

# High Volume Fly Ash-Based Glass Fibre Reinforced Concrete

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**Abstract:** Chapter 1: 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 focussed. 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 of relevant information in regard to glass fibre reinforced based concrete. For this I had to go for different websites to get knowledge of above subject and put my opinions. All references which required completing 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 [photograph of the specimen shown in Fig.4.] have considerable influence on the design, efficiency, output and particularly the reliability and durability of the glass fibre-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. A particular in regard to design mix, specially its calculation has been annexed in Appendix – A and B after the 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 the conventional concrete has been stated in this chapter. It was found that percentage of saving per cubic meter of fly ash-based glass fibre reinforced concrete is to the tune of 3% compare 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 After completing my second semester I have started the 3<sup>rd</sup> semester dealing with my thesis paper as stated above. I have chosen this paper because I got grade “E” (80-90%marks) in ‘Advanced Concrete Technology’ (SE205B) in my last University exam of MTech conducted by MAKAUT. In my second semester Prof. Dr. Sudhir Kumar Das (Dr. SKD) taught us SE205B. Due to his excellent teaching I got “E” grade in the above subject. So, I have chosen Prof. Dr. SKD as one of my guide with the permission of HOD Prof. Dr. Arup Saha Chaudhury (Dr. ASC) of the above subject. I got consent of Dr. SKD to guide me the above subject despite he used to keep busy in other academic field.

1.2 Glass Fibre Reinforced Concrete: Glass fibre reinforced concrete (GFRC) is a cementitious composite product reinforced with discrete glass fibres of varying length and size. The glass fibre used is alkaline resistant as glass fibre are 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 fresh state has lower slump and hence less workable, therefore water reducing admixtures are used. Further the properties of GFRC depend

on various parameters like 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 considerable effect on the GFRC. The length of the fibre, sand/filler type, cement ratio methods and duration of curing also effect the properties of GFRC.

## 1.3 Applications

The main area of FRC applications are: [5]

- 1) Runway, Aircraft parking, and Pavements
- 2) Tunnel Lining and Slope Stabilization
- 3) Blast Resistant Structures
- 4) Thin Shell, Walls, Pipes, and Manholes
- 5) Dams and Hydraulic Structure
- 6) GFRC is also used for machine tool frames, lighting poles, water and oil tanks and also for concrete repairs.

## 1.4 Advantages and Disadvantages of using Glass Fibres in Concrete:

### 1.4.1 Advantages

- 1) It is a great material for restoration of 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.

- 2) GFRC is lightweight and is about 75% lighter than traditional concrete. The lighter weight of GFRC brings economy 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.
- 3) The flexural strength gives it a high strength to weight ratio.
- 4) The reinforcement for this concrete is internal and does not need additional reinforcements.
- 5) Heavy duty or expensive equipment is not necessary when pouring or spraying GFRC.
- 6) It is easy to cut and is very difficult to crack.
- 7) GFRC is very adaptable in that it can be poured or sprayed.
- 8) 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.
- 9) 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.

#### 1.4.2 Disadvantages

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

## 2. Objectives

2.1 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.

- i) Residual waste can be reduced and easily disposed.
- ii) 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 is 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, attempt is being made to use GFRC in Indian cities for architecturally finished materials.



**Figure 1:** Glass Fibre (Length 36 mm –as per IRC 15 – 2011)

2.2 The purpose of my dissertation work is to

- i) Study the mix design aspects of the GRC.
- ii) Understand the various applications involving GRC.
- iii) Compare GRC with alternatives such as stone, aluminium, wood, glass, steel, marble, and granite.
- iv) Perform laboratory tests that are related to compressive, tensile, and flexure by 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.

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 (i.e. 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]

## 2.4 Aims

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 basement of Techno India College, Salt Lake Campus. I will examine to what extent these concrete is cost effective.

## 3. Review of Literature

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

**(a) Materials**

- i) Fly ash
- ii) 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**

**3.1.1 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 I 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.

**3.1.2 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 be a 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.

**3.1.3 Magudeaswaran P et.al (2013)** observed that for the increase in the percentage of fly ash and silica fume there was 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 a 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):**

**3.2.1 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 fresh mix as represented by the Vebe time test.

**3.2.2 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 concretes of 0% RCA and 50% RCA. Large deflections of beams before failure indicated improved ductility with the addition of fibres.

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

**3.3 Rigid Pavement: Rural Road/National Highway:**

**3.3.1 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.

**3.3.2 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 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 percent will make the fly ash suitable for these conditions.

**3.3.3 S L Patil et al (2013)** concluded that Deep Nagar fly 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:**

- 1) While using fly ash for road construction, potential impacts to ground water and soil must be considered and studied.

- 2) 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.
- 3) The pavement structure and its designed thickness is an important parameter when evaluating harmful effects of fly ash on the environment.
- 4) We should take care when using or disposing off any construction material in a hydro-geologically vulnerable area.
- 5) We should follow proper engineering requirements when using unencapsulated fly ash.
- 6) Dust control and erosion prevention measures are essential during construction phase.
- 7) Scientific proportion of fly ash in the construction materials should be practiced.
- 8) 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.
- 9) When construction is finished, a properly seeded soil cover will reduce infiltration. For highway embankments, the pavement may be an effective barrier to infiltration.
- 10) Occupational issues include the handling of dry ash prior to or during its inclusion in a concrete mix or exposures during demolition of concrete structures. In such cases, work inhalation and skin contact precautions should be observed.

### 3.5 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 is 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.



Figure 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.

#### 3.5.1 The advantages of using fly ash in concrete includes the followings

- 1) Fly ash in the concrete mix efficiently replaces Portland cement that in turn can aid in making big savings in concrete material prices.

- 2) It is also an environmentally-friendly solution, which meets the performance specifications. It can also contribute to LEED points.
- 3) It improves the strength over time and thus, it offers greater strength to the building.
- 4) 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.
- 5) 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.
- 6) It effectively combines with alkalis from cement, which thereby prevents the destructive expansion.
- 7) 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.
- 8) 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]

#### 3.5.2 The disadvantages of using fly ash in concrete:

There are also some disadvantages of using fly ash that should be considered.

- 1) The quality of fly ash to be utilized is very vital. Poor quality often has a negative impact on the concrete.
- 2) The poor quality can increase the permeability and thus damaging the building.
- 3) 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 using 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 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]

### 4. Desired Characteristics for fly Ash-Based Glass Fibre Reinforced Concrete (GFRC)

**4.1 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:

**i) 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 are 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.

**ii) 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 spray-up GFRC. The fibres are oriented randomly within a thin plane. As the fibres are sprayed into the forms, they lay flat, confirming to the shape of the form. Typically, 30 to 50 % of the fibres are optimally oriented.

**iii) 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 depends 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.

#### 4.2 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, 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 an 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 of 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. 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, chemical attack may become significant so there is need to develop special glass fibres for better alkali resistance.

#### 4.3 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 percent less 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.

- 1) 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 percent).
- 2) 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 percent increase in fibre content by volume there is an increase of 3 percent in the modulus of elasticity.
- 3) Stress-Strain Curve:** Stress-strain behaviour is affected from 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.
- 4) 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.

- 5) **Toughness:** For GFRC, toughness is about 10 to 40 times that of plain concrete.
- 6) **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.
- 7) **Fatigue Strength:** The addition of fibres increases fatigue strength of about 90 percent and 70 percent of the static strength at  $2 \times 10^6$  cycles for non-reverse and full reversal of loading, respectively.
- 8) **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.

#### 4.4 Physical Properties of GFRC

**i) 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 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 concrete. Alkali-resistant glass fibres are effective in controlling restrained shrinkage cracking of concrete and they promote multiple cracking and reduce crack widths.

**ii) 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, 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.

**iii) 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. Resistivity of concrete is influenced by many factors such as water-cement ratio, concrete composition, admixtures, curing condition, 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 completely dehydrated process which triggered 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 -

#### 4.5 HP 67/36 Characteristics:

##### 4.5.1 Benefits:

- 1) It is a resistant to alkali
- 2) It can control and prevent of cracking in fresh and hard concrete and mortars
- 3) Improve durability
- 4) It improves mechanical properties of hardened concrete
- 5) It provides excellent workability
- 6) It allows high dosages without affecting the workability
- 7) It is virtually invisible on finished surface
- 8) It does not corrode
- 9) ix) Its mixing becomes homogeneous
- 10) No additional water needed
- 11) Safe and easy to handle [10]

##### 4.5.2 Technical Characteristics:

- 1) Fibre length: 36 mm - 1½" inches (as per IRC: 15 - 2011)
- 2) Aspect ratio (length / diameter): 67
- 3) Specific Gravity: 2.68 g/cm<sup>3</sup>
- 4) Modulus of elasticity: 72 GPa -  $10 \times 10^6$  psi
- 5) Moisture: 0.3% max (ISO 3344:1977)
- 6) Material: Alkali Resistant Glass
- 7) Softening point: 860°C - 1580°F
- 8) Electrical Conductivity: Very low
- 9) Chemical Resistance: Very high
- 10) Tensile Strength: 1,700 MPa -  $250 \times 10^3$  psi [10]

##### 4.5.3 Advantages of HP 67/36 Glass Fibre:

- 1) 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.
- 2) 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.
- 3) 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]



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

#### 4.6 Fly Ash characteristics:

**4.6.1 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 a sub-bituminous ash to a high value of 2.96 for an iron-rich bituminous ash. Some sub-bituminous ash had a comparatively low specific gravity of  $\approx 2.0$ , 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 45 $\mu$ m sieve.

**4.6.2 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 ( $\leq 90\%$ ), 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.

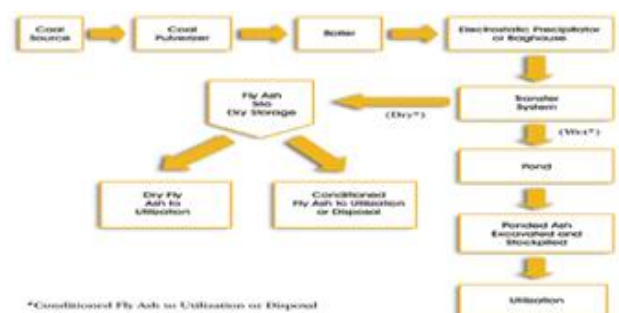
**Table 1:** Chemical compounds of Fly Ash

CHEMICAL COMPOUND	POZZOLAN TYPE			CEMENT
	CLASS F	CLASS C	CLASS N	
SiO <sub>2</sub>	54.90	39.90	58.20	22.60
Al <sub>2</sub> O <sub>3</sub>	25.80	16.70	18.40	4.30
Fe <sub>2</sub> O <sub>3</sub>	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 <sub>3</sub>	0.60	3.30	1.10	2.30
Na <sub>2</sub> O & K <sub>2</sub> O	0.60	1.30	1.10	0.60

#### 4.6.3 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 aggravate the surrounding environment and affect the biodiversity that is why ponds were built surrounding the plant and water store in it. The flying ash fall 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 –

- 1) Minimizing environmental impact of direct disposal,
- 2) Minimizing disposal costs,
- 3) Enabling other uses of the land since less area is reserved for fly ash disposal,
- 4) Procuring financial returns from the sale of the by-product,
- 5) 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:



**Figure 4:** Utilization of Fly ash

#### 4.7 Reason for inclination to fly ash-based glass fibre reinforced concrete

**A] 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, chance of disposing the old glass materials after



sometime 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 as 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.

**B] 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 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 emit smoke mixed with fly ash from the chimney. The smoke is disposed to the atmosphere along with some fly ash. But huge amount of fly ash uses to fall within the boundary of the plant. The dry fly ash being aggressive to 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.

## 5. Materials and Methods for GFRC

### 5.1 Materials for GFRC

**5.1.1 What is Concrete?** **Concrete:** Concrete is the most widely used construction material. The basic materials of concrete are Portland cement, water, fine aggregates i.e. sand and coarse aggregates. The cement and water form a paste that hardens and bonds the aggregates together. Concrete in 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 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 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 desire workability.



Figure 5: Concrete laying procedure

### 5.1.2 Materials for Casting:

The following materials were used in conducting my experiment in concrete laboratory situated in 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 experimental programme was obtained from 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 a good and durable concrete. The coarse aggregates were of two different grading 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 mix.
- Flyash:** Fly ash class F were used for 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 a 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<sup>3</sup>, tensile strength 1700 MPa and Young's Modulus 72GPa.

### 5.2 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 concrete beam in regard to obtain the flexural strength of the concrete product.

The lists of equipment's used in the laboratory by me are –

- 1) Balance with different capacities (digital)
- 2) Motorised Sieve shaker
- 3) Laboratory concrete mixtures
- 4) Needle vibrators
- 5) Curing tanks
- 6) Compression testing machine electrically operated
- 7) Universal testing machine



- 8) Flexural testing machine
- 9) Oven
- 10) Slump test apparatus
- 11) Vicat apparatus
- 12) Le chateleir apparatus
- 13) Mould (150mm×150mm×150mm)
- 14) Gauging trowel
- 15) Tamping rod
- 16) Beam mould  
(100mm×100mm×500mm),(150mm×150mm×700mm)
- 17) Cylindrical mould (150mm×300mm)
- 18) Aluminium boxes for measuring moisture contents
- 19) Specific gravity bottle
- 20) Bulk density voids and bulking apparatus
- 21) Metal tray
- 22) Measuring cylinders (25-1000ml capacity)
- 23) IS Sieve set 20 cm diameter, brass made, 10mm – 38 microns with pan & cover
- 24) 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 the clause 5.1.8. The nominal maximum size of coarse aggregate was 20mm.

### 5.3 Form Work

Form work may be defined as a temporary structure or a permanent structure used to contain poured concrete in 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 where 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 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 equipment's. In our case permanent moulds were used which are commercially available in market. However, for preparation of beams, moulds were specially ordered and procured from local steel fabricating shops.

### 5.4 Mixing of Concrete

Concrete can be prepared either by hand mixing or machine mixing. Hand mixing can be done in a plane levelled surface 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 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  $\frac{3}{4}$  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.

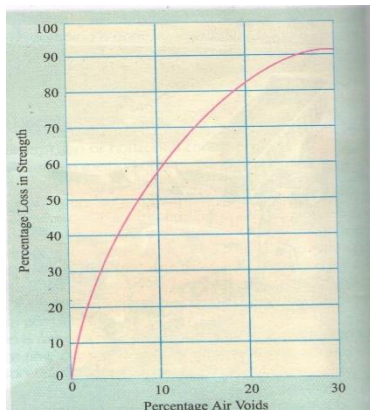
In case of machine mixing, machine drum must be clean and wrapped with a clean cloth and then moistened to prevent any loss of water during hydration. All the dry materials along with glass fibres and fly ash are put in the drum and then mixed thoroughly by rotating drum. After water is added in the 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 slurry is taken and put in the formwork as needed for concreting.



Figure 6 & 7: Different methods of concrete mixing

### 5.5 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 entered into the concrete. The amount of air will be higher for lower workability. Such air need 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 deficit of compaction is shown in the figure below –



**Figure 8:** Relationship between loss of strength and air-void space

It is observed at 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 are 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 a reasonable compacting equipment available in the site. The following methods are adopted for compacting the concrete –

(a) Hand Compaction

- (i) Rodding
- (ii) Ramming
- (iii) Tamping

(b) Compaction by vibration

- (i) Internal vibrator (Needle vibrator)
- (ii) Formwork vibrator (External vibrator)
- (iii) Table vibrator
- (iv) Platform vibrator
- (v) Surface vibrator (Screed vibrator)
- (vi) Vibratory Roller

(c) Compaction by Pressure and Jolting

(d) Compaction by Spinning

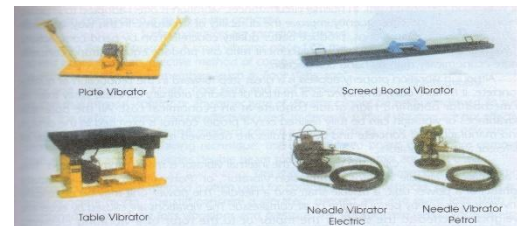
- (i) Hand Compaction:

Hand compaction of concrete is practiced 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 consist of rodding, ramming and/or tamping. In hand compaction the consistency of concrete is maintained at 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 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.

(ii) Compaction by vibration

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



**Figure 9:** Some vibrator equipment's



**Figure 10:** Concrete compaction procedure

## 5.6 Curing of Concrete

Curing of concrete play, a vital role to get the strength of concrete. The primary objective of curing is to complete full hydration process of concrete product to take place at 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 tank curing method was used for all specimens including the beams.



**Figure 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 steam 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 concrete must not exceed 75°C for more than 1 hour during the entire steam curing period. Sufficient moisture need to be provided inside the curing jacket so that all the surface of the concrete remains wet.

### 5.7 Mix Design

Please see Appendix A, B & C.

### 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: -

- 1) Cement – It is the basic binding material in concrete.
- 2) Water – It hydrates cement and also makes concrete workable.
- 3) Coarse Aggregate – It is the basic building component of concrete.
- 4) Fine Aggregate – Along with cement paste it forms mortar grout and fills the voids in the coarse aggregates.
- 5) 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: -

- i) Workability
- ii) Cohesiveness
- iii) Initial set retardation

#### Properties desired from concrete in hardened stage: -

- i) Strength
- ii) Imperviousness
- iii) 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 a most economical way.

#### Advantages of mix design:

Mix design aims to achieve good quality concrete at site economically.

I. Quality concrete means

- Better strength

- Better imperviousness and durability
- Dense and homogeneous concrete

#### II. Economy of mix design:

- 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.
- 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 type of aggregates to be used in 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.
- 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:

- i) Grade of concrete (designation) = M20
- ii) Type of cement = PPC 43 grade
- iii) Minimum nominal size of aggregate = 20 mm
- iv) Workability (slump) = 25 – 50 mm
- v) Exposure condition = mild
- vi) Method of concrete placing = normal
- vii) Degree of supervision = good
- viii) Specific gravity of cement = 3.15
- ix) Specific gravity of coarse aggregate = 2.74
- x) Specific gravity of fine aggregate = 2.74
- xi) Sieve analysis = zone 1 (IS 383 – 1970)

#### DESIGN:

##### Step 1: Target mean strength

$$f_{ck}' = f_{ck} + 1.65s \quad \text{From Table 1 of IS 10262 - 2009}$$

$$= 20 + 1.65 \times 4 \quad \text{standard deviation, } s = 4 \text{ N/mm}^2$$

$$f_{ck}' = 26.6 \text{ N/mm}^2$$

##### 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 =  $186 / 0.45 = 413.33 \text{ kg/m}^3$

From Table 5 of IS 456-2000,

Minimum cement content for 'severe' exposure condition =  $300 \text{ kg/m}^3$

$413.33 \text{ kg/m}^3 > 300 \text{ kg/m}^3$ , hence O.K.



**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 water-cement ratio is 0.45. Therefore, 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 volume of coarse aggregate is increased by 0.02 (at the rate of  $\pm 0.01$  for every  $\pm 0.05$  change in water-cement ratio). Therefore, corrected proportion of 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 volume of coarse aggregate may be required to 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 =  $1 \text{ m}^3$

b) Volume of cement = (Mass of cement / Specific gravity of cement)  $\times (1/1000)$   
 $= (413.33/3.15) \times (1/1000)$  [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 =  $\{a - (b+c)\}$   
 $= 1 - (0.131 + 0.186)$   
 $= 0.683 \text{ m}^3$

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

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

**Step 7: Mix proportions for trial number 1**

Cement = 413 kg

Water = 186 kg/m<sup>3</sup>

Fine aggregate = 730 kg

Coarse aggregate = 1142 kg

Water-cement ratio = 0.45

NOTE –(i)Aggregates should be used in saturated surface dry condition. If otherwise when computing the requirement of mixing water, 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.

(ii)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.

(iii)Two more trials having variation of  $\pm 10$  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, durability requirement shall be met.

**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:

i) Grade of concrete (designation) = M20

ii) Type of cement = OPC 43 grade

iii) Minimum nominal size of aggregate = 20 mm

iv) Workability = 25 – 50 mm (slump)

v) Exposure condition = mild

vi) Method of concrete placing = normal

vii) Degree of supervision = good

viii) Specific gravity of cement = 3.15

ix) Specific gravity of coarse aggregate = 2.74

x) Specific gravity of fine aggregate = 2.74

xi) Sieve analysis = zone 1 (IS 383 – 1970)

Design:

**Step 1: Target mean strength**

$f_{ck}' = f_{ck} + 1.65s$  From Table 1 of IS 10262 - 2009

$= 20 + 1.65 \times 4$  standard deviation,  $s = 4$

$f_{ck}' = 26.6 \text{ N/mm}^2$

**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<sup>3</sup> (for 25 to 50 mm slump range)

Maximum water content for 20 mm aggregate = 186 kg/m<sup>3</sup> [for 25 to 50 mm slump]

**Step 4: Calculation of cement and fly ash content:**

Water-cement ratio = 0.45

Cement content =  $186/0.45 = 413.33 \text{ kg/m}^3$

From Table 5 of IS 456-2000,

Minimum cement content for 'severe' exposure condition = 300 kg/m<sup>3</sup>

$413.33 \text{ kg/m}^3 > 300 \text{ kg/m}^3$ , hence, O.K.

From Table 5 of IS 456:2000

Minimum cement content for 'mild' exposure condition = 300 kg/m<sup>3</sup>

Above cement content value is  $> 300 \text{ kg/m}^3$  (Hence ok)

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

Cementitious material content =  $413.33 \times 1.10 = 454.66 \text{ kg/m}^3 \approx 455 \text{ kg/m}^3$

Water content =  $186 \text{ kg/m}^3$

So, water cement ratio =  $186/455 = 0.4088 \approx 0.41$

Fly ash @ 50% of total cementitious material content =  $455 \times 50\% = 227.5 \text{ kg/m}^3$

Cement (OPC) =  $455 - 228 = 228 \text{ kg/m}^3$

Fly ash being utilized =  $228 \text{ kg/m}^3$

Saving of cement while using fly ash =  $413 - 228 = 185 \text{ kg/m}^3$

#### 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 water-cement ratio of 0.50 = 0.60.

In the present case water-cement ratio is 0.45. Therefore, 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 volume of coarse aggregate is increased by 0.02 (at the rate of  $\pm 0.01$  for every  $\pm 0.05$  change in water-cement ratio). Therefore, corrected proportion of 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 volume of coarse aggregate may be required to 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 =  $1 \text{ m}^3$

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

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

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

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

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

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

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

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

So, 0.6 percent of cementitious product =  $(0.6/100) \times 456 = 2.74 \text{ kg/m}^3$

#### Step 7: Mix proportions for trial number 1

Cement (OPC) =  $228 \text{ kg/m}^3$

Fly ash =  $228 \text{ kg/m}^3$

Water =  $186 \text{ kg/m}^3$

Fine aggregate =  $682 \text{ kg/m}^3$

Coarse aggregate =  $1066 \text{ kg/m}^3$

Water-cement ratio = 0.41

Glass Fibre =  $2.74 \text{ kg/m}^3$

Note –

(i) Aggregates should be used in saturated surface dry condition. If otherwise when computing the requirement of mixing water, 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.

(ii) 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.

(iii) Two more trials having variation of  $\pm 10$  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, durability requirement shall be met. [11][12][13]

#### 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

$f_{ck}' = f_{ck} + 1.65s$  From Table 1 of IS 10262 - 2009  
 $= 20 + 1.65 \times 4$  standard deviation,  $s = 4$   
 $f_{ck}' = 26.6 \text{ N/mm}^2$

**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 =  $186 \text{ kg/m}^3$  (for 25 to 50 mm slump range)

Maximum water content for 20 mm aggregate =  $186 \text{ kg/m}^3$  [for 25 to 50 mm slump]

**Step 4: Calculation of cement and fly ash content:**

Water-cement ratio = 0.45

Cement content =  $186/0.45 = 413.33 \text{ kg/m}^3$

From Table 5 of IS 456-2000,

Minimum cement content for 'severe' exposure condition =  $300 \text{ kg/m}^3$

$413.33 \text{ kg/m}^3 > 300 \text{ kg/m}^3$ , hence, O.K.

From Table 5 of IS 456:2000

Minimum cement content for 'mild' exposure condition =  $300 \text{ kg/m}^3$

Above cement content value is  $> 300 \text{ kg/m}^3$  (Hence ok)

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

Cementitious material content =  $413.33 \times 1.10 = 454.66 \text{ kg/m}^3 \approx 455 \text{ kg/m}^3$

Water content =  $186 \text{ kg/m}^3$

So, water cement ratio =  $186/455 = 0.4088 \approx 0.41$

Fly ash @ 30% of total cementitious material content =  $455 \times 30\% = 136.5 \text{ kg/m}^3 \approx 137 \text{ kg/m}^3$

Cement (OPC) =  $455 - 137 = 318 \text{ kg/m}^3$

Fly ash being utilized =  $137 \text{ kg/m}^3$

Saving of cement while using fly ash =  $413 - 318 = 95 \text{ kg/m}^3$

**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 water-cement ratio is 0.45. Therefore, 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 volume of coarse aggregate is increased by 0.02 (at the rate of  $\pm 0.01$  for every  $\pm 0.05$  change in water-cement ratio). Therefore, corrected proportion of 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 volume of coarse aggregate may be required to 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 =  $1 \text{ m}^3$

b) Volume of cement = (Mass of cement/Specific gravity of cement)  $\times (1/1000)$

=  $(318/3.15) \times (1/1000)$

=  $0.101 \text{ m}^3$

c) Volume of fly ash = (Mass of fly ash/Specific gravity of fly ash)  $\times (1/1000)$

=  $(137/2.2) \times (1/1000)$

=  $0.062 \text{ m}^3$

d) Volume of water = (Mass of water/Specific gravity of water)  $\times (1/1000)$

=  $(186/1) \times (1/1000)$

=  $0.186 \text{ m}^3$

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

=  $1 - (0.101 + 0.062 + 0.186)$

=  $0.651 \text{ m}^3$

f) Mass of coarse aggregate = (e  $\times$  Volume of coarse aggregate  $\times$  Specific gravity of coarse aggregate  $\times 1000$ )

=  $0.651 \times 0.61 \times 2.74 \times 1000$

=  $1088 \text{ kg}$

g) Mass of fine aggregate = (e  $\times$  Volume of fine aggregate  $\times$  Specific gravity of fine aggregate  $\times 1000$ )

=  $0.651 \times 0.39 \times 2.74 \times 1000$

=  $696 \text{ kg}$

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

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

So, 0.6 percent of cementitious product =  $(0.6/100) \times 456 = 2.74 \text{ kg/m}^3$

**Step 7: Mix proportions for trial number 1**

Cement (PPC) =  $318 \text{ kg/m}^3$

Fly ash =  $137 \text{ kg/m}^3$

Water =  $186 \text{ kg/m}^3$

Fine aggregate =  $696 \text{ kg/m}^3$

Coarse aggregate =  $1088 \text{ kg/m}^3$

Water-cement ratio = 0.41

Glass Fibre =  $2.74 \text{ kg/m}^3$

Note –

(i) Aggregates should be used in saturated surface dry condition. If otherwise when computing the requirement of mixing water, 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.

(ii) 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.

(iii) Two more trials having variation of  $\pm 10$  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, durability requirement shall be met. [11] [12] [13]



## 6. 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.

### 6.1 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 concrete slurry for the above work in the concrete laboratory situated in 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°C.



**Figure 12:** Selfie taken by me on 12.09.18 while cube & beam casting & curing

### 6.2 The specimens cast as follows:

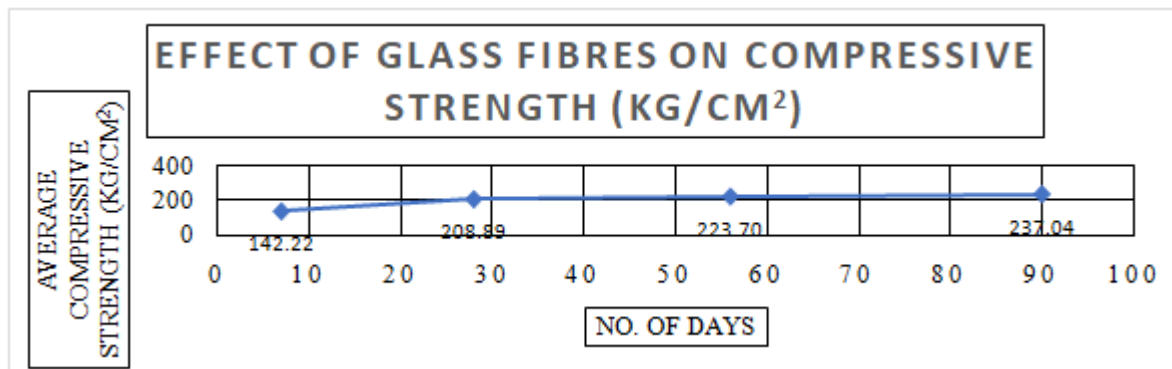
Initially the mould is applied with oil for lubrication. Concrete is laid in the mould. Concrete has been filled in both the Cube Specimens & Beam Specimens. The results obtained from the detailed experimental program conducted on M20 grade Fly Ash based Glass Fibre Reinforced concrete are presented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

### 6.3 Compressive Strength of Concrete (in N/mm<sup>2</sup>)

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 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 addition of fibres.

**Table 2:** Compressive Strength

Sr No.	Cube Specification	Grade of concrete	Age of specimen in days	Dimension of specimen in cm	Cross sectional area of specimen in cm <sup>2</sup>	Actual crushing load in Kg	Comp. strength in Kg/cm <sup>2</sup>	Average comp. strength in Kg/cm <sup>2</sup>	Specified limit for days Kg/cm <sup>2</sup>	
									7 days	28 days
1	1	M 20	7	15 × 15 × 15	225	31500	140.00	142.22		
2	2	M 20	7	15 × 15 × 15	225	32500	144.44		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	208.89		
5	2	M 20	28	15 × 15 × 15	225	47500	211.11			
6	3	M 20	28	15 × 15 × 15	225	47000	208.89			
7	1	M 20	56	15 × 15 × 15	225	50000	222.22	223.70		
8	2	M 20	56	15 × 15 × 15	225	51000	226.67			
9	3	M 20	56	15 × 15 × 15	225	50000	222.22			
10	1	M 20	90	15 × 15 × 15	225	53500	237.78	237.04		
11	2	M 20	90	15 × 15 × 15	225	53500	237.78			
12	3	M 20	90	15 × 15 × 15	225	53000	235.56			



**Figure 13:** Effect of Glass Fibres on compressive strength (kg/cm<sup>2</sup>)

### 6.4 Flexural Tensile Strength (in N/mm<sup>2</sup>):

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KOLKATA-700 096, INDIA  
☎ 9477246579

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

**Laboratory Test Certificate**

1. Test done for : Mr. Somsuhra 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 <sup>2</sup> )
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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We are recommending the average value of 4.12 and 4.36, that is  $(4.12+4.36)/2 = 4.24 \text{ N/mm}^2$

### 7. Economic Analysis of Glass fibre reinforced concrete

To make my economic analysis I have made 1 m<sup>3</sup> of concrete, the ingredients of which are

- 1) Portland Pozzolana Cement [PPC] of Ultratech brand;
- 2) Fine aggregates and
- 3) 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 the chapter 6 Results and Discussion. The test results obtained were satisfactory and the same are stated in the chapter 6 Results and Discussion. The cost for 1 m<sup>3</sup> as prepared above are given below in 'A'. The appropriate rates of the materials were collected from internet. The percentage ratio of cement and fly ash were taken as 70:30.

#### A) Cost per m<sup>3</sup> for GFRC with PPC used

**Table 3:** Cost per m<sup>3</sup> for high volume fly ash-based glass fibre reinforced concrete (M20)

S NO	Material	Rate (Per Kg)	Quantity Kg/m <sup>3</sup>	Cost (Per m <sup>3</sup> )
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 =  $\{(4977.00 - 4880.70)/4977.00\} \times 100 = 1.93\% \approx 2\%$

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

If 1 m<sup>3</sup> of concrete is prepared with the following ingredients –

- (i) Ordinary Portland Cement [OPC]
- (ii) Fine aggregate
- (iii) Coarse aggregate and
- (iv) Water as used in GFRC with PPC the cost per m<sup>3</sup> of concrete would come as follows in 'B'.

#### B) Cost per m<sup>3</sup> for conventional concrete (M20):

**Table 4:** Cost per m<sup>3</sup> for conventional concrete (M20)

S NO	Material	Rate (Per Kg)	Quantity Kg/m <sup>3</sup>	Cost (Per m <sup>3</sup> )
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<sup>3</sup> concrete is prepared with the following ingredients–

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

The cost per m<sup>3</sup> 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<sup>3</sup> for GFRC with OPC used:

**Table 5:** Cost per m<sup>3</sup> for high volume fly ash-based glass fibre reinforced concrete (M20)

S. NO	Material	Rate (Per Kg)	Quantity Kg/m <sup>3</sup>	Cost (Per m <sup>3</sup> )
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 =  $\{(4880.70 - 4744.90)/4744.90\} \times 100 = 2.86\% \approx 3\%$

From above it is inferred that if GFRC is made with OPC the cost per cubic meter of GFRC compared to cost per meter cube of conventional concrete will be cheaper by 3% as shown in the calculation. The decrease in cost of 3% seems reasonable compared to the different benefits obtained by using GFRC in concrete projects.

## 8. 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 a 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 facade of buildings. It has good resistance to alkalinity that contains in cement ( $\text{pH} > 12.3$ ) with high level.

GRC (In British term) can be used as alternative material of natural stone, especially in those countries where stone is less or unavailable.

Changing GRC panel is very easy as compared to other cladding because of making GRC by panel and just installing on the site. Also, 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 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 in earthquake prone areas.

## 9. Acknowledgement

I would like to express my gratitude to Prof. (Dr) Sudhir Kumar Das, PhD (Engg), visiting faculty in civil engineering department of Techno India college of Salt Lake, Sector V campus, who has kindly agreed to guide me in dissertation works on “High volume fly ash-based glass fibre reinforced concrete”. I express my sincere thanks to him for teaching us SE205B “Advanced Concrete Technology” in such a manner that I got “E” (Excellent) grade in the university exam on the above subject.

I would like to express my gratitude and offer my sincere thanks to Prof. (Dr.) Arup Saha Chaudhury, Head of Department in Civil Engineering Department of Techno India College, Salt Lake, Sector V Campus, who has allowed me to take up the dissertation works on “High volume fly ash-based glass fibre reinforced concrete”. I also thank him for allowing to do my practical works in the Concrete Lab set up in the college and the methodology of conducting the laboratory work.

I will be failing in my duty if I do not acknowledge Prof. Gaurav Ghosh regular faculty Engineering Department of Techno India, Salt Lake, Sector V, who has guided me in all laboratory works.

Last but not the least my sincere thanks goes to other faculties of the above Civil Engineering Department of Techno India, Salt Lake, Sector V, for supplying any other materials if any need for thesis so as to conduct my dissertation work.

## References

- [1] M.S. Shetty, Concrete Technology Theory & Practice, S. Chand & Company Ltd., Chapter 2, article Types of Cement-(j) Portland Pozzolana Cement (PPC).
- [2] IS 383: Coarse and Fine Aggregates From Natural.....[PDF]  
<https://gwssb.gujarat.gov.in/>downloads>
- [3] Anti-Crak® HP 67/36 – OCV Reinforcements.....[PDF]  
[www.ocvreinforcements.com/>library](http://www.ocvreinforcements.com/>library)
- [4] Fly ash – Wikipedia ..<https://en.m.wikipedia.org/>wiki> > Fly ash
- [5] Properties and Applications of Fiber Reinforced Concrete..... [PDF] <https://www.kau.edu.sa/>Files> > Researches
- [6] Fibreglass Reinforced Concrete – Uses, Advantages and Disadvantages ... [civilengineersforum.com > fiberglass-rei...](http://civilengineersforum.com/>fiberglass-rei...)
- [7] “Green” Building Material? – GRCA.....[PDF]  
<https://grca.org.uk/>pdf> > congress-



2011[8]shodhganga.inflibnet.ac.in/bitstream/10603/55381/8/08\_chapter%203.pdf

- [8] Advantages and disadvantages of using fly ash in concrete: [civilengineersforum.com/fly-ash-in-concrete-advantages-disadvantages/](http://civilengineersforum.com/fly-ash-in-concrete-advantages-disadvantages/)
- [9] ANTI-CRAK® HP 67/36 - OCV Reinforcements
- [10] [www.ocvreinforcements.com/.../CemFIL\\_AntiCrak\\_HP\\_6736\\_product\\_sheet\\_ww\\_10](http://www.ocvreinforcements.com/.../CemFIL_AntiCrak_HP_6736_product_sheet_ww_10)
- [11] IRC: 15-2011 INDIAN ROADS CONGRESS 2011 Standard Specifications and code of practice for construction of concrete roads
- [12] IS 456:2000 Plain and reinforced concrete – code of practice
- [13] IS 10262:2009 Concrete mix proportioning - guidelines

## Synopsis

**Synopsis of thesis:** 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 focussed. 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 of relevant information in regard to glass fibre reinforced based concrete. For this I had to go for different websites to get knowledge of 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 [photograph of the specimen shown in Fig.4.] have considerable influence on the design, efficiency, output and particularly the reliability and durability of the glass fibre-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 regard to design mix, specially its calculation has been annexed in Appendix – A and B after the 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 the conventional concrete has been stated in this chapter. It was found that percentage of saving per cubic meter of fly ash-based glass fibre reinforced concrete is to the tune of 3% compare 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.