tend to have direct access to the matrix.

5.2 Properties of GFRC

Different parameters such as water–cement ratio, porosity, composite density, inter filler content, fibre content, orientation and length, and type of cure influence properties and behaviour of GFRC. GFRC derives its strength from an optimal dosage of fibres and acrylic polymer. The polymer and concrete matrix serves to bind the fibres together and transfer loads from one fibre to another via shear stresses through the matrix. Density and porosity are effective on the degree of compaction.

In concrete structure, the efficiency of fibres depends upon their orientation. When the fibres are aligned perpendicular to the crack openings in the direction of stress, the positive effect of fibres on the performance of GFRC is increased. Along with that because of requiring the improvement in the long–term performance of GFRC the type of glass fibres such as E and Alkali– Resistant (AR) glass fibres must also be considered as well as the environmental conditions. When alkali attack considered main deterioration mechanism in E glass, there should be made attention to seal the fibres completely from the matrix or used a very low alkali cementitious material. On the other hand, so as to improve the alkaline resistance and durability of GFRC with AR glass fibres, the main effort should be directed modifying the microstructure of the matrix in the vicinity of the glass filaments. This could be provided with controlling the hydration process in its vicinity or changing the composition of the matrix.

The rate of ageing is a function of the type of glass fibre. A new generation of AR–glass fibres are better than E glass ones. The ageing performance of the composite is also sensitive to the weathering conditions. As the ageing continues in different environments, a chemical attack may become significant so there is a need to develop special glass fibres for better alkali resistance.

5.3 Mechanical Properties of GFRC

Addition of fibres to concrete influences its mechanical properties which significantly depend on the type and percentage of fibre. Fibres with end anchorage and high aspect ratio were found to have improved effectiveness. It was shown that for the same length and diameter, crimped-end fibres can achieve the same properties as straight fibres using 40 per cent fewer fibres. In determining the mechanical properties of GFRC, the same equipment and procedure as used for conventional concrete can also be used. Below are cited some properties of FRC determined by different researchers.

- **Compressive Strength:** The compressive strength of concrete has been increased with the addition of fibres to concrete mixes, however further addition of fibre indicated a gradual decrease in strength aspects. The presence of fibres may alter the failure mode of cylinders, but the fibre effect will be minor on the improvement of compressive strength values (0 to 15 per cent).
- **Modulus of Elasticity:** In heterogeneous and multiphase materials such as concrete, the density and the characteristics of the transition zone determine the elastic modulus behaviour of the composite. The experimental test results exhibit that the use of fibres has no important influence on the modulus of elasticity of concrete. It was reported that mostly a little reduction in the modulus of elasticity of the concrete at a low glass fibre content. Modulus of elasticity of GFRC increases slightly with an increase in the fibres content. It was found that for each 1 per cent increase in fibre content by volume there is an increase of 3 per cent in the modulus of elasticity.
- **Stress-Strain Curve:** Stress-strain behaviour is affected by different parameters such as the effect of fibre lengths, aggregate type and effect of loading rate. GFRC has a significant impact on the ascending portion of the stress-strain curve and additionally, descending part of the stress-strain curve is an essential key element under compression loads.
- **Flexural Strength:** Glass fibres have an effect on the increase in the flexural strength of concrete. The fibres resist the propagation of cracks and tend to reduce the sudden failure of structure of concrete and so they lead to an increase in the load carrying capacity of concrete. The flexural strength was reported to be increased by 2.5 times using 4 percent fibres. The use of fibres in reinforced concrete flexure members increases ductility, tensile strength, moment capacity, and stiffness. The fibres improve crack control and preserve post cracking structural integrity of members.
- **Toughness:** For GFRC, toughness is about 10 to 40 times that of plain concrete.
- **Splitting Tensile Strength:** The presence of 3 percent fibre by volume was reported to increase the splitting tensile strength of mortar about 2.5 times that of the unreinforced one.
- **Fatigue Strength:** The addition of fibres increases the fatigue strength of about 90 percent and 70 percent of the static strength at 2 x 106 cycles for non-reverse and full reversal of loading, respectively.
- **Impact Resistance:** The impact strength for fibrous concrete is generally 5 to 10 times that of plain concrete depending on the volume of fibre used.

5.4 Physical Properties of GFRC

- **Drying shrinkage:** Drying shrinkage has a significant effect on the structural and durability performance of the concrete. The mechanism of shrinkage of cementitious material is complex, but total shrinkage is principally affected by the aggregate proportion and type, and water/cement ratio, having an influence on drying and causing many micro cracks propagation simultaneously. Shrinkage in concrete structures may also trigger forms of damage in concrete like as corrosion, freeze damage in this manner, seriously, shorten the service life of concretes. Alkali–resistant glass fibres are effective in controlling restrained shrinkage cracking of concrete and they promote multiple cracking and reduce crack widths.
- **Creep:** Because of its poor strain capacity and low tensile strength, concrete is a brittle material and highly susceptible to cracking. These cracks can decrease the lifetime of a structure by allowing aggressive agents. Therefore, the evolution of crack openings through time is important for the durability of concrete. In terms of creep and shrinkage, the application technique of GFRC must be taken into account. With pneumatic spraying, glass fibre added into mortar mixture at the time of pouring and there is a significant modification of the compositions embodied in binder consumption. This can affect creep strain.
- **Porosity, Chloride Penetration Resistance and Electrical Resistivity:** Concrete is a multiple–phased material, and it has lots of micro pores which can be transferred thanks to the migrating ions. Therefore, resistivity measurement is a determinative way to explore the microstructure of concrete. The resistivity of concrete is influenced by many factors such as water-cement ratio, concrete composition, admixtures, curing condition, and humidity. As a result, all of these impacts can trigger to increase the risk of steel rebar corrosion in the concrete. Along with this, chloride presence in the concrete structure can increase electrical current and the risk of corrosion. Alkali resistance GFRC depicts less permeability of chloride into concrete increasing corrosion resistance. Thus, durability which is one of the most important aspects of the concrete can be improved during working conditions of concrete structures.

The electrical resistivity of concrete is observed to decrease with the increase in water–cement ratio. Fibres can play strong positive result by holding the matrix together even if it is a completely dehydrated process which triggered the possibility of explosion. Addition of polymer materials to GFRC will affect the fire performance properties.
For laboratory experiment, I used HP 67/36 Anti-Crack® Alkali Resistant Glass fibre. The characteristics of HP 67/36 Anti-Crack® Glass fibres are mentioned below -

5.5 HP 67/36 Characteristics

5.5.1 Benefits:

(a) It is resistant to alkali
(b) It can control and prevention cracking in fresh and hard concrete and mortars
(c) Improve durability
(d) It improves the mechanical properties of hardened concrete
(e) It provides excellent workability

(f) It allows high dosages without affecting the workability
(g) It is virtually invisible on the finished surface
(h) It does not corrode
(i) Its mixing becomes homogeneous
(j) No additional water needed
(k) Safe and easy to handle [10]

5.5.2 Technical Characteristics:
(a) Fibre length: 36 mm - 1½'' inches (as per IRC: 15 – 2011)
(b) Aspect ratio (length / diameter): 67
(c) Specific Gravity: 2.68 g/cm^3
(d) Modulus of elasticity: 72GPa - 10x10^6 psi
(e) Moisture: 0.3% max (ISO 3344:1977)
(f) Material: Alkali Resistant Glass
(g) Softening point: 860°C - 1580°F
(h) Electrical Conductivity: Very low
(i) Chemical Resistance: Very high
(j) Tensile Strength: 1,700MPa - 250x10^3 psi **[10]**

5.5.3 Advantages of HP 67/36 Glass Fibre:
(a) Anti-Crack® HP 67/36 is a "High Performance" Alkali Resistant glass macro fibre, engineered to reinforce against plastic, thermal and drying shrinkage cracking. Anti-Crack® HP 67/36 increases flexural strength and ductility and adds toughness, impact and fatigue resistance to the concrete. Anti-Crack® HP 67/36 can be used as secondary reinforcement and in specific applications also as primary reinforcement.
(b) Anti-Crack® HP 67/36 disperses quickly and evenly throughout the concrete matrix because the specific gravity is similar to the aggregates used in concrete. This inherent characteristic of glass guarantees high fibre performance throughout the concrete mass.
(c) Anti-Crack® HP 67/36 has been specifically designed to replace secondary and primary reinforcement (welded wire reinforcement, light rebar, steel and synthetic fibres) in residential, commercial and industrial slabs-on-ground, compression layers, pavements and precast concrete. [10]

Fig. 3: Glass Fibre (Length = 36 mm), (as per IRC: 15 – 2011)

5.6 Fly Ash characteristics:
5.6.1 Specific Gravity of Fly Ash: The specific gravity of different fly ashes varies over a wide range. The specific gravity ranged from a low value of 1.90 for sub-bituminous ash to a high value of 2.96 for iron-rich bituminous ash. Some sub-bituminous ash had a comparatively low specific gravity of ≈ 2.0, and this shows that hollow particles, such as cenospheres or plerospheres, were present in significant proportions in the ashes. In general, the physical characteristics of fly ashes vary over a significant range, corresponding to their source. Fineness is probably influenced more by factors such as coal combustion and ash collection and classification than by the nature of the coal itself. Similarly, the type of fly ash showed no apparent influence on the specific surface as measured by the Blaine technique. Moreover, except in some cases, there was very little relationship between the specific surface as measured by the Blaine and the fineness as determined by percentage retained on a 45цm sieve.

5.6.2 Mineralogical Characteristic of Fly Ash: Type and source both influence on its mineralogical composition. Owing to the rapid cooling of burned coal in the power plant, fly ashes consist of non-crystalline particles (≤ 90%), or glass and a small amount of crystalline material. Depending on the system of burning, some unburned coal may be collected with ash particles. In addition to a substantial amount of glassy material, each fly ash may contain one or more of the four major crystalline phases: quartz, mullite, magnetite and hematite. In sub-bituminous fly ashes, the crystalline phases may include C_3A, C_4A_3S, calcium sulphate and alkali sulphates. The reactivity of fly ashes is related to the noncrystalline phase or glass. The reasons for the high reactivity of high-calcium fly ashes may partially lie in the chemical composition of the glass. The composition of glass in low-calcium fly ashes are different from that is in high-calcium fly ashes.

Table 1: Chemical compounds of Fly Ash

CHEMICAL COMPOUND	POZZOLAN TYPE			CEMENT
	CLASS F	CLASS C	CLASS N	
SiO	54.90	39.90	58.20	22.60
Al_2O_3	25.80	16.70	18.40	4.30
Fe_2O_3	6.90	5.80	9.30	2.40
CaO	8.70	24.30	3.30	64.40
MgO	1.80	4.60	3.90	2.10
SO_3	0.60	3.30	1.10	2.30
Na_2O & K_2O	0.60	1.30	1.10	0.60

5.6.3 Utilization of fly ash: Since my residential area is near Kolaghat thermal power station I have the opportunity to visit Kolaghat thermal power plant once. In Kolaghat thermal power station washed coals are burnt to produce electricity. It was noticed by me huge fly ashes are coming out from the chimney and falling in the ground surrounding the plant. A part of fly ash, however, goes to the atmosphere affecting the environment. Had the fly ash fall on the ground from the chimney it would have aggravated the surrounding environment and affect the biodiversity that is why ponds were built surrounding the plant and water store in it. The flying ash falls on the pond and deposited there. These pond fly ashes are then dried and transported in trucks to various cement and brick factories to manufacture fly ash-based cement and bricks. The benefits of fly ash are given as under:

(a) Minimizing the environmental impact of direct disposal,
(b) Minimizing disposal costs,
(c) Enabling other uses of the land since less area is reserved for fly ash disposal,
(d) Procuring financial returns from the sale of the by-product,
(e) Replacing scarce or expensive natural resources. In India, one of the major areas for fly ash utilization is in construction (cement production, brick manufacturing and road embankments). Typical highway engineering applications include fly ash for encapsulated purposes and unencapsulated purposes:

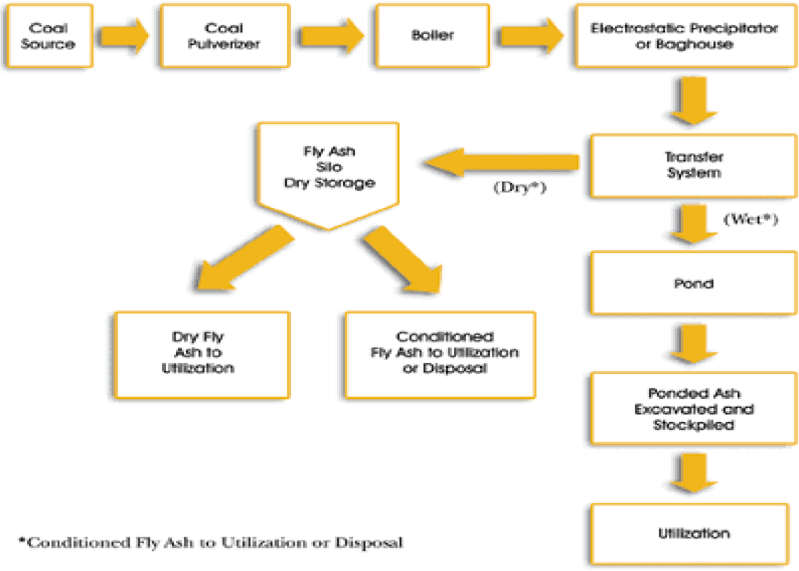


Fig. 4: Utilization of Fly ash

5.7 Reason for the inclination to fly ash-based glass fibre reinforced concrete

5.7.1 Glass Fibre (Length 36 mm – as per IRC: 15 – 2011): India is a developing nation until now. Indians consume glass products in their domestic and other commercial houses. So, the chance of disposing of the old glass materials after some time as waste cannot be denied with. It is apparent that if the waste glass materials can be recycled instead of throwing as waste, the recycled glass materials can be converted into glass fibres and conveniently used in GRC. The western countries usually recycle the old glass materials for using glass fibre in the GRC. In India, the practice of recycling old glass materials is still restricted. It is anticipated that the practice of glass fibre manufacture from recycled old glass materials will go in the same degree as of western countries in future.

5.7.2 Fly Ash: In India, the electricity is produced normally by burning coals in different plants –Kolaghat Thermal Power plant is one such. As time progresses attempt is being made to practice renewable energy for generating electricity from coal. Until now 12% of the production of electricity can be made with renewable energy fuel resources from solar, wind, hydro, bio mass etc. The rest 88% of electricity is still made by burning coal in India. Burning of coal emits smoke mixed with fly ash from the chimney. The smoke is disposed to the atmosphere along with some fly ash. But a huge amount of fly ash uses to fall within the boundary of the plant. The dry fly ash being aggressive to the environment are deposited in a nearby pond [built around the plant] to stop flying in the air which may deteriorate the atmosphere of the surrounding neighbourhood. These pond fly ashes are then transported to either cement factories or to other factories. These fly ashes are then utilized as a constituent of GFRC product.

6. MATERIALS AND METHODS FOR GFRC

6.1 Materials for GFRC

6.1.1 What is Concrete? Concrete: Concrete is the most widely used construction material. The basic materials of concrete are Portland cement, water, fine aggregates that is. sand and coarse aggregates. The cement and water form a paste that hardens and bonds the aggregates together. Concrete in the fresh state is plastic and can be easily moulded to any shape, as time passes it hardens and gains strength. The initial gain in strength is due to a chemical reaction between water and C_2S and latter gain in strength is due to the reaction between C_3S and water. Concrete is produced by either following nominal mix proportions in which the mix proportions are fixed as per grade of concrete required or mix design proportions. Mix design produces more economical concrete. In my work Portland Pozzolana Cement (PPC) -43-grade Ultratech cement was used. Standard consistency, initial setting time, final setting time, 28-day compressive strength tests were carried out as per the Indian standard specifications. Clean river sand passing through 4.75 mm sieve was used as fine aggregates. The specific gravity of sand was 2.74 and grading zone of sand was zone 1 as per IS Angular stones were used as coarse aggregates maximum size 20mm and specific gravity 2.74. Concrete was mixed and cured by clean water as stated in 5.1.4. For casting cubes, cylinders and beams the maximum size of aggregate used was 20mm. The water-cement ratio used for concrete cube and beam was 0.45 and admixture was used to attain the desired workability.

Fig. 5: Concrete laying procedure

6.1.2 Materials for Casting: The following materials were used in conducting my experiment in a concrete laboratory situated in the basement of Techno India College, Salt Lake Campus.

- **Cement:** Portland Pozzolana Cement (PPC) – 43 grade (Ultratech Cement) as stated in clause 5.1.1 was used for the experimental programme. It was tested for its physical properties in accordance with IS standards.
- **Fine Aggregates:** The fine aggregates used for the experimental programme was obtained from the bed of river Koel. The fine aggregates used passed through 4.75mm sieve and had a specific gravity of 2.74. The fine aggregates belonged to Zone I according to IS 383 as stated in clause 5.3.
- **Coarse Aggregates:** The coarse aggregates used were non-reactive and as per the requirements to produce good and durable concrete. The coarse aggregates were of two different gradings of 20 mm and 10 mm sizes were used to prepare the mix.
- **Water:** Clean water which is safe and potable for drinking was used for producing all types of the mix.
- **Fly ash:** Fly ash class F was used for a laboratory experiment. The Fly Ash used in replacement of cement in concrete is brought from Kolaghat Thermal Power Station near Mecheda.
- **Glass Fibres (Length 36 mm – as per IRC 15 – 2011):** Glass fibre also known as fibreglass is made from extremely fine fibres of glass. It is a light weight, extremely strong and robust material. Glass fibres are relatively less stiff and made from relatively less expensive material as compared to carbon fibres. It is less brittle and also has lower strength than carbon fibres.

In my case, AR-HP 67/36 glass fibres were used. The glass fibres used had a specific gravity of 2.68 gm/cm^3, tensile strength 1700 MPa and Young's Modulus 72GPa.

6.2 Methods

I have taken sample concrete cubes of size 150mm×150mm×150mm for testing the compressive strength of the product. Additionally, I have taken the sample of the concrete beam in regard to obtaining the flexural strength of the concrete product.

The list of equipments used in the laboratory by me are:

(a) Balance with different capacities (digital)
(b) Motorised Sieve shaker
(c) Laboratory concrete mixtures
(d) Needle vibrators
(e) Curing tanks
(f) Compression testing machine electrically operated
(g) Universal testing machine
(h) Flexural testing machine
(i) Oven
(j) Slump test apparatus
(k) Vicat apparatus
(l) Le chateleir apparatus
(m) Mould (150mm×150mm×150mm)
(n) Gauging Trowel
(o) Tamping rod
(p) Beam mould (100mm×100mm×500mm),(150mm×150mm×700mm)
(q) Cylindrical mould (150mm×300mm)
(r) Aluminium boxes for measuring moisture contents

(s) Specific gravity bottle
(t) Bulk density voids and bulking apparatus
(u) Metal tray
(v) Measuring cylinders (25-1000ml capacity)
(w) IS Sieve set 20 cm diameter, brass made, 10mm – 38 microns with pan & cover
(x) IS Sieve set 45 cm diameter, GI made, 40mm-2.36mm with pan & cover

Various tests conducted on the specimens are described below along with the description and importance. The investigation was carried out for casting of cubes, beams and the grade of concrete was M-20. The materials of the concrete were described in clause. The nominal maximum size of coarse aggregate was 20mm.

6.3 Form Work

Form work may be defined as a temporary structure or a permanent structure used to contain poured concrete in a fresh state. The form work which is removed after placing concrete and getting it hardened is called a temporary formwork. But sometimes form work used in slender columns with stiffness value very low were steel plated formwork is used which is kept permanently after concreting and hardening so that there is no chance of appearing major cracks in the column section due to the opening of the formwork. Fresh concrete is plastic and can be easily moulded in formwork. Formwork plays an important role in shaping the concrete and supporting it while gaining sufficient strength to support itself. It is required that the formwork be sufficiently strong to take the dead load and live load that may come upon it during construction and also it should be sufficiently rigid at the same time to avoid bulging, twisting, swaging due to these loads. Dead loads are the weight of the formwork along with the weight of the fresh concrete. The live loads may be taken as the weight of the workers, equipment's, runways and material storage and compacting equipments.

In our case, permanent moulds were used which are commercially available in the market. However, for the preparation of beams, moulds were specially ordered and procured from local steel fabricating shops.

6.4 Mixing of Concrete

Concrete can be prepared either by hand mixing or machine mixing. Hand mixing can be done in a plane levelled surfaces such as a wooden platform or a paved concrete surface having tight joints to prevent loss of water due to hydration. To do hand mixing the levelled surface is cleaned first and then moistened by spraying water. Sand is then poured on the surface. After putting sand covering the full area of the level surface cement is then spread over the sand. Cement and sand are then mixed thoroughly before putting coarse aggregates into the uniform mix of cement and sand. For mixing materials, either a hoe or a square-pointed D-handled shovel is used. Cement, fine and coarse aggregates are mixed thoroughly up to time, the colour of the mixture is uniform throughout. Then glass fibre and fly ash are added to the mix as per calculation on the percentage of the total weight of the mix. Then again, all the materials including fly ash and glass fibres mixed thoroughly. Then water is slowly added. The dry mix materials along with the admixtures are turned ¾ times for getting a uniform mix. The fresh concrete produced from the uniform mix is plastic in nature which can be moulded in the formwork as per our needs.

In my investigation hand mixing was used because the machine drum mixture was not cleaned and it was difficult to clean the drum. In the case of machine mixing, machine drum must be clean and wrapped with a clean cloth and then moistened to prevent any loss of water during hydration. All the dry materials along with glass fibres and fly ash are put in the drum and then mixed thoroughly by a rotating drum. After the water is added in the drum and mixed again up to the time the uniform coloured mix is obtained. After completing all the process concrete slurry is dropped from the drum on a flat and clean steel plate (good timber also will do), from where the slurry is taken and put in the formwork as needed for concrete.

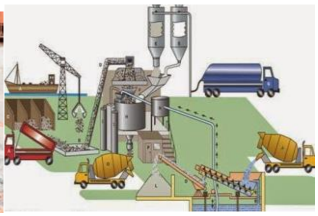



Fig. 6, 7: Different methods of concrete mixing

6.5 Compaction

Compaction of concrete is the methodology to expel the entrapped air from the concrete. During mixing, transportation and pouring the concrete in the formwork, outside air use to enter into the concrete. The amount of air will be higher for lower workability. Such air needs to be removed fully so that the concrete does not lose its strength considerably. The relationship between the percentage of losing strength and percentage of air voids due to a deficit of compaction is shown in the figure below:

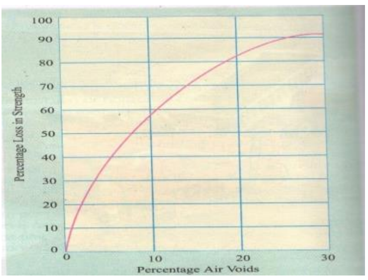


Fig. 8: Relationship between loss of strength and air-void space

It is observed at the site of concreting that 5% air voids reduce the strength of concrete by about 30% and 10% air voids reduce the strength by 50%. So, compaction of concrete raises an important and virtual role in making a good dense and durable concrete.

To achieve the optimum compaction with maximum density the following compacting process is normally adopted. The concrete mix should not be too wet to compact easily but with reduced strength of concrete. For maximum strength, concrete should be compacted by 100% with reasonable compacting equipment available in the site. The following methods are adopted for compacting the concrete:

(a) Hand Compaction
- Rodding
- Ramming
- Tamping

(b) Compaction by vibration
- Internal vibrator (Needle vibrator)
- Formwork vibrator (External vibrator)
- Table vibrator
- Platform vibrator
- Surface vibrator (Screed vibrator)
- Vibratory Roller

(c) Compaction by Pressure and Jolting

(d) Compaction by Spinning

6.5.1 Hand Compaction: Hand compaction of concrete is practised in case of less important concrete product and where the concrete is prepared in small quantity. Sometimes hand method is needed where there is congestion of reinforcement (as required as per design) which cannot be comfortably compacted mechanically. Hand compaction consists of rodding, ramming and/or tamping. In hand compaction, the consistency of concrete is maintained at a higher level. The thickness of the layer of concrete is limited to about 15 to 20 cm. The concrete is poked with a 2 m long and 16 mm diameter rod. It is used to pack the concrete between the reinforcement and sharp corners and edges. Rodding is done over the complete area of concrete to drive away from the entrapped air and making the concrete dense. Ramming is not generally permitted in case of upper floor construction where concrete is placed in the formwork supported on struts. If the process of ramming is used in such case the position of the reinforcement may be disturbed resulting in the formwork may fall.

6.5.2 Compaction by vibration: Where high strength of concrete is desired by the engineer at site, the stiff concrete with low water cement ratio needs to be used. To compact such concrete mechanically operated vibrated equipment, need to be used. The vibrated concrete with low water cement ratio has many advantages over the hand compacted concrete with higher water cement ratio. Some mechanically operated vibratory equipments are shown below:

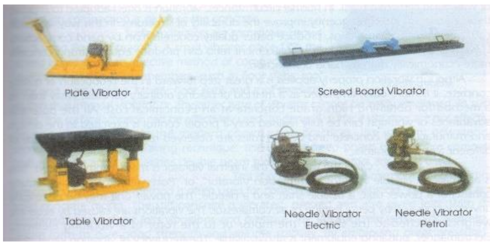


Fig. 9: Some vibrator equipment's

Fig. 10: Concrete compaction procedure

6.6 Curing of Concrete

Curing of concrete play, a vital role to get the strength of concrete. The primary objective of curing is to complete a full hydration process of the concrete product to take place at the site. The secondary objective of curing is to avoid shrinkage cracks appeared if any. The hardened cement paste has a porous structure and the pores can be divided into two categories as gel pores and capillary pores. Hydration of cement takes place only when the capillary pores remain saturated. Curing is necessary to make the concrete more durable, strong, impermeable and resistant to abrasion and frost. Curing starts as soon as the concrete reaches its final set. It is generally recommended to do curing for at least 14 days to attain at least 90% of the expected strength.
In our case, the tank curing method was used for all specimens including the beams.

Fig. 11: Concrete curing procedure

The conventional method of curing is ponding of water on the concrete surface or by spraying water on the surface and cover it with polyethene sheets/gunny bags to prevent evaporation loss. All the exposed surface of the concrete must be kept wet continuously for the required curing time of different concrete structures as specified in IS codes. Now a day's stream curing is also done by keeping the temperature above 40°C. When concrete is steam cured the temperature inside the curing jacket at the surface of the concrete must not exceed 75°C for more than 1 hour during the entire stream curing period. Sufficient moisture needs to be provided inside the curing jacket so that all the surface of the concrete remains wet.

6.7 Mix Design: Please see Appendix A, B & C.
6.7.1 Appendix: A [Mix design for conventional concrete]
(A) Characteristics of Mix Design
Concrete is an extremely versatile building material because it can be designed for strength ranging from M10 (10Mpa) to M100 (100 Mpa) and workability ranging from 0 mm slump to 150 mm slump. In all these cases the basic ingredients of concrete are the same, but it is their relative proportioning that makes the difference.

Basic Ingredients of Concrete:
(a) Cement: It is the basic binding material in concrete.
(b) Water: It hydrates cement and also makes concrete workable.
(c) Coarse Aggregate: It is the basic building component of concrete.
(d) Fine Aggregate: Along with cement paste it forms mortar grout and fills the voids in the coarse aggregates.
(e) Admixtures: They enhance certain properties of concrete e.g. gain of strength, workability, setting properties, imperviousness etc.
Concrete needs to be designed for certain properties in the plastic stage as well as in the hardened stage.

Properties desired from concrete in plastic stage:
- Workability
- Cohesiveness
- Initial set retardation

Properties desired from concrete in the hardened stage:
- Strength
- Imperviousness
- Durability

Concrete mix design is the method of correct proportioning of ingredients of concrete, in order to optimise the above properties of concrete as per site requirements.

In other words, we determine the relative proportions of ingredients of concrete to achieve desired strength & workability in the most economical way.

Advantages of mix design
Mix design aims to achieve good quality concrete at site economically.
1) Quality concrete means
- Better strength
- Better imperviousness and durability
- Dense and homogeneous concrete

2) The economy of mix design:
(a) The economy in cement consumption: It is possible to save up to 15% of cement for M20 grade of concrete with the help of concrete mix design. In fact, higher the grade of concrete more are the savings. Lower cement content also results in lower heat of hydration and hence reduces shrinkage cracks.

(b) Best use of available materials: Site conditions often restrict the quality and quantity of ingredient materials. Concrete mix design offers a lot of flexibility on the type of aggregates to be used in the mix design. Mix design can give an economical solution based on the available materials if they meet the basic IS requirements. This can lead to saving in transportation costs from longer distances.

(c) Other properties: Mix design can help us to achieve form finishes, high early strengths for early deshuttering, concrete with better flexural strengths, concrete with pumpability and concrete with lower densities.

(B) Calculation:
Design Stipulations:

Grade of concrete (designation)	= M20
Type of cement	= PPC 43 grade
Minimum nominal size of aggregate	= 20 mm
Workability	= 25 – 50 mm (slump)
Exposure condition	= mild
Method of concrete placing	= normal
Degree of supervision	= good
Specific gravity of cement	= 3.15
Specific gravity of coarse aggregate	= 2.74
Specific gravity of fine aggregate	= 2.74
Sieve analysis	= zone 1 (IS 383 – 1970)

DESIGN:
Step 1: Target mean strength

$fck' = fck + 1.65s$ From Table 1 of IS 10262 - 2009

$= 20 + 1.65 \times 4$ standard deviation, $s = 4\text{N/mm2}$

$fck' = 26.6\ N/mm2$

Step 2: Selection of water cement ratio
From Table 5 of IS 456 – 2000

For M20 concrete, maximum w/c ratio = 0.5
Based on experience adopt water cement ratio = 0.45
0.45<0.50

Step 3: Selection of water content
From Table 2 of IS 10262:2009 maximum water content for 20 mm aggregate =186 litre (for 25 to 50 mm slump range)

Step 4: Calculation of cement content

Water-cement ratio = 0.45
Cement content = 186/0.45 = 413.33 kg/m^3

From Table 5 of IS 456-2000,

Minimum cement content for 'severe' exposure condition = 300 kg/m^3
413.33 kg/m^3 > 300 kg/m^3, hence O.K.

Step5: Proportion of volume of coarse aggregate and fine aggregate content
From Table 3 volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for a water-cement ratio of 0.50 =0.60.

In the present case, the water-cement ratio is 0.45. Therefore, the volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.10 the proportion of the volume of coarse aggregate is increased by 0.02 (at the rate of -/+ 0.01 for every ± 0.05 change in the water-cement ratio). Therefore, the corrected proportion of the volume of coarse aggregate for the water-cement ratio of 0.45 = 0.61.

Note— In case the coarse aggregate is not angular one then also the volume of coarse aggregate may be required 10 be increased suitably, based on experience.

Therefore, volume of coarse aggregate = 0.61
Volume of fine aggregate content=1 - 0.61 =0.39.

Step 6: Mix calculations
The mix calculations per unit volume of concrete shall be as follows:
(a) Volume of concrete = 1 m^3
(b)

$$The\ volume\ of\ cement = (Mass\ of\ cement/Specific\ gravity\ of\ cement) \times (1/1000)$$
$$= (413.33/3.15) \times (1/1000) \quad \text{[For w/c ratio = 0.45]}$$
$$= 0.131\ \text{m}^3$$

(c)

$$Volume\ of\ water = (Mass\ of\ water/Specific\ gravity\ of\ water) \times (1/1000)$$
$$= (186/1) \times (1/1000)$$
$$= 0.186\text{m}^3$$

(d)

$$Volume\ of\ all\ in\ aggregate = \{a - (b + c)\}$$

$$= 1 - (0.131 + 0.186)$$
$$= 0.683 \ m^3$$

(e)

$$Mass\ of\ coarse\ aggregate = (d \times Volume\ of\ coarse\ aggregate \times Specific\ gravity\ of\ coarse\ aggregate \times 1000)$$
$$= 0.683 \times 0.61 \times 2.74\ x\ 1000$$
$$= 1141.57\ kg$$

(f)

$$Mass\ of\ fine\ aggregate = (d \times Volume\ of\ fine\ aggregate \times Specific\ gravity\ of\ fine\ aggregate \times 1000)$$
$$= 0.683 \times 0.39\ x\ 2.74 \times 1000$$
$$= 729.85\ kg$$

Step 7: Mix proportions for trial number 1

Cement	= 413 kg
Water	= 186 kg/m^3
Fine aggregate	= 730 kg
Coarse aggregate	= 1142 kg
Water-cement ratio	= 0.45

Note—

(a) Aggregates should be used in saturated surface dry condition. If otherwise when computing the requirement of mixing water, the allowance shall be made for the free (surface) moisture contributed by the fine and coarse aggregates. On the other hand, if the aggregates are dry, the amount of mixing water should be increased by an amount equal to the moisture likely to be absorbed by the aggregates. Necessary adjustments are also required to be made in mass of aggregates. The surface water and percent of water absorption of aggregates shall be determined according to IS 2386.

(b) The slump shall be measured and the water content and dosage of admixture shall be adjusted for achieving the required slump based on trial if required. The mix proportions shall be reworked for the actual water content and checked for durability requirements.

(c) Two more trials having a variation of ±10 percent of water-cement ratio in (ii) shall be carried out and a graph between three water-cement ratios and their corresponding strengths shall be plotted to work out the mix proportions for the given target strength for field trials. However, the durability requirement shall be met.

6.7.2 Appendix: B [For high volume fly ash-based glass fibre reinforced concrete (with OPC)]

(A) Characteristics of Mix Design:

Same as in Appendix A and as given in Chapter 4.

(B) Calculation:

Design Stipulations:

Grade of concrete (designation) = M20
Type of cement = OPC 43 grade
Minimum nominal size of aggregate = 20 mm
Workability = 25 – 50 mm (Slump)
Exposure condition = Mild
Method of concrete placing = Normal
Degree of supervision = Good
Specific gravity of cement = 3.15
Specific gravity of coarse aggregate = 2.74
Specific gravity of fine aggregate = 2.74
Sieve analysis = zone 1 (IS 383 – 1970)

Design:

Step 1: Target mean strength

$$fck' = fck + 1.65s \qquad \text{From Table 1 of IS 10262 - 2009}$$
$$= 20 + 1.65 \times 4 \qquad \text{Standard deviation, s = 4}$$
$$fck' = 26.6\ N/mm2$$

Step 2: Selection of water cement ratio

From Table 5 of IS 456 – 2000

For M20 concrete, maximum w/c ratio = 0.5
Based on experience adopt water cement ratio = 0.45

0.45<0.50; hence ok.

Step 3: Selection of water content

From Table 2 of IS 10262:2009 maximum water content for 20 mm aggregate =186 kg/m^3 (for 25 to 50 mm slump range)
Maximum water content for 20 mm aggregate =186 kg/m^3 [for 25 to 50 mm slump]

Step 4: Calculation of cement and fly ash content:

Water-cement ratio = 0.45

Cement content = 186/0.45 = 413.33 kg/m^3

From Table 5 of IS 456-2000,
Minimum cement content for 'severe' exposure condition = 300 kg/m^3
413.33 kg/m^3 > 300 kg/m^3, hence, O.K.

From Table 5 of IS 456:2000
Minimum cement content for 'mild' exposure condition = 300 kg/m^3
Above cement content value is > 300 kg/m^3 (Hence ok)

Note: This illustration example is with an increase of 10 percent cementitious material content.

Cementitious material content = 413.33 × 1.10 = 454.66 kg/m^3 ≈ 455 kg/m^3

Water content = 186 kg/m^3

So, water cement ratio = 186/455 = 0.4088 ≈ 0.41

Fly ash @ 50% of total cementitious material content = 455 × 50% = 227.5 kg/m^3

Cement (OPC) = 456 – 228 = 228 kg/m^3

Fly ash being utilized = 228 kg/m^3

Saving of cement while using fly ash = 413 – 228 = 185 kg/m^3

Step 5: Proportion of volume of coarse aggregate and fine aggregate content:

From Table 3 volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60.

In the present case, the water-cement ratio is 0.45. Therefore, the volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.10 the proportion of the volume of coarse aggregate is increased by 0.02 (at the rate of -/+ 0.01 for every ± 0.05 change in the water-cement ratio). Therefore, the corrected proportion of the volume of coarse aggregate for the water-cement ratio of 0.45 = 0.61.

Note— In case the coarse aggregate is not angular one then also the volume of coarse aggregate may be required 10 be increased suitably, based on experience.

Therefore, Volume of coarse aggregate = 0.61

Volume of fine aggregate content=1 - 0.61 =0.39.

Step 6: Mix calculations:

The mix calculations per unit volume of concrete shall be as follows:

(a) Volume of concrete = 1 m^3

(b)

$$\textit{The volume of cement} = (\textit{Mass of cement}/\textit{Specific gravity of cement}) \times (1/1000)$$
$$= (228/3.15) \times (1/1000)$$
$$= 0.072 \text{ m}^3$$

(c)

$$\textit{Volume of fly ash} = (\textit{Mass of fly ash}/\textit{Specific gravity of fly ash}) \times (1/1000)$$
$$= (228/2.2) \times (1/1000)$$
$$= 0.104 \text{ m}^3$$

(d)

$$\textit{Volume of water} = (\textit{Mass of water}/\textit{Specific gravity of water}) \times (1/1000)$$
$$= (186/1) \times (1/1000)$$
$$= 0.186 \text{ m}^3$$

(e)

$$\textit{Volume of all in aggregate} = \{a - (b + c + d)\}$$
$$= 1 - (0.072 + 0.104 + 0.186)$$
$$= 0.638 \text{ m}^3$$

(f)

$$\textit{Mass of coarse aggregate} = (e \times \textit{Volume of coarse aggregate} \times \textit{Specific gravity of coarse aggregate} \times 1000)$$
$$= 0.638 \times 0.61 \times 2.74 \times 1000$$
$$= 1066 \text{ kg}$$

(g)

$$\textit{Mass of fine aggregate} = (e \times \textit{Volume of fine aggregate} \times \textit{Specific gravity of fine aggregate} \times 1000)$$
$$= 0.638 \times 0.39\, x\, 2.74 \times 1000$$
$$= 682 \text{ kg}$$

(h) Mass of glass fibres = According to clause 3.8 of IRC 15 – 2011

Suggested dosage = 0.6 to 2.0 kg/m^3 (0.2 to 0.6 percent by weight of cement in mix)
So, 0.6 percent of cementitious product = (0.6/100) × 456 = 2.74 kg/m^3

Step 7: Mix proportions for trial number 1

Cement (OPC) = 228 kg/m^3
Fly ash = 228 kg/m^3
Water = 186 kg/m^3
Fine aggregate = 682 kg/m^3
Coarse aggregate = 1066 kg/m^3
Water-cement ratio = 0.41
Glass Fibre = 2.74 kg/m^3

Note—

(a) Aggregates should be used in saturated surface dry condition. If otherwise when computing the requirement of mixing water, the allowance shall be made for the free (surface) moisture contributed by the fine and coarse aggregates. On the other hand, if the aggregates are dry, the amount of mixing water should be increased by an amount equal to the moisture likely to be absorbed by the aggregates. Necessary adjustments are also required to be made in mass of aggregates. The surface water and percent of water absorption of aggregates shall be determined according to IS 2386.

(b) The slump shall be measured and the water content and dosage of admixture shall be adjusted for achieving the required slump based on trial if required. The mix proportions shall be reworked for the actual water content and checked for durability requirements.

(c) Two more trials having a variation of ±10 percent of water-cement ratio in (ii) shall be carried out and a graph between three water-cement ratios and their corresponding strengths shall be plotted to work out the mix proportions for the given target strength for field trials. However, the durability requirement shall be met. [11] [12] [13]

6.7.3 Appendix: C [For high volume fly ash-based glass fibre reinforced concrete (with PPC)]

(A) Characteristics of Mix Design: Same as in Appendix A and as given in Chapter 4.

(B) Calculation:

Design Stipulations:

Grade of concrete (designation) = M20
Type of cement= PPC 43 grade
Minimum nominal size of aggregate = 20 mm
Workability= 25 – 50 mm (slump)
Exposure condition = Mild
Method of concrete placing = Normal
Degree of supervision= Good
Specific gravity of cement= 3.15
Specific gravity of coarse aggregate = 2.74
Specific gravity of fine aggregate = 2.74
Sieve analysis = zone 1 (IS 383 – 1970)

DESIGN:

Step 1: Target mean strength

$$fck' = fck + 1.65s$$
$$= 20 + 1.65 \times 4$$
$$fck' = 26.6\ N/mm2$$

From Table 1 of IS 10262 - 2009
Standard deviation, s = 4

Step 2: Selection of water cement ratio

From Table 5 of IS 456 – 2000

For M20 concrete, maximum w/c ratio = 0.5
Based on experience adopt water cement ratio = 0.45
0.45<0.50; hence ok.

Step 3: Selection of water content

From Table 2 of IS 10262:2009 maximum water content for 20 mm aggregate =186 kg/m^3 (for 25 to 50 mm slump range)
Maximum water content for 20 mm aggregate =186 kg/m^3 [for 25 to 50 mm slump]

Step 4: Calculation of cement and fly ash content:

Water-cement ratio = 0.45
Cement content= 186/0.45 = 413.33 kg/m^3

From Table 5 of IS 456-2000,
Minimum cement content for 'severe' exposure condition = 300 kg/m^3

413.33 kg/m^3 > 300 kg/m^3, hence, O.K.

From Table 5 of IS 456:2000
Minimum cement content for ‘mild’ exposure condition = 300 kg/m^3
Above cement content value is > 300 kg/m^3 (Hence ok)

Note— This illustration example is with an increase of 10 percent cementitious material content.

Cementitious material content = 413.33 × 1.10 = 454.66 kg/m^3 ≈ 455 kg/m^3

Water content = 186 kg/m^3

So, Water cement ratio = 186/455 = 0.4088 ≈ 0.41

Fly ash @ 30% of total cementitious material content = 455 ×30% = 136.5 kg/m^3 ≈137 kg/m^3

Cement (OPC) = 455 – 137 = 318 kg/m^3

Fly ash being utilized = 137 kg/m^3

Saving of cement while using fly ash = 413 – 318 = 95 kg/m^3

Step 5: Proportion of volume of coarse aggregate and fine aggregate content:

From Table 3 volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone I) for water-cement ratio of 0.50 =0.60.

In the present case, the water-cement ratio is 0.45. Therefore, the volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water-cement ratio is lower by 0.10 the proportion of the volume of coarse aggregate is increased by 0.02 (at the rate of -/+ 0.01 for every ± 0.05 change in the water-cement ratio). Therefore, the corrected proportion of the volume of coarse aggregate for the water-cement ratio of 0.45 = 0.61.

Note— In case the coarse aggregate is not angular one then also the volume of coarse aggregate may be required 10 be increased suitably, based on experience.

Therefore, Volume of coarse aggregate = 0.61

Volume of fine aggregate content = 1 - 0.61 = 0.39.

Step 6: Mix calculations:

The mix calculations per unit volume of concrete shall be as follows:

(a) Volume of concrete = 1 m^3

(b)

$$The\ volume\ of\ cement\ = (Mass\ of\ cement/Specific\ gravity\ of\ cement) \times (1/1000)$$
$$= (318/3.15) \times (1/1000)$$
$$= 0.101\ m^3$$

(c)

$$Volume\ of\ fly\ ash\ = (Mass\ of\ fly\ ash/Specific\ gravity\ of\ fly\ ash) \times (1/1000)$$
$$= (137/2.2) \times (1/1000)$$
$$= 0.062\ m^3$$

(d)

$$Volume\ of\ water\ = (Mass\ of\ water/Specific\ gravity\ of\ water) \times (1/1000)$$
$$= (186/1) \times (1/1000)$$
$$= 0.186\ m^3$$

(e)

$$Volume\ of\ all\ in\ aggregate\ = \{a - (b + c + d)\}$$
$$= 1 - (0.101 + 0.062 + 0.186)$$
$$= 0.651\ m^3$$

(f)

$$Mass\ of\ coarse\ aggregate\ = (e\ \times Volume\ of\ coarse\ aggregate\ \times Specific\ gravity\ of\ coarse\ aggregate\ \times 1000)$$
$$= 0.651\ x\ 0.61\ x\ 2.74\ x\ 1000$$
$$= 1088\ kg$$

(g)

$$Mass\ of\ fine\ aggregate\ = (e\ \times\ Volume\ of\ fine\ aggregate\ \times\ Specific\ gravity\ of\ fine\ aggregate\ \times 1000)$$
$$= 0.651\ x\ 0.39\ x\ 2.74\ x\ 1000$$
$$= 696\ kg$$

(h) Mass of glass fibres = According to clause 3.8 of IRC 15 – 2011

Suggested dosage = 0.6 to 2.0 kg/m^3 (0.2 to 0.6 percent by weight of cement in mix)

So, 0.6 percent of cementitious product = (0.6/100) × 456 = 2.74 kg/m^3

Step 7: Mix proportions for trial number 1

Cement (PPC) = 318 kg/m^3

Fly ash = 137 kg/m^3

Water = 186 kg/m^3

Fine aggregate = 696 kg/m^3

Coarse aggregate = 1088 kg/m^3

Water-cement ratio = 0.41

Glass Fibre = 2.74 kg/m^3

Note—

(a) Aggregates should be used in saturated surface dry condition. If otherwise when computing the requirement of mixing water, the allowance shall be made for the free (surface) moisture contributed by the fine and coarse aggregates. On the other hand, if the aggregates are dry, the amount of mixing water should be increased by an amount equal to the moisture likely to be absorbed by the aggregates. Necessary adjustments are also required to be made in mass of aggregates. The surface water and percent of water absorption of aggregates shall be determined according to IS 2386.

(b) The slump shall be measured and the water content and dosage of admixture shall be adjusted for achieving the required slump based on trial if required. The mix proportions shall be reworked for the actual water content and checked for durability requirements.

(c) Two more trials having a variation of ±10 percent of water-cement ratio in (ii) shall be carried out and a graph between three water-cement ratios and their corresponding strengths shall be plotted to work out the mix proportions for the given target strength for field trials. However, the durability requirement shall be met. [11] [12] [13]

7. RESULTS AND DISCUSSION

For testing of glass fibre reinforced concrete, it is required to cast the various moulds like cubes and beams. It is cured for the required period after 24 hrs of casting.

7.1 My pre-submission work

I did my preliminary laboratory work in regard to testing of cubes of size 150mm×150mm×150mm and plain concrete beams of sizes 100mm×100mm×500mm & 150mm×150mm×700mm. For this work, I have taken the guidance of Prof Gaurav Ghosh. I prepared the concrete slurry for the above work in the concrete laboratory situated in the basement of Techno India College, Salt Lake Campus. The constituents of all ingredients had been mixed in hand machine adding the required quantity of pure water at 4℃.

Fig. 12: Selfie taken by me on 12.09.18 while cube & beam casting & curing

7.2 The specimens cast as follows

Initially, the mould is applied with oil for lubrication. Concrete is laid in the mould. Concrete has been filled in both the Cube Specimens &Beam Specimens. The results obtained from the detailed experimental program conducted on M20 grade Fly Ash based Glass Fibre Reinforced concrete is presented below.

7.3 Compressive Strength of Concrete (in N/mm^2)

The 7 days, 28 days, 56 days and 90 days compressive strength was studied and the values of 3 samples on 7 days, 28 days, 56 days and 90 days studied are shown in the tabular form. Table 6 shows the data of 7 days, 28 days, 56 days and 90 days compressive strength obtained. Table 6 gives the compressive strength of concrete with a maximum nominal size of aggregates 20mm. The 7 days, 28 days, 56 days and 90 days compressive strength was also plotted in Fig 27 by taking the average of these three values with the addition of fibres.

Table 2: Compressive Strength

S no.	Cube Specification	Grade of concrete	Age of specimen in days	The dimension of specimen in cm	Cross sectional area of specimen in cm^2	Actual crushing load in Kg	Comp. strength in Kg/cm^2	Average comp. strength in Kg/cm^2	Specified limit for days Kg/cm^2	
									7 days	28 days
1.	1	M 20	7	15 × 15 × 15	225	31500	140.00			
2.	2	M 20	7	15 × 15 × 15	225	32500	144.44	142.22	M20	M20
3.	3	M 20	7	15 × 15 × 15	225	32000	142.22		135	200
4.	1	M 20	28	15 × 15 × 15	225	46500	206.67			
5.	2	M 20	28	15 × 15 × 15	225	47500	211.11	208.89		
6.	3	M 20	28	15 × 15 × 15	225	47000	208.89			
7.	1	M 20	56	15 × 15 × 15	225	50000	222.22			
8.	2	M 20	56	15 × 15 × 15	225	51000	226.67	223.70		
9.	3	M 20	56	15 × 15 × 15	225	50000	222.22			
10.	1	M 20	90	15 × 15 × 15	225	53500	237.78			
11.	2	M 20	90	15 × 15 × 15	225	53500	237.78	237.04		
12.	3	M 20	90	15 × 15 × 15	225	53000	235.56			

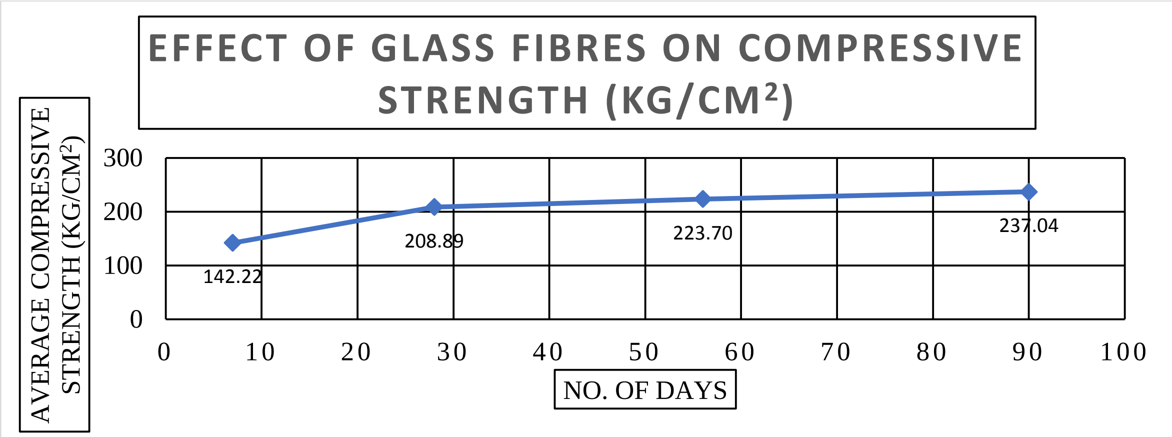
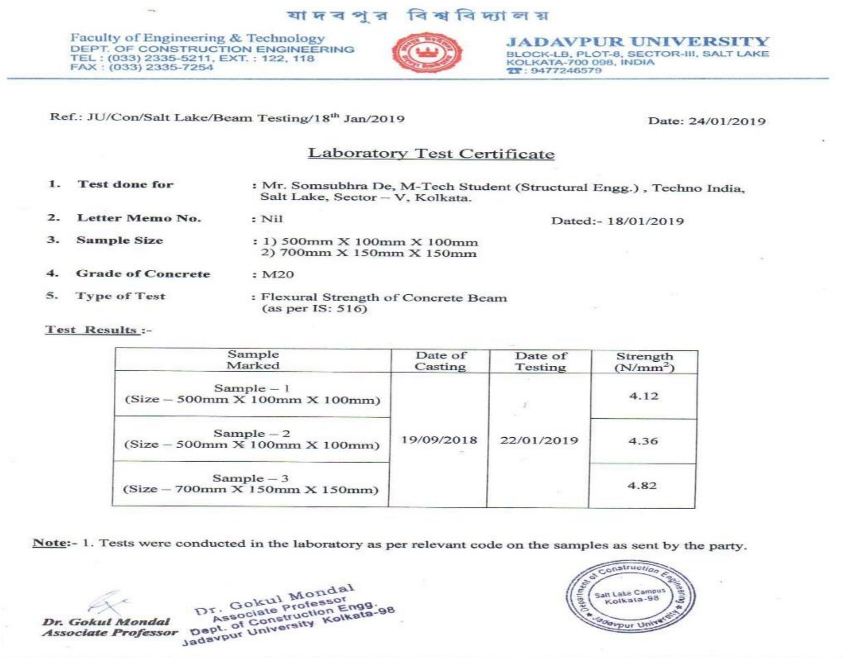


Fig. 13: Effect of Glass Fibres on compressive strength (kg/cm^2)

7.4 Flexural Tensile Strength (in N/mm^2)



যাদবপুর বিশ্ববিদ্যালয়

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Ref.: JU/Con/Salt Lake/Beam Testing/18th Jan/2019 Date: 24/01/2019

Laboratory Test Certificate

1. Test done for : Mr. Somsubhra De, M-Tech Student (Structural Engg.), Techno India, Salt Lake, Sector – V, Kolkata.
2. Letter Memo No. : Nil Dated:- 18/01/2019
3. Sample Size : 1) 500mm X 100mm X 100mm 2) 700mm X 150mm X 150mm
4. Grade of Concrete : M20
5. Type of Test : Flexural Strength of Concrete Beam (as per IS: 516)

Test Results :-

Sample Marked	Date of Casting	Date of Testing	Strength (N/mm^2)
Sample – 1 (Size – 500mm X 100mm X 100mm)	19/09/2018	22/01/2019	4.12
Sample – 2 (Size – 500mm X 100mm X 100mm)			4.36
Sample – 3 (Size – 700mm X 150mm X 150mm)			4.82

Note:- 1. Tests were conducted in the laboratory as per relevant code on the samples as sent by the party.

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Associate Professor

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Jadavpur University Kolkata-98

We are recommending the average value of 4.12 and 4.36, that is (4.12+4.36)/2 = 4.24 N/mm^2

8. ECONOMIC ANALYSIS OF GLASS FIBRE REINFORCED CONCRETE

To make my economic analysis I have made 1 m^3 of concrete, the ingredients of which are
(a) Portland Pozzolana Cement [PPC] of Ultratech brand;
(b) Fine aggregates and
(c) Coarse aggregates collected from local sources.

I have used pure water as available in the laboratory. I collected three cubes from the above made concrete each after 7 days, 28 days, 56 days and 90 days as already stated in chapter 6 Results and Discussion. The test results obtained were satisfactory and the same is stated in chapter 6 Results and Discussion. The cost for 1 m^3 as prepared above are given below in 'A'. The appropriate rates of the materials were collected from the internet. The percentage ratio of cement and fly ash were taken as 70:30.

(A) Cost per m^3 for GFRC with PPC used

Table 3: Cost per m^3 for high volume fly ash-based glass fibre reinforced concrete (M20)

S no.	Material	Rate (Per Kg)	Quantity Kg/m^3	Cost (Per m^3)
1.	Cement (PPC)	6.00	318	1908.00
2.	Fly Ash	1.20	137	164.40
3.	Natural Sand	1.50	348	522.00
4.	Crush Sand	0.80	348	278.40
5.	Coarse Aggregate (10mm)	0.60	544	326.40
6.	Coarse Aggregate (20mm)	0.60	544	326.40
7.	Glass Fibre (HP 67/36) (Length 36 mm – as per IRC: 15 – 2011)	360.00	2.74	986.40
8.	Water (Water-cement ratio = 0.40)	2.50	186	465.00
Total =				4977.00

Percent of losses per cubic meter of concrete = {(4977.00 – 4880.70)/4977.00} × 100 = 1.93% ≈ 2 %

From above it is inferred that if GFRC is made with PPC the cost per cubic meter of GFRC compared to the cost per meter cube of conventional concrete will be costlier by 2% as shown in the calculation. The increase in the cost of 2% seems reasonable compared to the different benefits obtained by using GFRC in concrete projects.

If 1 m^3 of concrete is prepared with the following ingredients –

- Ordinary Portland Cement [OPC]
- Fine aggregate
- Coarse aggregate and
- Water as used in GFRC with PPC the cost per m^3 of concrete would come as follows in 'B

(B) Cost per m^3 for conventional concrete (M20)

Table 4: Cost per m^3 for conventional concrete (M20)

S no.	Material	Rate (Per Kg)	Quantity Kg/m^3	Cost (Per m^3)
1.	Cement (OPC)	7.00	413	2891.00
2.	Natural Sand	1.50	365	547.50
3.	Crush Sand	0.80	365	292.00
4.	Coarse Aggregate (10mm)	0.60	571	342.60
5.	Coarse Aggregate (20mm)	0.60	571	342.60
6.	Water (Water-cement ratio = 0.40)	2.50	186	465.00
			Total =	4880.70

If 1 m^3 concrete is prepared with the following ingredients:

- Ordinary Portland Cement [OPC]
- Glass Fibre (HP 67/36) (Length 36 mm – as per IRC:15 – 2011)
- Fly ash
- Fine aggregate
- Coarse aggregate and
- Water

The cost per m^3 of concrete would come as follows in 'C'. The percentage ratio of cement and fly ash were taken as 50:50.

(C) Cost per m^3 for GFRC with OPC used

Table 5: Cost per m^3 for high volume fly ash-based glass fibre reinforced concrete (M20)

S no.	Material	Rate (Per Kg)	Quantity Kg/m^3	Cost (Per m^3)
1.	Cement (OPC)	7.00	228	1596.00
2.	Fly Ash	1.20	228	273.60
3.	Natural Sand	1.50	341	511.50
4.	Crush Sand	0.80	341	272.80
5.	Coarse Aggregate (10mm)	0.60	533	319.80
6.	Coarse Aggregate (20mm)	0.60	533	319.80
7.	Glass Fibre (HP 67/36) (Length 36 mm – as per IRC: 15 – 2011)	360.00	2.74	986.40
8.	Water (Water-cement ratio = 0.40)	2.50	186	465.00
			Total =	4744.90

Percent of savings per cubic meter of concrete = {(4880.70 – 4744.90)/4744.90} × 100 = 2.86% ≈ 3 %
From above it is inferred that if GFRC is made with OPC the cost per cubic meter of GFRC compared to the cost per meter cube of conventional concrete will be cheaper by 3% as shown in the calculation. The decrease in the cost of 3% seems reasonable compared to the different benefits obtained by using GFRC in concrete projects.

9. CONCLUSION

GFRC is one of the most versatile building materials available to architects and engineers. It has contributed significantly to the economy, technology and aesthetics of the construction industry.

Generally, the service life of GFRC is higher than that of traditional concrete due to controlling of micro cracks propagation, corrosion (especially AR–glass fibre) and less permeability. Alkali Resistant (AR) -glass fibre (Length 36 mm – as per IRC: 15 – 2011) can control shrinkage cracks easily. GFRC is lightweight and is about 50–70 % lighter than traditional concrete. Its cost is higher than that of traditional concrete due to the fibre glass, addition of additives and acrylic co–polymer, but developing technology can substantially change this comparison and in that case, it is seen GFRC concrete is cheaper than traditional concrete. These have been focussed in chapter 7 in my dissertation.

GFRC is widely and reliably used in architecture, building, engineering applications. Consequently, there are lots of GFRC applications in practice, but with very little research to support it. In response to this expanding use requirement in practice, advanced GFRC research can be performed so as to improve its properties further.

The materials have good resistance for tension. That is why Glass fibre is chosen as reinforcement for concrete. Right now, it is used mostly for cladding buildings, lining, sewer pipe, shoulder of roads etc.

Compatibility of glass fibre with concrete or mortar helps us to use it easily in our daily project especially for the facade of buildings. It has good resistance to alkalinity that contains in cement (pH > 12.3) with high level.
GRC (In British term) can be used as an alternative material of natural stone, especially in those countries where the stone is less or unavailable.

Changing the GRC panel is very easy as compared to other cladding because of making GRC by the panel and just installing on the site. Also, a broken panel can be repaired or removed and a new one can be put. But if stone or tile is broken, it is not easy to change. GFRC is an eco-friendly material because it consumes less energy during production.

GRC is a new growing industry in India. Customer awareness is increasing and more GFRC projects are seen in India.
GFRC has the facilities to provide in the structure indicate shapes, curves and profiles.
It is suitable for earthquake prone areas.

10. ACKNOWLEDGEMENT

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