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FRP COMPOSITES APPLICATION IN RC STRUCTURES

Dr. M. Mageshwari
(HOD, Department of Civil, Panimalar Engineering College)

Abishek P.V.S.S.S
(Department of civil, Panimalar Engineering College)

Ramkumar. V
(Department of civil, Panimalar Engineering College)

Abstract: The paper discusses the development of the advanced polymer composite material applications in the building and civil/structural infrastructure over the past three to four decades. Considering the advantages of steel reinforcing bar, replacement of rebar is not the best methods. It has been long felt need of construction industry to apply some protective coating on construction steels to protect from corrosion. Corrosion loss consumes considerable portion of the budget of the country by way of either restoration measures or reconstruction. The paper suggest that FRP coated application are of great interest for the building industry. This still quite new and needs to be researched further. The paper concludes that the usage of Epoxy primer and Zinc primer coated rebar sounds to be an effective method of preventing corrosion and to increase the service life..

INTRODUCTION

1.1 GENERAL

Several mechanical properties of reinforcing bars are important for purposes of design, including strength, ductility, and bond. The yield strength and tensile strength of the reinforcing steel are determined from uniaxial tension tests. The reinforcing steel must have sufficient ductility to enable fabrication and to ensure that structures can deform plastically at the ultimate limit state. The maximum plastic deformation of structures is a function of the maximum plastic strain, which is measured between the yield point and tensile strength.Considering the advantages of steel reinforcing bar, replacement of rebar is notthe best methods.

It has been long felt need of construction industry to apply some protective coating on construction steels to protect from corrosion. Recently Fusion bond epoxy re-bar has been sighted in the market but viewing some of its drawbacks, we are doubtful about its successful utility and acceptance over prolonged period.

Corrosion loss consumes considerable portion of the budget of the country by way of either restoration measures or reconstruction. There have been a large number of investigations on the problems of consequent corrosion of steel in concrete. Reinforced concrete is a versatile, economical and successful material. It is durable and strong, performing well throughout its service life. Nevertheless, the corrosion of reinforcing steel in concrete is becoming an issue in the collapse of the concrete structures as engineers maintain an aging infrastructure in recent years.

Many new systems and materials have been developed to delay the onset of corrosion and to increase durability. However it has only limited success in delaying the corrosion. In view of economical and engineering points, quantitative assessment of corrosion is also important.

1.2 CORROSION MECHANISM IN CONCRETE

Corrosionis a chemical reaction between metal and surroundings during which the metal is oxidized. It is mainly due to carbonation, chloride, acid, and sulphate attack. Following are the two electrochemical reactions that occur during thecorrosion of steel (Jones 1996):

- Anodic Reaction:

$$Fe \rightarrow Fe^{2+} + 2e^-$$

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$$

$$4\,Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3\ (rust) + 4H_2O$$

- Cathodic Reaction:

$$4e^- + 2H_2O + O_2 \rightarrow 4OH^-$$

$Fe(OH)_2$ is a weak base formed during the reaction and is unstable. In the presence of oxygen, another reduction reaction occurs and $Fe(OH)_2$ is converted into $Fe(OH)_3$ or rust, which precipitates out of solution.

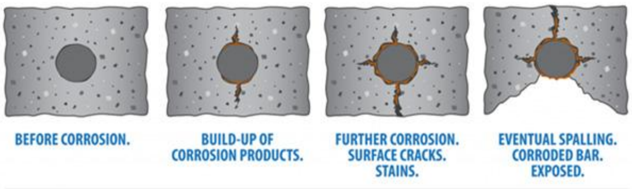

Fig 1.1 Corrosion Mechanism in concrete

Deterioration of concrete due to corrosion is a progressive process. Corrosion byproducts occupy a much larger volume than does the original reinforcing steel. This increase in volume creates high radial pressures and tensile forces in the concrete surrounding the steel and quickly causes cracking. There may be only a few early clues to indicate that corrosion is occurring beneath the surface, such as cracking, staining, or delaminating concrete. As corrosion continues, the concrete cover begins to spall. Structural distress may eventually result owing to the loss of cross-sectional areas of the reinforcement or the loss of bond from continued spalling.

Fig 1.2 Cracking of concrete

Fig 1.3 Spalling of concrete

1.3 CORROSION PREVENTION STRATEGIES

Careful attention must be given to the detailing of a structure during design and good construction practices must be followed for the likelihood of corrosion to be minimized. Several details and specifications that enhance corrosion resistance include

- » Increased concrete cover.
- » Use of low permeability concrete.
- » **Coated reinforcing bars.**
- » **Polymer-or latex modified concrete.**
- » Corrosion inhibitors.
- » Limited chloride content of concrete mix ingredients.
- » Waterproof membranes.

Each method has its own advantages and disadvantages.

1.4 SEQUENCE

The sequences of process that we have followed in our project are.

- ✓ Scope & Objective.
- ✓ Materials & Methodology.
- ✓ Preliminary Tests.
- ✓ Experimental Tests.
- ✓ Results & Conclusion.

1.5GLASS FIBERS

A fiber is material made up of long filament with a diameter generally in the order of 10µm. The length of glass fiber used ranges from 5cm - 6cm.The aspect ratio of length to diameter can be ranging from thousand to infinity. The peculiar characteristic is their high strength. Glass is mainly made of silicon (SiO_2) with a tetrahedral structure (SiO_4). Some aluminum oxides and other metallic ions are then added in various proportions to either case the working operations or modify some properties.

Material	Density (g/cm^3)	Tensile Modulus E (GPa)	Tensile Strength σ (GPa)	Specific Modulus (E/σ)	Specific Strength	Relative Cost
E-glass	2.54	70	3.45	27	1.35	Low

Table 1.1 Properties of E-glass fibers

Glass fiber is also available as thin sheets, called mats. A mat maybe made of both continuous and short fibers randomly arranged and kept together by a chemical bond. The width of this mat ranges from 5cm to 2m. The thickness of CSM is generally 1mm, their density being roughly 0.5 kg/m^2 and young's modulus of 70 GPa. FRP composites based on fiber glass are usually denoted as GFRP.


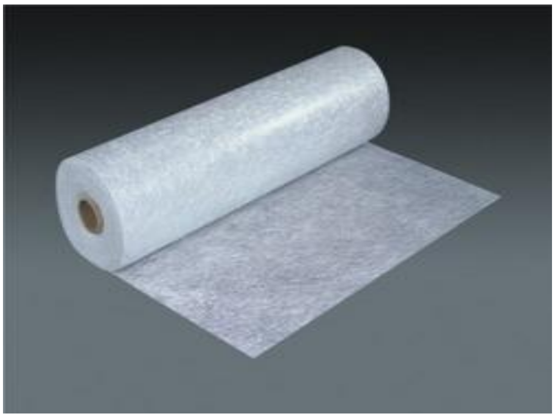

Fig 1.4 E-glass chopped strands Fig 1.5 E-glass chopped strand mat

1.6COATING INSTALLATION PROCESS

There are a few approaches for installing externally bonded FRP systems including either pre-cures or hand layup application. The hand layup method involves saturating the fibre mat with resin, applying the mat to steel bar surface, and then allowing the system to cure in-place. The bonding technique is the manual application of hand layup or wet layup using adhesive bonding. The FRP mat is bonded externally to enhance anti corrosion. The following procedure is followed.

Step #1 surface preparation: The surface of the rebar must be free of scale, oil and grease. The rebar should be dry and properly prepared.

Step #2 Prime the clean surface: The steel bar is protected by brushing on mix isothalic resin and to increase the bonding strength between FRP mat and rebar.

Step #3 Apply the FRP mat: After applying resin, FRP mat as corrosion barrier should be coated. Roll the chopped strand mat (CSM) over the steel rod.

Step #4 Bonding of FRP mat: During application of FRP mat the mix isothalic resin is applied with brush simultaneously. To ensure it bonds effectively and minimize the surface free of pin-holes, air pockets.

Step #5 Finishing: The rebar is left undisturbed to dry for period of 30 to 60 minutes. For best use let it dry for 24 hours.

Fig 1.6 FRP coated rebars

Fig 1.7Side view of coated rebar

1.7 STANDARDS USED

Grade of concrete	: M20
Type of rod	: Turbo Mechanically Treated Steel rod
Type of fibre	: E-glass chopped strand fiber
Type of coating	: E-glass chopped strand mat CSM 350
Mat type	: Continuous filament mat
Grade of cement	: 53 (OPC)
Size of sand used	: ZoneII
Size of aggregate used	: 10mm – 20mm

LITERTAURE REVIEW

“A science which hesitates to forget its founder is lost.”

- *Alfred North Whitehead*

Vladmir Zivica (April 2003) studied the causes for corrosion on reinforcement are studied where the action carbonation and chloride attack are given preliminary importance. The prime factor that causes corrosion are also specified that gives us a detailed outline about the environmental factors that induce corrosion. Out of these factors, humidity and pH are two parameters that has a direct effect on corrosion and thus by these features we get detailed sketch about terms of corrosion.

Ted R. Mortan (December 1973) in this paper talks about fiber glass reinforced plastics used in many applications; from boats to missiles. The article is mainly concerned with the use of fiber glass reinforced plastics for corrosion resistant applications. The paper reviews the properties of fiber glass reinforced plastics, various advantages in using fiber glass reinforced plastics and finally method of fabrication.

Anees U. Malik (March 2001) the paper dealswith studies carried out on the corrosion and mechanical behaviour of fusion bonded epoxy (FBE) coating on steel in aqueous media which include product water, distilled water and saline water. The mechanical testing’s on coating include adhesion, bending and Cathodic disbondment testing. The corrosion studies include immersion testing under static and dynamic conditions, autoclave tests and accelerated (salt-fog) tests. These test where used for our project reference.

Alsayed S.H.(August 2000) studied therole of fiber reinforced plastic (FRP) bars to reinforced concrete structures necessitates the need for either developing a new design code or adopt the current one to account for the engineering characteristics of FRP materials. The paper suggests some modifications to currently used ACI model for computing flexural strength, service load deflection, and the minimum reinforcement needed to avoid rupturing of the tensile reinforcement so as to use them when reinforcement is provided by GFRP bars.

William J. Gold (November 1998) studied about the use of externally bond reinforcement. The FRP Fiber reinforced polymer (FRP) materials are continuing to show great promise for use in strengthening reinforced concrete (RC) structures. These materials are an excellent option for use as external reinforcing because of their light weight, resistance to corrosion, and high strength. Methods of FRP sheet based on delamination of the sheet from the concrete surface are presented. The method of external lamination was identified and implemented in our project of coating the rebar with FRP.

M.R. Ehsani (March 1996) in this paper talks about design guidelines for bond strength of glass fiber reinforced plastic rebars to concrete. Various specimens were tested to monolithic static loading. The tensile load was applied to the rebars ingradual increment of load level until pull out failure occurs. The slip between the rebars and concrete was measured at the loaded free ends at each load level. New criteria for acceptable bond performance of GFRP rebars to concrete were developed and were used to evaluate experimental results.

Kim D. Basham (October 1999) studied the choices in corrosion resistant rebar. A comparison of the features, performance, and cost of rebar options because corrosion of reinforcement can result in concrete cracking, staining, spalling and costly repairs, corrosion-resistant reinforcement often is the obvious choice for concrete structures exposed to high chloride levels. What isn't so clear-cut is the best type of rebar to use for a particular project. Epoxy-coated, galvanized, glass-fiber-reinforced-polymer, solid stainless steel, and stainless-steel-clad reinforcing bars all are designed to resist corrosion. Before selecting one of these products for your next job, you should consider such factors as initial cost, construction concerns, degree of corrosion resistance, and long-term performance.

Nishikant Dash (June 2009) studied aboutFiber-reinforced polymer (FRP) application is a very effective way to repair and strengthen structures that have become structurally weak over their life span. FRP repair systems provide an economically viable alternative to traditional repair systems and materials. FRP repair systems provide an economically viable alternative to traditional repair systems and materials.Experimental investigations on the flexural and shear behaviour of RC beams strengthened using continuous glass fiber reinforced polymer (GFRP) sheets are carried out. Externally reinforced concrete beams with epoxy-bonded GFRP sheets were tested to failure using a symmetrical two point concentrated static loading system. The detail procedure and application of GFRP sheets for strengthening of RC beams is also included. The effect of number of GFRP layers and its orientation on ultimate load carrying capacity and failure mode of the beams are investigated. The effective use of GFRP sheets was identified from this paper.

A. Sivakumar (November 2006) This paper focuses on the experimental investigation carried out on high strength concrete reinforced with hybrid fibres (combination of hooked steel and a non-metallic fibre) up to a volume fraction of 0.5%. The mechanical properties, namely, compressive strength, split tensile strength, flexural strength and flexural toughness were studied for concrete prepared using different hybrid fibre combinations. Addition of steel fibres generally contributed towards the energy absorbing mechanism whereas, the non-metallic fibres resulted in delaying the formation of micro-cracks.

B.L.P. Swami (October 2011) studied about Glass fibers in cement mortar. It has been tried in applications like architectural features, panel walls, tunnel lining etc. The present paper outlines the experimental investigation conducted on the use of glass fiber with structural concrete. CEMFIL Anti Crack High Dispersion, Alkali resistant glass fiber of diameter 14 micron, having an aspect ratio of 855 was employed in percentages, varying from 0.2 to 1.5 in concrete and the properties of this FRC (Fiber Reinforced Concrete) like compressive strength, tensile strength, and flexural strength were studied. In addition by employing steel fiber along with glass fiber in concrete, the properties of Mixed Fiber Reinforced Concrete (MFRC) were also studied. Conclusions are drawn on properties like strength, ductility and crack resistance of structural concrete.

SCOPE & OBJECTIVE

3.1 SCOPE

The scope of this research project is to investigate the performance of newtype of material coating for concrete reinforcement in corrosive environments and their effects on the concrete-reinforcement bond. The purpose of this study was to identify types of new materials that would be suitable for reducing the effects of reinforcement corrosion in concrete.

3.2 OBJECTIVE

The conventional approach to improve the corrosion resistance of steel rebar is to apply a coating, like epoxy, that provides a physical barrier to the corroding environment.The overall goal of this study is to optimize this new type of fiber reinforced plastic material coated rebars for the construction of RC structures in various applications, with the objective of reducing construction and maintenance costs and improving structural performance. The main objectivetasks that would together achieve overall goal of the project include.

- Characterize the corrosion resistant properties of coated rebar in alkaline environments, including reinforced concrete.
- To study the best corrosion resistant rebars suitable for RC structures.
- To study the mechanical properties of thermo mechanically treated steel rebar.
- To study the corrosion effects on rebars and method to control it effectively.

- Characterize the bond strength between FRP coated steel rebar and concrete.
- To study flexural strength characteristics of concrete by addition of fiber glass reinforced plastics.
- To study the feasibility of using Fiber Glass composites in reinforced concrete construction.
- To reduce corrosion effects in concrete by inclusion of glass reinforced plastics.

The results of this study should be of benefit in the selection of more corrosion resistant coatings and metals for concrete reinforcement. This research should also help develop a more efficient method to evaluate the corrosion and bond performance of new materials.

MATERIAL & METHODOLOGY

The selection of the materials used for the casting have been done based on basic preliminary tests that are conducted and compared to the criteria as stated in their respective codes. The tests that have been performed on the materials and their results are listed below under their respective material chapters.

4.1 CEMENT

The cement used to cast is Jaypee 53 grade Ordinary Portland cement. The specific gravity of cement is 3.16. As per code the limiting value of specific gravity of cement ranges from 3.15 – 3.25.

4.2 FINE AGGREGATE

The fine aggregate is from river bed, clear from all sorts of organic impurities was used in experimental program. The fine aggregate was passing through 4.75 mm sieve and had a specific gravity of 2.53.As per code the limiting value of specific gravity of cement ranges from 2.25 – 3. The grading zone of fine aggregate was zone II as per Indian Standards specification.

4.3COARSEAGGREGATE

The coarse aggregate used were available in local quarry. The size of aggregate used is 10mm – 20mm. The coarse aggregate was passing through 40mm sieve and had specific gravity of 2.68. As per code the limiting value of specific gravity of cement ranges from 2.4 – 2.9. The grading zone of coarse aggregate was zone II as per Indian standards.

4.4 PRELIMINARY TESTS

The tests performed for the cement, fine aggregate and coarse aggregate are listed below.

4.4.1 SETTING TIME TEST

The aim of this test is to find out the initial and final setting time of the cement sample used for the casting. This test is done using Vicat apparatus and Vicat needle. About 500g of cement with the percentage of water required for normal consistency is used. The specimen is placed in moist room for 30 minutes then the needle was released and the settlement of needle is measured. The initial setting time was 28 minutes and final setting time is 530 minutes.

4.4.2SIEVE ANALYSIS

The sieve analysis test is performed to obtain a distribution of grain size larger than 75 microns of a soil and classify the coarse grain soil. The aggregates are sieved in a sieve shaker for about 5 minutes. The test was performed for 20mm, 10mm aggregates and the river sand obtained for our project. Comparing the test results with IS 383 – 1970 fine aggregate & coarse aggregate comes under zone II.

4.4.3SLUMP TEST

The aim of this test is to determine the workability of the cement concrete to be used. The mix is prepared and placed in a clean mould and tampered and the top of the cone is levelled off. Then the mould is lifted up vertically and the nature of the slump is analyzed to get the workability of the given cement concrete sample. For the water cement ratio of 0.45 the slump obtained was 26mm which was favourable workability level and was within permissible limit as per IS code 456.

4.4.4 SPECIFIC GRAVITY TEST

This test is done to determine the specific gravity value of the aggregates used. It is done using pyconometer. The test for the river sand, 10 mm aggregates&20mm aggregates are performed separately.

4.4.5 WATER ABSORPTION TEST

This test is performed in order to determine the water absorption capacity of the aggregate used. Here about 1 kg of various aggregate is taken separately and immersed in water for about 24 hours. These aggregates are then kept in oven at a temperature of 100 C˚ to 110 C˚ for a time of 3 hours and brought to SSD condition. The change in weight is noted as per code the limiting value for water absorption is 2%. The results of the aggregates tested are 1% for fine aggregate and 0.5% for coarse aggregate.

4.5 CONCRETE

The grade of concrete chosen is M20 grade. The concrete selection criteria tests performed are mentioned below.

4.6 REINFORCING STEEL BAR

I steel HYSD bars of 12mm φ were used for test purpose. TMT bars were selected for experiment.

4.7 MIXING & COMPACTION

Mixing of concrete should be done thoroughly to ensure the concrete of uniform quantity is obtained. Hand mixing is done in all small works, while machine mixing sometimes maybe necessary. All specimens were compacted by using tamping rod. Finally the surface of the concrete is levelled, finished and smoothened by metal trowel.

4.8 CURING OF CONCRETE

The concrete is cured to prevent or replenish loss of water which is essential for the process of hydration and hence for hardening. Curing of concrete makes it stronger, durable, permeable, and resistant to abrasion. The concrete is cured for 7, 21, and 28 days respectively.

EXPERIMENTAL TEST PROCEDURE

The following tests were carried out on coated sample to check its feasibility of using reinforcement steel bars in construction. The results may provide reference for future design of concrete structures in surrounding environment.

5.1MECHANICAL TEST

The mechanical test was carried out according to IS 1608:1995 code procedure. Adjust the universal testing machine (UTM) for the selected range of load. The steel bar is cut to length of 20cm and a gauge length of 60mm. Take a convenient length of the specimen and mark at the centre. From the mark 50mm on either side using dot punch and hammer. Care must be taken to provide at least 50mm for grip on both ends. Measure the diameter of the given specimen at least at 3 different places with vernier calliper and determine the average diameter of the specimen.

Fig 5.1 Measure diameter of bar Fig 5.2 Marking gauge length

Fix the specimen in the grips between the movable and the fixed cross heads. Adjust the load stabilizer start the oil pump and open the inlet valve slightly. When the load pointer kicks it indicates that the rod is held tight between the grips. Then adjust the pointer to zero. Apply the load at a steady uniform rate. At a particular stage there will be a pause in the increase in the load. The load at that position is noted down as yield point load. Apply the load continuously when the load reaches the maximum valve both the actual pointer and dummy pointer which has been accompanying it will remain stationary.

Fig 5.3 Fix the bar in the grips of UTM Fig 5.4Load application of UTM

Record the maximum load reaches as ultimate load. After some time the actual pointer returns slowly. At this stage a neck is formed in the specimen and the specimen breaks. Note the position of actual pointer during breaking. Record this load as breaking load. After breaking remove the specimen from the grips. A typical cup and cone fracture is observed. Measure the final gauge length of the specimen. The data of the test is noted in computer during the test by default it is setup. The graph of load versus deformation and load versus elongation is shown on the computer. After the test all the other parameters like ultimate load, area in mm^2, elongation can be observed.

5.2SALT SPRAY TEST

Basically, the salt spray test procedure involves spraying of a salt solution onto the samples being tested. Cleaning of rebar is optional or as per code suggestion test specimen is prepared. The samples being tested are inserted in the chamber. The rebar are positioned such that they are suspended 15˚ to 30˚ from the vertical & preferably parallel. It shall not come in contact with other specimen at any point of time. Salt solution from one specimen shall not dip on any other specimen.

Fig 5.5 Specimens for salt spray test

Starting from left: Epoxy primer coated rebar, Zinc chromate coated rebar, FRP coated rebar, Nito zinc primer coated rebar, Epoxy paint coated rebar, Normal rebar.

Salt spray test is done inside a temperature-controlled chamber. Typically, the solution is a 5 ±1 parts by mass sodium chloride in 95 parts of water solution. The salt-containing solution is sprayed as a very fine fog mist over the samples. The temperature within the chamber is maintained constant. The pH of salt solution shall be such that when atomized at 35˚c the collected solution will be in pH range from 6.5 to 7.2. Measurement is made at 25˚c using pH meter.

Through the years, there have been some new twists added to better simulate special environmental conditions, but the most common procedure by far is the test described in ASTM B 117 Standard Practice for Operating Salt Spray (Fog) Apparatus. Within the chamber, the samples are rotated frequently so that all samples are exposed as uniformly as possible to the salt spray mist. Test duration can be from 24 to 480 hours, or longer in some cases. Since the spray is continual, the samples are constantly wet, and thus, constantly subject to corrosion.

Fig 5.6 Saltspraychamber Fig 5.7Placingthe rebar

When the salt spray test is used for testing, the corrosion performance is rated in the following ways:

- ✓ Number of hours until rusting of the steel is first evident.
- ✓ Number of hours until 5% of the surface area is rusted.

The onset of red rust on a samplemeans that the coating has been consumed by the corrosion reaction, and the corrosion of the base steel is beginning.

5.3 PULLOUT TEST

The pull - out test were carried out according to IS 2771 part I procedure. Pull -out tests were performed in order to measure the interfacial strength between the rebar and a concrete matrix. The tests were performed on the composite rebars partially encased in a 150 × 150mm cube of concrete. The FRP coated rods were cut into 1m lengths. The rebars were held by a retort stand at the centre of the 150 × 150mm cubic moulds, as concrete was cast inside the moulds to provide samples for the pull-out test, as shown in figure 5.8 and 5.9 respectively.

Fig 5.8Rebar setup in mould Fig 5.9Typical Form for Pull out

During the pull-out test the composite rebar was gripped by the cross head of the 600 kN testing machine while the concrete cube was secured to the loading frame. Nuts and studding were used to prevent splitting of the concrete cube. The loading configuration is shown in figure 5.10 and 5.11 respectively.

Fig 5.10Secure the sample in UTM

Fig 5.11 Pull-out loading setup

Pull-out tests were carried out on three sets of samples, one isFRP coated rebar and the other isplain circular rebar. Pull - out tests were carried out at room temperature. The samples were made and tested to evaluate the bond strength of the FRP coated rebars to the concrete under various conditions. The standard diameter, maximum diameter and nominal cross section of the rebars were, 12.78mm, and 150.32 mm^2 respectively. After initializing the setup a Linear displacement dial gauge (0-5mm calibration) is placed at the free end of the sample below the cube. The average load at slip of 0.025mm and 0.25mm is noted using the dial gauge. The load is increased steadily average loads at slip and maximum load at failure is observed. Type of failure mode is studied at the end of the experiment.

5.4 FLEXURAL STRENGTH TEST

The flexural strength test was carried out according to IS 516-1959 code procedure. After curing period is over the beam is removed for testing. The most commonly used load arrangement for testing of beams will consists of two point loading system. The size of the beam is 100 × 100 × 500mm. The test member is supported on roller bearings acting on similar spreader plates.

Fig 5.12 Adding fibers during mixingFig 5.13Placing beam in system

The specimen was placed over the two steel rollers bearing leaving 5cm from the ends of the beam. The remaining 40cm is placed on point load arrangement. Loading was done by hydraulic jack capacity of 100kN. Dial gauges were placed below the point loads to measure deflection.

Fig 5.14 Failure of beam

Fig 5.15 Dial gauge reading

Before testing the member was checked dimensionally, and a detailed visual inspection made with all information correctly recorded. After setting and reading all gauges, the load was increased incrementally up to the calculated working load, with loads and deflection recorded each time. Loads will then normally be increased again in similar increments up to failure. The deflection at this stage is large and easily measured from the distance. Cracking and failure mode was checked visually, and a load/mix proportions plot was prepared.

The flexural strength of the specimen shall be expressed as the modules of rupture 'fb' which if 'a' equals the distance between the line of fracture and the nearer support measured on the centreline of the tensile side of the specimen, in cm, the flexural strength shall be calculated to the nearest 0.5 kg/cm^{2}when 'a' is is greater than 13.3cm for a 10cm specimen.

$$fb = \frac{p \times l}{b \times d^2}$$

Where

fb is modulus of rupture
p is Maximum load applied to specimen before failure
l is span of the beam in cm.
b is breadth of the beam in cm.
dis depth of the beam in cm.
a is distance between the line of fracture from the nearest support

RESULTS & DISCUSSION

The results of our project work can be divided into two phases. Phase 1 FRP coated rebar test analysis and Phase 2 Glass fiber reinforced concrete test analysis.

#PHASE 1 FRP COATED REBARS EVALUATION

6.1 MECHANICAL TEST

6.1.1 Tensile Test

The primary objective of tensile testing program was to determine stress – strain curve of FRP coated rebar. The computerised stress – strain curve is shown in figure 6.1.

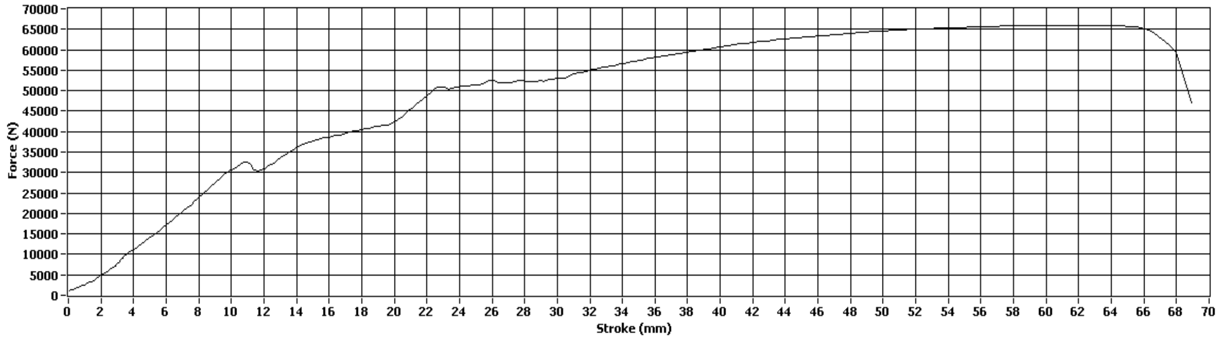

Fig 6.1Computerised stress - strain curve

The average ultimate strength from tensile loading of the FRP coated rebar was found to be slightly higher than the manufacturer's specification for uncoated rebar. The yield and ultimate tensile stress of the FRP coated rebar were determined by stress – strain curve. The ultimate tensile and yield stress observed are 583.40 Mpa & 448.46 Mpa respectively. The maximum test load is 65.99 kN. The original gauge length of rebar was 60mm and increased gauge length is 75.7mm. The elongation of the specimen was expressed as a percentage of the original gauge length to final gauge length. The percentage elongation of FRP coated rebar is 26.17 %.

6.2 SALT SPRAY TEST

6.2.1 Corrosion Results

SPECIMEN	TOTAL NO OF HOURS	NO OF HOURS UNTIL CORROSION	REMARKS
FRP coated	168	-	No signs of corrosion
Zinc Chromate Primer coated	168	70	Red rust appeared
Epoxy Primer coated	168	-	No signs of corrosion
Nito Zinc Primer coated	168	119	Red rust appeared
Epoxy Paint coated	168	49	Red rust appeared
Normal rebar	168	21	Red rust appeared

Table 6.1 Salt spray test results

6.2.2 Loss in Weight Ratio Table

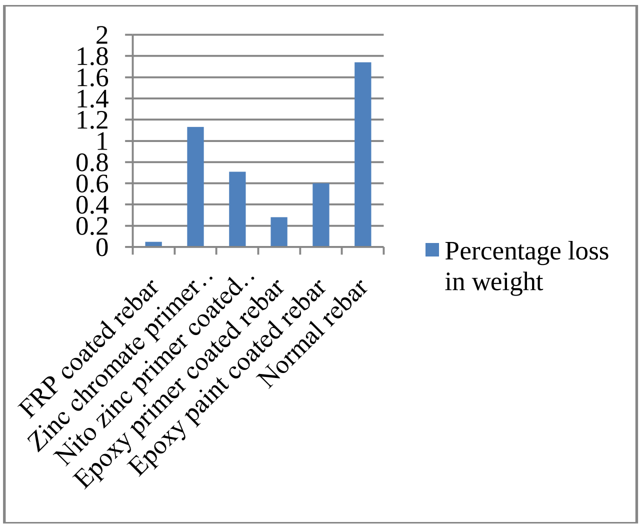

Fig 6.2Percentage Loss in Weight Ratio

Among all the rebars used the comparison level of resistance shown by each rebar was done with the normal rebar. The normal rebar showed a percentage loss of 1.74 %. This is due to corrosion action without any artificial resistance substance brought into action for the rebar to resist. The FRP coated rebar has shown maximum resistance with loss in percentage in weight ratio followed by epoxy primer coating. From the above table we conclude that on the basis of loss in weight the FRP coated rebar shows maximum resistance and is recommendable.

6.3 PULL OUT TEST

Pull out type specimens have been used extensively in an attempt to quantify the bond capacity between FRP coated rebar and plain circular rebar.In this section, the results of the pull out tests for each of the bars tested are individually presented in figure 6.3, 6.4 and 6.5 respectively.

Three samples were tested to determine pull out strength. Each sample consists of one plain rebar and FRP coated rebar. The comparison of the rebar includes average load at slip at 0.025mm, 0.25mm and average maximum load at failure. The comparison results are shown below.

6.3.1 Sample 1

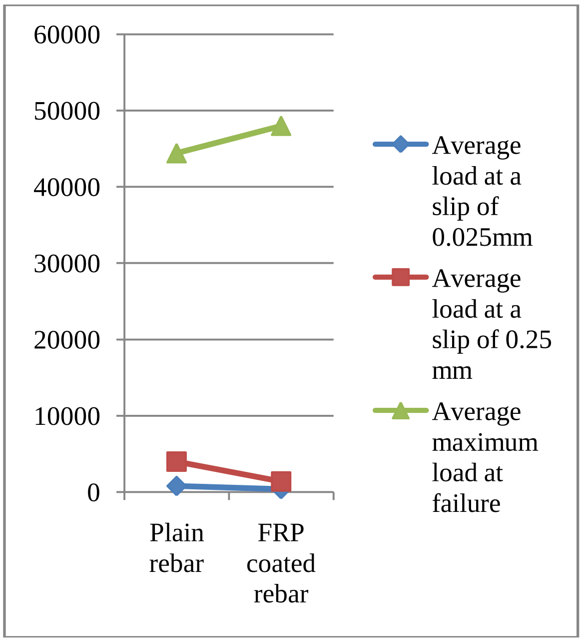

Fig 6.3 Load at slip & maximum load at failure sample 1

6.3.2 Sample 2

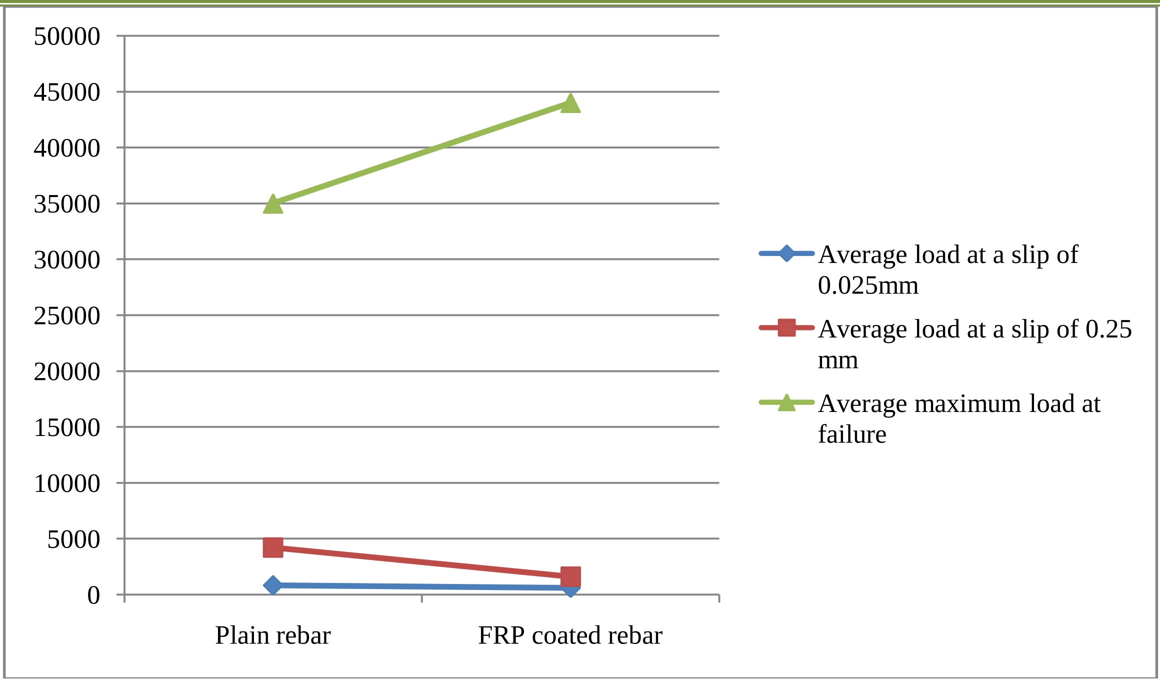

Fig 6.4 Load at slip & maximum load at failure sample 2

6.3.3 Sample 3

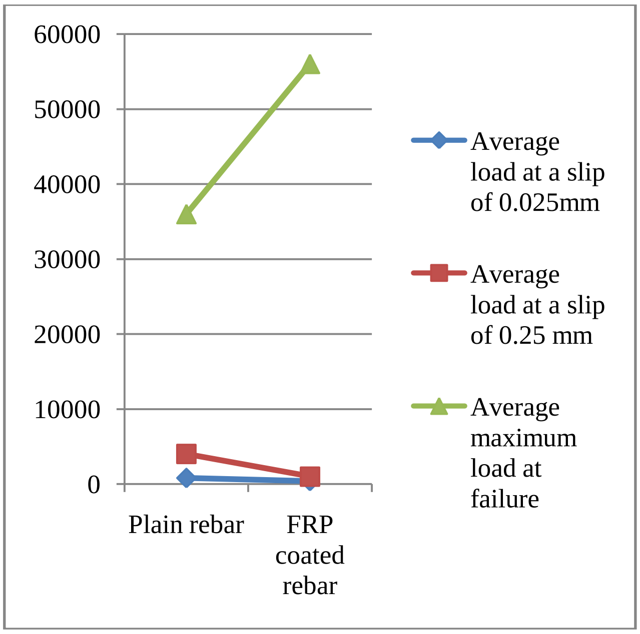

Fig 6.5 Load at slip & maximum load at failure sample 3

The average load at a slip of 0.025 mm and 0.25 mm were observed and the plain rebar was found to be effective than FRP coated rebar. On analysing the average maximum load of failure significantly FRP coated rebar gives much more bond strength than plain rebar.

The average pull out strength of FRP coated rebar was greater than the average pull out of plain circular rebar. The FRP coated rebar shows 30 % increase in average maximum load of failure than plain circular rebar. So it confirms to IS code standards and can be effectively used in the construction process in place of plain rebar.

6.3.4 Failure modes

Typical failure of the two specimens coated and plain rebar are presented in figure6.6and 6.7 respectively. FRP coated bars and plain steel bars have been pulled out from the concrete cube. Neither the bars nor the concrete cubes were broken.

Fig 6.6 No failure in cubes

Fig 6.7 No failure in bars

#PHASE 2 GLASS FIBER REINFORCED CONCRETE EVALUATION

6.4 FLEXURAL STRENGTH TEST

The flexural strength is obtained for various fiber volume fractions and the variations of flexural strength with respect to fiber volume fraction are presented in Figure 6.8.

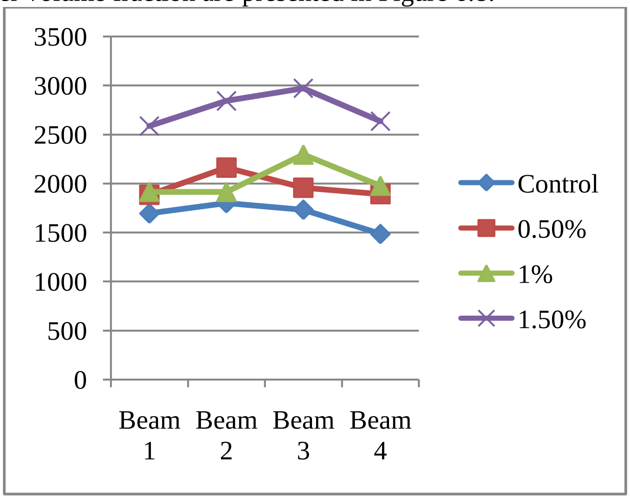

Fig6.8 Flexural strength results of beam

From flexural strength test it could be inferred that the flexural strength of beam with 1.5 % glass fibers shows almost 65 % increase in strength when compared to control beam. This significant increase in flexural strength with increase in fiber content maybe due to the random orientation of fibers, the ability of fiber to take up some part of the flexural load, good bonding between the fiber and concrete, a high length to diameter ratio which makes the fibers working like reinforcing agents. The fibers occupy high volume; hence it is almost impractical to use them in quantities more than 2 % of weight of concrete matrix.

TEST PREMISES

» The mechanical testing and Salt spray test were carried out at the “Omega Inspection & Analytical Laboratory”, Chennai 32.

» The pull – out test were tested in loading frame of the "Ministry of Micro, Small & Medium Enterprises (MSME) Testing Centre", Chennai 32.

» All the beam specimens were tested in the loading frame of the "Highway & Concrete Laboratory" of Panimalar Engineering College, Chennai 123.

SUMMARY & RECOMENDATION

8.1 SUMMARY

The various corrosion resistant rebar prevalently used in working applications are given below in figure 7.1.The comparisons are made with Epoxy coated, Zinc coated, GFRP, Solid stainless steel rebar by Kim D. Basham.A comparison of the features, performance, and cost of rebar were made. This was helpful in making correct observation of FRP coated rebars. The main purpose of this project is to bring the Performance of GFRP bars by not replacing steel rebar.

Comparison of corrosion-resistant rebar

Type of rebar	Times more corrosion resistant than black rebar	Scratch and chip resistance	Bending	Cutting	Welding	Chloride threshold	Cost, $/lb[1]
Epoxy-coated ▪ Damage level 0.5% ▪ Damage level 0.004%	150 to 1,175 69 to 1,762	Easily damaged, requiring field repairs	Allowed but can damage epoxy coating	Allowed; coating of cut end required	Allowed; coating of weld required	Same as black rebar Very high	0.32
Galvanized (zinc-coated)	38	Very tough; hard to damage	Allowed but may weaken coating	Allowed; coating of cut end required	Allowed; coating of weld required	4 to 10 times higher than black steel	0.50
GFRP	Won't corrode	Fairly tough; difficult to damage	Field bends not allowed	Allowed; sealing of cut end may be required	Nonweldable	Immune to chloride attack	3.00 to 4.00[2]
Solid stainless steel	800 to 1,500	Not an issue	Allowed	Allowed	Allowed; special welding procedures apply	15 to 24 times higher than black rebar	1.60
FRP-coated	Same as GFRP	Nearly impossible to damage	Allowed	Allowed; coating of cut end may be required	Allowed	Same as GFRP	0.6

Fig 7.1 Choices in Corrosion resistant rebar

8.2 RECOMMENDATION

Even though the hand layup technique is the best way of coating FRP coated rebars. There is a significant disadvantage using it since there is no threading on the coated rebar. The bond strength between concrete and rebar is reduced has discussed in chapter 6. In order to overcome this problem Spray up technique is recommended. This is very similar to hand layup technique. Spray up is simply automated way of depositing the chopped glass. Glass in continuous fiber form is pulled through gun head and sprayed at mould. At same time, catalyst and resin are sprayed through the gun head. Thus all deposited at the same time. By this method the bond strength can be achieved.

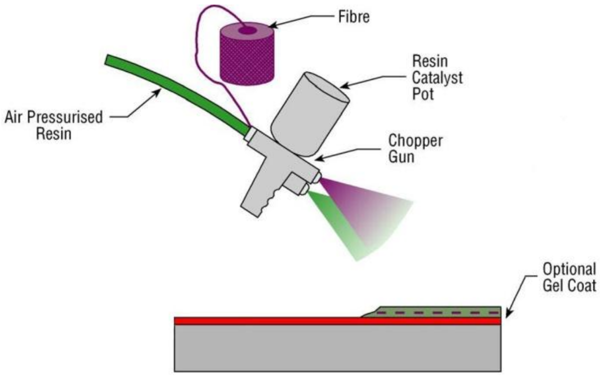

Fig 7.2 Spray up technique used for coating

The bonding of FRP material to the concrete can be solved by using anchors fastened to bar ends to prevent slip in the concrete.

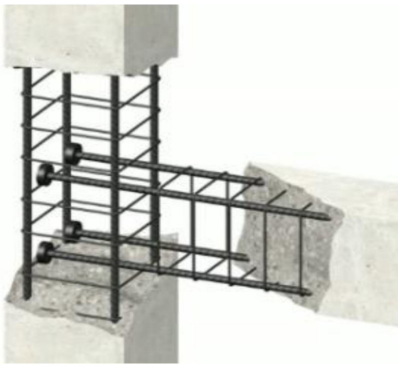

Fig 7.3 Anchors at bar end to prevent slip

CONCLUSION

The conclusions obtained by investigation carried out in the laboratory were already given in detail at the end of each related chapter. Based on important findings derived from each phase, the following major conclusions can be made regarding the effectiveness of the FRP-coated reinforcing steel bars and glass fiber reinforced concrete.

- Excellent corrosion protection system.
- Extended service life.
- Increase durability of reinforced concrete structures.
- Repair and rehabilitation cost is reduced.
- Easily handled and highly sustainable.
- Increase in flexural strength due to addition of glass fibers.

Based on the test results it is concluded FRP coated application are of great interest for the building industry. This still quite new and needs to be researched further. By our research & experiment, we came to know the usage of Epoxy primer and Zinc primer coated rebar sounds to be an effective method of preventing corrosion and to increase the service life. But in the field once the structure shows any signs of failure the replacement process of these coated bars becomes tedious whereas FRP coated rebar application at the site during repair and rehab process is at ease and its resistance to corrosion also being high it is highly recommendable. Thus the effective means of preventing corrosion in perspective of site usage is by FRP coated rebar application.

APPENDIX- A

A.1 WATER ABSORPTION TEST

A.1.1 Aggregate

Water absorption $=\frac{w_1-w_2}{w_1}\times 100$

Weight of saturated surface- dried sample in grams = W_1

Weight oven dried sample in grams = W_2

Sample: Fine Aggregate

Weight of saturated surface- dried sample in grams (W_1) = 306

Weight oven dried sample in grams (W_2) = 303

Water Absorption = $\frac{306-303}{303}$ x 100 = 1%

Sample: Coarse Aggregate

Weight of saturated surface- dried sample in grams (W_1) = 304.5

Weight oven dried sample in grams (W_2) = 303

Water Absorption = $\frac{304.5-303}{303}$ x 100 = 0.5%

A.2 SPECIFIC GRAVITY TEST

A.2.1 Cement

Specific gravity = $\frac{(w_2-w_1)}{(w_2-w_1)+\{(w_4-w_3)\text{specific gravity of kerosene}\}}$

Weight of empty bottle = W_1

Weight of bottle + Soil = W_2

Weight of the bottle + Soil + Water = W_3

Weight of the bottle + Water = W_4

Specific gravity of kerosene = 0.82

S.No	Determination	Grams
1	Weight of pyconometer (W_1)	41
2	Weight of pyconometer + mass of dry soil (W_2)	50
3	Weight of pyconometer + soil + water (W_3)	90.5
4	Weight of pyconometer + water (W_4)	83
5	Specific gravity of Cement = 3.16	

Table A.1 Specific gravity of cement

A.2.2 Aggregate

Specific gravity = $\frac{(w_2-w_1)}{(w_4-w_1)-(w_3-w_2)}$

Sample: Fine Aggregate

S.No	Determination	Grams
1	Weight of pyconometer (W_1)	590
2	Weight of pyconometer + mass of dry soil (W_2)	1272
3	Weight of pyconometer + soil + water (W_3)	1865
4	Weight of pyconometer + water (W_4)	1452
5	Specific gravity of fine aggregate = 2.53	

Table A.2 Specific gravity of fine aggregate

Sample: Coarse Aggregate

S.No	Determination	Grams
1	Weight of pyconometer (W_1)	590
2	Weight of pyconometer + mass of dry soil (W_2)	1290
3	Weight of pyconometer + soil + water (W_3)	1891
4	Weight of pyconometer + water (W_4)	1452
5	Specific gravity of Coarse aggregate = 2.68	

Table A.3 Specific gravity of coarse aggregate

A.3 SIEVE ANALYSIS

Sample: Fine Aggregate

IS SIEVE (mm)	Weight Retained (grams)	% Retained	Cumulative % Retained	Cumulative % Passing
10	-	-		
4.75	12	12	2.4	97.6
2.36	52	64	12.8	87.2
1.18	51	115	23	77
0.6	90	205	41	59
0.3	171	376	75.2	24.8
0.15	89	465	93	7
Pan	35	500	-	-
Total	500	-	245.4	-

Table A.4 Sieve analysis of fine aggregate

Fineness modulus = $\frac{\sum \text{cumulative percentage retained}}{100}$

Fines Modulus = $\frac{245.4}{100}$ = 2.45

Sample: Coarse Aggregate

IS SIEVE (mm)	Weight Retained (kg)	Cumulative weight Retained	Cumulative % Retained	Cumulative % Passing
40	-	-	-	100
20	0.585	0.585	14.625	85.375
10	3.26	3.845	96.125	3.875
4.75	0.155	4	100	-
2.36	-	-	100	-
1.18	-	-	100	-
0.6	-	-	100	-
0.3	-	-	100	-
Pan	-	-	100	-
Total	4	-	710.75	

Table A.5 Sieve analysis of coarse aggregate

Fines Modulus = $\frac{710.75}{100}$ = 7.11

A.4 SLUMP CONE TEST

S.No	% of Glass fiber	Slump (mm)
1	0.0 %	26
2	0.5 %	09
3	1 %	0
4	1.5 %	0

Table A.6 Slump cone test of concrete

A.5 MIX DESIGN

Target meanstrength of concrete:

The target mean strength for the specified characteristic cube strength is.

fck' = fck+ 1.65 s

= 20 + (1.65 x 4) {s = 4, accordingto IS10262:2009}

= 26.6 N/mm^2

Selection of water cement ratio:

The free water cement ratio for target means strength of 26.6 N/mm^2 is 0.45

From IS 456:1978,0.45<0.55

This is lower than the maximum value prescribed for mild exposure.

Selection of water content:

From IS 456:2000,

Maximum water content for 20mm aggregate = 186 litres

Determination of cement content:

Cement content $=\frac{watercontent}{\frac{w}{c}ratio}$

$= \frac{18.6}{0.45}$ = 413.33 kg/m^3

From IS456:2000,

Minimum cement content for mild exposure condition = 300 kg/m^3

413.33 kg/m^3>300 kg/m^3

Hence Ok

Proportion of volume of coarse aggregate and fine aggregate cement:

From IS10262:2009,

Volume of coarse aggregate corresponding to 20mm size aggregate and Fine aggregate (zone II) for w/c ratio of 0.50 =0.62

Volume of coarse aggregate = 0.62

Volume of fine aggregate = 1- 0.62 =0.38

Mix calculation:

a) Volume of concrete = 1m^3

b) Volume of cement$=\frac{massofcement}{specificgravityofcement}$ x $\frac{1}{1000}$

$= \frac{413.33}{3.16}$ x $\frac{1}{1000}$

= 0.1308 m^3

c) Volume of water = $\frac{watercontent}{specificgravityofwater}$ x $\frac{1}{1000}$

$= \frac{186}{1}$ x $\frac{1}{1000}$

= 0.186 m^3

d) Volume of admixtures = 0

e) Volume of all aggregates = [a - (b + c + d)]

= [1 – (0.1308 + 0.186 + 0)]

= 0.6832 m^3

f) Mass of coarse aggregate = e x volume of coarse aggregate x specific gravity of coarse aggregate x 1000

= 0.6832 x 0.62 x 2.68 x 1000

= 1135.20 kg

g) Mass of fine aggregate = e x volume egate x specific gravity of fine aggregate x 1000

= 0.6832 x 0.38 x 2.53 x 1000

= 656.83 kg

Cement	Fine aggregate	Coarse aggregate
413.33	656.83	1135.20
1	1.6	2.8

Table A.7 Mix design of conventional concrete

Therefore the mix design of conventional concrete is 1: 1.6: 2.8

For cube	For beam
$x + 1.6x + 2.8x = 0.003375 \times 2400$ $x = 1.5$ kg	$x + 1.6x + 2.8x = 0.005 \times 2400$ $x = 2.2$ kg
Cement = 1.5 kg	Cement = 2.2 kg
Sand = 2.4 kg	Sand = 3.52 kg
Aggregate = 4.2 kg	Aggregate = 6.2 kg

Table A.8 Mix Proportions for cube & beam

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