

Experimental and analytical study of GFRP reinforced concrete beams under marine environment

Submitted in partial fulfilment of the requirements for the award of
Master of Engineering Degree in Structural Engineering

by

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**DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF BUILDING AND ENVIRONMENT**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of MALARVIZHI L (39380007) who carried out the project entitled “**Experimental and analytical study of GFRP reinforced concrete beams under marine environment**” under my supervision from November 2020 to April 2021

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Submitted for Viva voce Examination held on_____

Internal Examiner

External Examiner

DECLARATION

I **MALARVIZHI L** hereby declare that the Project Report entitled **“Experimental and analytical study of GFRP reinforced concrete beams under marine environment ”** done by me under the guidance of **Dr. S. Packialakshmi** at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** is submitted in partial fulfilment of the requirements for the award of Masters of Engineering degree in Structural Engineering.

DATE : 12/04/2021

PLACE : Chennai

A photograph of a handwritten signature in blue ink on a white background. The signature reads "L. Malarvizhi".

SIGNATURE OF THE CANDIDATE

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ABSTRACT

In the present years, due to enhanced properties of Glass Fiber-Reinforced Polymers (GFRP) there has been a rapid increase in usage of GFRP reinforcing bars for concrete structure. The GFRP bars have been used extensively in the marine structures where the conventional steel reinforcement which is affected by corrosion is more overriding. Deterioration of structures due to corrosion can be solved by the GFRP rebar which is reinforced in concrete structures were subjected to harsh environments, namely high-temperature and marine conditions. After all these years of investigation and implementation, researchers have concluded GFRP as the corrosion resistant reinforcing material in the corrosion protection policies. The present study made the comparative analysis of concrete cube of size 150 mm x 150 mm x 150 mm which was cured with saline solution as well as potable water were compared to investigate the strength characteristic of test specimens. Further, concrete beam of size 700 mm x 150 mm x 150 mm with 12 mm diameter GFRP rebar and conventional steel rebar which was cured in saline solution for 21 days. Then the Flexural test has been conducted experimentally for both the beams and the results which were obtained from experimentally are compared with analytical results which are obtained using Ansys workbench 2020.

TABLE OF CONTENT

CHAPTER NO	TITLE	PAGE NO
	ABSTRACT	v
	LIST OF FIGURES	ix
	LIST OF TABLES	xi
1	INTRODUCTION	1
	1.1 Generals	1
	1.2 Glass fiber reinforced polymer (GFRP)	2
	1.3 Advantages of GFRP	3
2	LITRATURE SURVEY	4
	2.1 General	4
	2.2 Review of literature	4
3	AIM AND SCOPE OF THE STUDY	8
	3.1 Aim	8
	3.3 Scope of study	8
	3.4 Objectives	8
4	METHODOLOGY AND MATERIALS	10
	4.1 Methodology	10
	4.2 Material used	11
	4.2.1 Cement	11
	4.2.2 Fine aggregate	12
	4.2.3 Coarse aggregate	14

4.2.4 Water	16
4.2.5 Reinforcement	17
4.2.6 Material properties of rebar	18
4.3 Concrete mix design	18
4.3.1 General	18
4.3.2 Requirement of concrete mix design	19
4.3.3 Types of mix	19
4.3.4 Factors affecting the choice of mix Proportions	20
4.3.5 Mix design procedure	22
4.4 Experimental investigation	25
4.4.1 General	25
4.4.2 Slump cone test	26
4.4.3 Compression strength test	27
4.4.4 Water penetration test	28
4.4.5 Rapid chloride penetration test	30
4.4.6 Flexural strength test	32
4.4.7 Tension test	32
4.5 Numerical investigation	34
4.5.1 General	34
4.5.2 Ansys model description	34
4.5.3 Ansys modelling procedure	34
4.5.3.1 Engineering data	34
4.5.3.2 Geometry creation	35
4.5.3.3 Assigning the section properties	35
4.5.3.4 Setting up the finite element model	36
4.5.3.5 Material properties	36

	4.5.3.6 Mesh generation	36
	4.5.3.7 Loading pattern	37
5	RESULT AND DISCUSSION	38
	5.1 Experimental investigation results	38
	5.1.1 Compression strength test	38
	5.1.2 Water penetration test	39
	5.1.3 Rapid chloride penetration test	41
	5.1.4 Flexural strength test	42
	5.1.5 Tension test	45
	5.2 Numerical investigation results	47
	5.2.1 Beams without corrosion	47
	5.2.3 Steel beam with 20% corrosion	48
	5.3 Comparison of experimental with analytical results	50
6	SUMMARY AND CONCLUSION	54
	REFERENCES	55

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
1.1	Glass fibre reinforced polymer	2
4.1	Methodology frame work of the study	10
4.2	Cement	11
4.3	Fine aggregate	13
4.4	Coarse aggregate	15
4.5	Reinforcement	24
4.6	Reinforcement detailing	25
4.7	Measuring the slump of concrete	26
4.8	Compression strength test	28
4.9	Water penetration equipment	29
4.10	Splitting of the concrete samples	29
4.11	Measuring the depth of water penetration	30
4.12	Water penetration equipment	31
4.13	Beam subjected to three point loading	32
4.14	Tension test conducted on steel rebar	33
4.15	Tension test conducted on GFRP rebar	33
4.16	Engineering data for steel rebar	35
4.17	Engineering data for GFRP rebar	35
4.18	Beam model created	35
4.19	Mesh generation of beam model	36
4.20	Loading pattern	37
5.1	Compression strength test (7, 14, 21 days)	39
5.2	Water penetration test (21 days)	41
5.3	Rapid chloride penetration test (21 days)	42
5.4	Flexural test conducted on steel reinforced beam	43

5.5	Flexural test conducted on GFRP reinforced beam	45
5.6	Load deflection curve (14 days)	46
5.7	Load deflection curve (21 days)	47
5.8	Tension test conducted on steel rebar	48
5.9	Tension test conducted on GFRP rebar	48
5.10	Tension test on steel and GFRP rebar	49
5.11	Load deflection curve of the beam in Ansys 2020	50
5.12	Total deflection of the GFRP reinforced beam	50
5.13	Total deflection of the steel reinforced beam	51
5.14	Load deflection curve of beam with 20% of steel Corrosion and GFRP without corrosion in Ansys 2020	52
5.15	Total deflection of the steel reinforced beam with 20% corrosion	52
5.16	Load deflection curve (Comparison)	53

LIST OF TABLES

TABLE NO	TITLE	PAGE NO
4.1	Physical properties of cement	12
4.2	Physical properties of fine aggregate	14
4.3	Physical properties of coarse aggregate	16
4.4	Material properties and steel and GFRP rebar	18
4.5	Conventional mix proportion	24
4.6	Test specimen for experimental analysis	25
4.7	Slump cone test	27
4.8	Range of Water penetration	31
4.9	Material properties	36
5.1	Compression strength test result	39
5.2	Water penetration test result	40
5.3	Rapid chloride penetration result	42
5.4	Tension test result	46

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete reinforced with steel bar is one of the typical materials used for constructing structures. Usually concrete have low tensile strength hence steel bars are used as the reinforcement which are cost efficient but the steel bars are not recommended as reinforcements in costal and marine areas. The factors like faulty design, bad workmanship, inadequate cover in concrete and other environmental factors leads the concrete to crack and the steel to corrode.

To avoid corrosion, the utilization of FRP (Fibre reinforced polymer) rebar instead of steel rebar is recommended in aggressive and marine environment. FRP (Fibre reinforced polymer) obtained in various forms like bars, hoops, and stirrups are used as the reinforcement in various structures like marine structures, parking garages, water treatment plants, bridge decks and tunnels.

The fibres are embedded in the polymeric resin to form FRP (fibre reinforced polymer). The variant of FRP is commercially available as CFRP (Carbon Fibre reinforced polymer), GFRP (Glass fibre reinforced polymer), AFRP (Aramid fibre reinforced polymer) and BFRP (Basalt fibre reinforced polymer) for the purpose of construction. Because of the non-metallic and non-corrosive properties of the FRP rebar the problems of corrosion is avoided. FRP is used for repairing and strengthening of the concrete structures which already exist. Usually the FRP sheets and strips are used for repairing and strengthening the concrete structures. The externally bonded FRP (fibre reinforced polymer) are highly vulnerable of damaging from temperature and fire, moisture absorption, ultraviolet rays. Lacking of maintenance and protection may reduce the durability and service life of the structure.

1.2 GLASS FIBER REINFORCED POLYMER (GFRP)

For the last two decades, the GFRP (Glass fibre reinforced polymer) rebar are used as the replacements of steel rebar. The advances made recently in FRP technology leads to the GFRP rebar development of elasticity modulus which exceeds 60 Gpa so that the amount of reinforcement can be reduced and the cost efficient designs can be yielded. Moreover, the surface profiles of GFRP rebar is made in various textures such as ribbed, smooth, sand coated, deformed, and grooved to build up the bond with the concrete.

Due to the modulus which is lower in GFRP rebar than the steel rebar, the GFRP reinforced concrete structures is usually designed by the serviceability limit state instead of ultimate limit state. Therefore the increase in the tensile property and the elasticity modulus is predicted to increase the serviceability of GFRP reinforced concrete elements. Furthermore, the surface profiles like smooth, ribbed and sand coated may play an important role in the crack width and the cracking performance. Therefore, the various surface profiles and the modulus of elasticity of the GRRP rebar should be studied in consideration of ultimate limit state method and serviceability limit state method. Also the GFRP weighs quarter the time of the steel rebar and the GFRP rebar price worth double the time of the steel rebar, So the GFRP reinforced concrete structures is expensive than that of the steel rebar and to gratify the serviceability limit state more bars may be required. The development of the structural design will help in reduction of the total cost GFRP reinforced concrete structures. GFRP was shown in Fig 1.1.



Fig 1.1 Glass fibre reinforced polymer

1.3 ADVANTAGES OF GFRP

- In GFRP to increase the lifespan of a concrete structure a high-quality of corrosion resistant vinyl ester resin is included.
- Comparing the conventional steel rebar and the GFRP rebar, the GFRP rebar is double the tensile strength of the steel rebar and quarter the weight of the steel rebar.
- Heat and electricity act as non-conductive in the GFRP rebar which make it an better choice for power generation plants and scientific installations.
- In case of the durability of GFRP rebar, it is a cost-effective product when compared with conventional steel rebar.
- It is untouchable by chloride ions and other chemical elements.
- It can be manufactured in customized lengths, bends, shapes and sizes.
- The embedding process of GFRP rebar is very convenient and The cut and machined is at ease.
- radio frequencies and electrical field is transparent in the GFRP

CHAPTER 2

LITRATURE SURVEY

2.1 GENERAL

This review has been focused on the GFRP bar behaviour in RC structures. The data and the particulars collected in this review was collected from the numerical, analytical and experimental studies from precursory researches where limited research work had conducted to examine the behaviour of RC structures with Glass Fibre Reinforced Polymer bars under marine environment. The review on Glass fibre Reinforced Polymer rebar will enhance the application of GFRP for the new construction or for the rehabilitation of existing structure.

2.2 REVIEW OF LITERATURE

2.2.1 Flexural Behavior Of The GFRP Rebar

Steel rebar has a higher stiffness than Glass fiber reinforced polymer (GFRP) rebar, which should be accounted for its ultimate conditions and serviceability including the impact on crack widths and member deflection. Omar I. Abdelkarim et al. (2019) concluded that the increase in the GFRP rebar ratio has a better effect on the service moment than the resistance moment and the effects on the spacing of bar formed on the wide beams behaviour were examined and it is revealed that when the moment of service increases while the spacing of bar decreases, when the moment of resistance rises then the strength of concrete also rises. Moreover, the concept of the deformability formed has higher ductility. Fergani et al. (2018) had concluded that the stressed specimens of concrete which is hardened in the wet environment which experienced a decrease in the tension stiffening response. It also indicates that the accelerated aging conditions affect the flexural behavior of the element and it leads to larger crack widths and also higher deflections. Goldston et al. (2017) found that the over-reinforced high strength concrete and ultra high strength concrete in which the GFRP bar is

reinforced have an amount of ductility which is compared to under-reinforced high strength concrete and ultra high strength concrete reinforced with GFRP rebar. The energy absorption capacity was detected at the lower for GFRP reinforced high strength concrete and for the same amount of reinforcement collated to GFRP reinforced ultra high strength concrete. Edgaras Atutis et al. (2015) had investigated experimentally the concrete beams reinforced with GFRP rebar based on flexural strength. Both the prestressed concrete and the reinforced concrete beams had tested. The effect of prestressing on the cracking and deflection was analyzed and it is possible to predict the mode of failure of concrete members with GFRP reinforcement taken into account of flexural strength design methodology which is grounded on reinforcement ratio. Experimental and predicted mode of failure of concrete beams is coincided.

2.2.2 Durability Of The GFRP Rebar

Long-term behavior of composite materials is still a very provocative affair among the engineering circle though the fiber reinforced polymer (FRP) rebar are steadily used in infrastructure applications. Tarek H. Jikai Zhou et al. (2011) had experimentally investigated the durability of the bond between conventional steel rebar to the concrete and GFRP rebar to the concrete under acidic environment for comparison. These samples were forced to corrode by immersing it in the acid solutions with different concentration. For this test pullout samples were used just to expose the effect on the rebar in different environment on bond strength. The result shows that the maximum bond strength loss is higher in steel rebar compared to the GFRP rebar. It had evaluated that the durability of three different glass fiber reinforced polymer rebar types are based on the exposure to the

aggressive environments such as that those are experienced in coastal areas. The samples were submerged in seawater at 60 °C which counterfeits the alkalinity of the concrete at various time periods. The long term performance of these GFRP rebar was assessed by testing the four different mechanical properties such as elastic modulus, tensile strength, and horizontal and transverse shear strength. It is found that the tensile strength was the most affected mechanical properties of GFRP rebar (Alvaro Ruiz Emparanza et al. 2020). Jianwei Tua et al. (2020) had carried out durability tests on a GFRP rebar with the seawater and the concrete environment at various temperatures. The durability of the GFRP rebar was examined by analysing its tensile properties. The durability of GFRP rebar was exposed to concrete under various temperature levels and used by the method of Arrhenius theory. The GFRP rebar have a good durability property by comparing the design limits, literature results, test results.

2.2.3 Bond Behavior Of The GFRP Rebar

Bond characteristic of GFRP bars in concrete is the most critical parameter for implementation of the material to the corrosion-free concrete structures. Unlike steel reinforcement, GFRP materials behave anisotropic, non-homogeneous and linear elastic properties, which may result in different force transfer mechanism between reinforcement and concrete. Giulia Fava et al. (2016) they have presented a larger exploration on the bond behaviour of GFRP rebar and concrete and concluded that when the steel bar is debonded, the concrete crushed around the ribs of the steel due to the concrete splitting and in the case of GFRP rebar the failure is ascribed because of the striping of the rebar. When the bond length of the bar shorten then the bond strength of the bar increased and when the stress in

concrete rises then the problem of crushing, spalling and splitting of concrete are ascribed. It is concluded that the glass fiber reinforced polymer (GFRP) rebar tested showed a lower bond capacity than steel. The two beams reinforced with GFRP rebar failed at a higher peak load than the steel reinforced beam, since all of them were designed to be tension-controlled. At service loads, GFRP reinforced beams showed higher crack-width and mid-span deflection compared to the steel reinforced beams because of the lower stiffness of GFRP rebar in comparison to steel is concluded by Tassinari, A. et al. (2019). Eswanth and Dhinakaran (2017) found out that the assessment of bond properties of the GFRP rebar embedded in the normal concrete and the GFRP rebar embedded in the high strength concrete has disclosed that the pull out test loaded on the GFRP rebar is within the scale and also established that due to the bar surface and the length of embedment the bond failure was caused and due to the longer length of embedment and the increase in diameter the splitting failure occurs which curtail the average bond strength. It is also inaugurated that the Pullout load in high strength concrete was higher than that of the normal strength concrete. Moreover, the bond strength of the steel rebar are higher than that of the glass fiber reinforced polymer bars. When the splice length increases and the cover thickness decreases, then the average bond strength of GFRP rebar was decreased. Jose Sena-Cruz et al. (2018) they intend to study the RC structures where the concrete is mixed with sea water and also the change of conventional steel rebar is replaced with GFRP rebar. They concluded in the result that there is no effect on the bond behaviour even when the concrete is mixed with sea water and there was also no severe problem with the properties of both concrete and the GFRP rebar. These results are concluded by two phases, such as the manufacturing of concrete using

seawater and the other phase is to assessing the bond behavior between concrete and GFRP rebar using pullout test, in these both phases the effect caused because of the usage of seawater instead of tap water was studied. By doing the pullout test the factors such as anchorage length and rebar diameter were also evaluated.

CHAPTER 3

AIM AND SCOPE OF THE STUDY

3.1 AIM

The aim of the study is to explore the strength characteristics of concrete reinforced with GFRP bar and conventional steel concrete cured in saline solution and potable water. Further, the experimental study is compared with numerical investigation using Ansys workbench 2020.

3.2 SCOPE OF STUDY

The scope of this present study is to investigate the flexural behaviour of the GFRP reinforced concrete beams and steel reinforced concrete beams that had been carried out to find the structural behaviour of the beams by using three point loading. The flexural behaviour conducted includes the first crack, failure of the beam, load–deflection curves and load capacity are compared and analysed thoroughly based on the experimental results. Eventually, ANSYS Workbench was used for and the results were examined. The experimental results were verified with the results acquired from the numerical analysis.

3.3 OBJECTIVES

By conducting the intensive literature survey, the following objectives were formulated.

- To determine the test on cement, fine aggregate, coarse aggregate used in the concrete.
- To study the properties of GFRP rebar and Steel rebar.
- To compare the strength characteristics of concrete cubes cured in saline solution and potable water.
- To flexural the flexural behaviors of GFRP rebar concrete and conventional rebar concrete under the marine environment.
- To compare the tensile behavior of GFRP rebar and conventional rebar under the marine environment.
- To validate the results with FEM analysis software (ANSYS 2020 workbench).

CHAPTER 4

METHODOLOGY AND MATERIALS

4.1 METHODOLOGY

The present chapter elaborates the methodology of the study. To attain the objective of the study the below mentioned methodology has been adopted. The methodology of the study was shown in Fig 4.1.

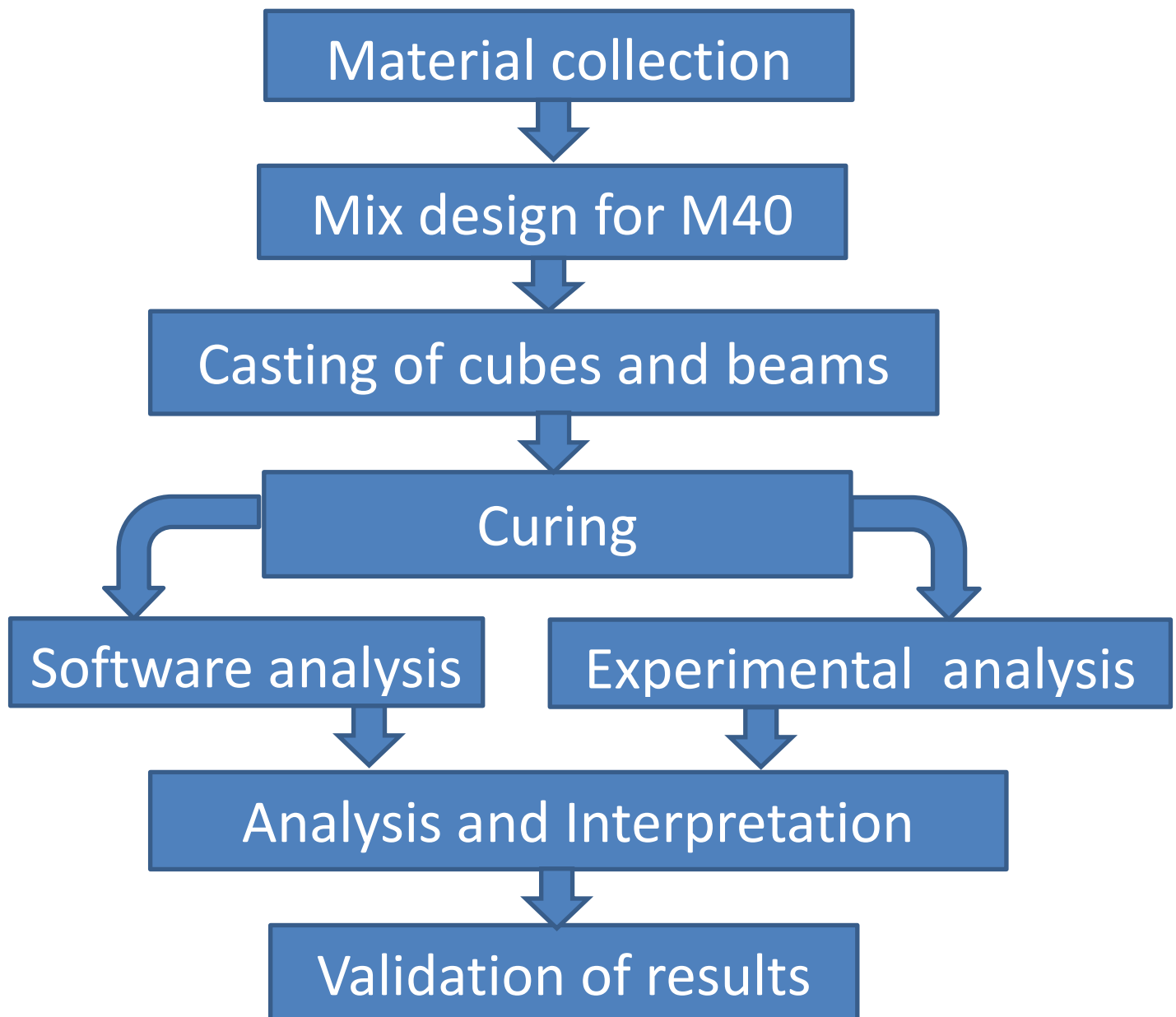


Fig 4.1 Methodology frame work of the study

4.2 MATERIAL USED

4.2.1 Cement

Cement is one of the important key ingredients used to make concrete which behave as a binding material which have both cohesive and adhesive properties. It is manufactured by using clinkers which is pulverized by utilizing raw materials like silica, alumina, calcium oxide, ferric oxide combined with some other oxides. Joseph Asp Din is the one who established Portland cement in the year 1824. The advancements of the product lead to the current mode of Portland cement which provides different material properties and functional specifications namely impermeability, durability, strength and the other dimensional constraints. Table 4.1 to 4.3 shows the properties of the concrete key ingredients respectively.

When the cement is mixed with the water it forms to the paste whose role is to bind the aggregates together to form a concrete mass. These concrete mass depends on the type, quantity and quality of cement for the characteristic behaviour of the concrete. The fig 4.2 to 4.4 shows the key ingredients of the concrete respectively.

These Portland cement contains four main components such as tricalcium silicate ($3\text{CaO} \cdot \text{SiO}_2$), dicalcium silicate ($2\text{CaO} \cdot \text{SiO}_2$), tricalcium aluminate ($3\text{CaO} \cdot \text{Al}_2\text{O}_3$), tetra calcium aluminoferrite ($4\text{CaO} \cdot \text{Al}_2\text{O}_3\text{Fe}_2\text{O}_3$). The properties of these main components were affected due to the proportion of raw materials and oxides. These affect the behaviour of the Portland cement which classifies it into different types. This various types of Portland cement are effectively used in various requirements and conditions of the structures. There are many other special cement which are used under different structural requirements and special conditions.



Fig 4.2 Cement

Physical properties of cement

- Fineness of cement
- Specific gravity
- Soundness
- Bulk density
- Consistency
- Loss of ignition
- Strength
- Heat of hydration
- Setting time

Table 4.1 properties of cement (Physical)

PROPERTIES	RESULTS
Specific gravity	3.10
Consistency	33%
Initial setting time	32 min
Final setting time	605 min
fineness	91%

4.2.2 Fine Aggregate

Fine aggregate is the widely used in the construction field, this material is granular which is used to manufacture mortar or concrete. The aggregates are fine when it passes through a 4.75 mm sieve. The fine aggregate that is used in concrete is either natural sand or crushed stone. The density and quality of the fine aggregate affects the hardened properties of the concrete.

If the selection of the fine aggregate is based on the particle shape, skid resistance, surface moisture, absorption, abrasion, surface texture and grading zone then the concrete which are made up of that fine aggregate will be stronger, durable and cheaper.

The role of the fine aggregate are described as

- Dimensional stability was provided to the mixture because of the fine aggregate
- Its quality will affect the hardening properties and mix proportions
- The fine aggregate also have influence over the shrinkage of the concrete
- It also have influence over abrasion resistance and the elastic modulus



Fig 4.3 Fine aggregate

Physical properties of fine aggregate

- Size
- Shape
- Silt content
- Surface texture
- Soundness
- Specific gravity
- Moisture content
- Bulk density
- Bulking
- Durability

Table 4.2 properties of fine aggregate (Physical)

PROPERTIES	RESULT
Particle size	4.75 mm
Silt content	1.67%
Specific gravity	2.73
Bulking of sand	4.19%
Bulk density	1793 kg/m ³
Water absorption	0.28
Fineness modulus	4.12%

4.2.3 Coarse Aggregate

Coarse aggregate is one of the important material and widely used as building material in construction industries. It is the key component in concrete and gains volume to the concrete. It is chemically inactive and serves as the filler material and gives strength to the concrete which will provide a homogeneous mass of the concrete.

The aggregate sized more than 4.75 mm are meant to be coarse aggregate. The natural rocks are crushed to form the coarse aggregates. The rocks can be sedimentary, igneous or metamorphic. The igneous rocks are strong, dense and fine grained which is gained by cooling down the parts of the molten materials which is commonly called as igneous rocks. These rocks are crushed to form the aggregate which are black in colour and mainly used for works done by concrete and it is known to be black trap. Sedimentary rocks are deposited ages ago gained through the wind, water and ice action and it is also known as derivative rocks. Three quarters of the earth's land surface are covered by these rocks. One of the rocks used for concrete production is sandstone which is durable and hard and it will be available in the form of strips which is used in slab construction. The metamorphic rocks are formed by both igneous and sedimentary rocks. It transforms from the existing rocks to the new rocks due to heat and pressure causing chemical and physical changes.



Fig 4.4 Coarse aggregate

Physical properties of fine aggregate

- Specific gravity and density
- Soundness
- Shape and size
- Bulk density
- Surface moisture
- Elongation index
- Fineness modulus
- Silt content
- Water absorption
- Hardness

Table 4.3 properties of fine aggregate (Physical)

PROPERTIES	RESULTS
Particle shape and size	Angular, 12mm
Specific gravity	2.66
Water absorption	0.62%
Bulk density	1497 kg/m ³
Flakiness index	21.26%
Elongation index	38.19%
Fineness modulus	7.16%

4.2.4 Water

Water is one of the main ingredient in preparing concrete, when the water is mixed with the cement it forms a paste which helps the aggregates to bind together. Hydration is the process which causes the hardening of the concrete by using water. In this hydration process the chemical reaction formed between the compounds in cements and water molecules to become hydrates. The water used in the concrete should be pure so that it would not affect the concrete to weaken or else it will interfere with the process of hydration.

The water plays the important role because the most critical factor in concrete is water to cement ratio to produce the best concrete. If too much water is mixed in the concrete then it leads to the reduction of concrete strength and if too little water is mixed in the concrete then it leads to the unworkable of the concrete. The concrete should be workable so that it can molded in to different shapes. Due to this reason the careful consideration in water to cement ratio is required while manufacturing concrete.

4.2.5 Reinforcement

The reinforcement detailing of both steel bar and GFRP rebar are given below. Here the Fig 4.5 shows the reinforcement used in this study and Fig 4.6 shows the detailing of the reinforcement.

- Diameter of the main rod = 12 mm
- Diameter of the stirrups = 8 mm
- Length of the main bar = 650 mm
- Length of the stirrups = 100 mm x 100 mm
- Total number of main rods = 4 Nos
- Spacing between stirrups = 100 mm
- Beam size = 700 mm x 150mm x 150mm



Fig 4.5 Reinforcement

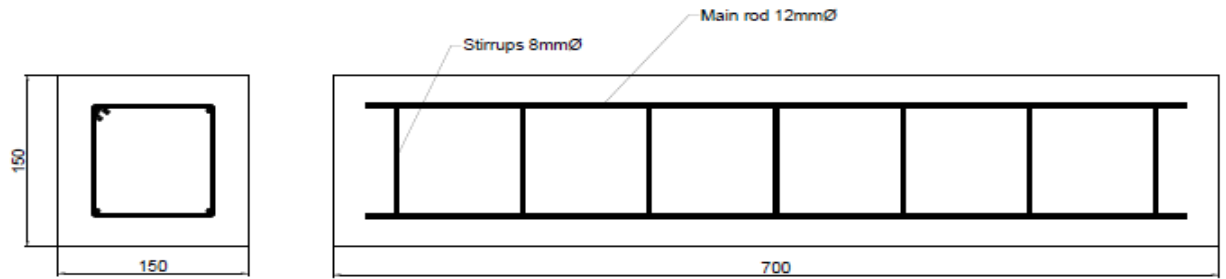


Fig 4.6 Reinforcement detailing

4.2.6 Material Properties Rebar

The material properties of the GFRP rebar and the steel rebar is discussed in the Table 4.4.

Table 4.4 Material properties of steel and GFRP rebar

SI NO	PROPERTIES	STEEL	GFRP
1	Tensile strength (Mpa)	390	1250
2	Modulus of elasticity (Gpa)	200000	50000
3	Elongation (%)	25	2.2
4	Density (Kg/m ³)	7800	1900

4.3 CONCRETE MIX DESIGN

4.3.1 General

The process of determination of the concrete ingredients such as fine aggregate, coarse aggregate, cement, water in proportion. It would give concrete which have specified properties likely durability, strength and workability. The proportioning of the components of concrete is controlled in two states for performance of concrete likely hardened state and plastic state if it is not workable for the plasticity of concrete, then it cannot be placed properly and compacted. Therefore the property of workability becomes more important.

The index properties which is said to be the compressive strength of the hardened concrete which counts on some factors such as concrete ingredients batching, mixing, placing, compacting and curing. The value of the concrete will be depending on cost of the used materials, machines and labours. The cost of materials varies due to the fact that the cement is much time costlier than the aggregates. In the technical view rich mix which may lead the concrete to the high heat in hydration which makes the concrete to crack.

The genuine value of concrete is connected to the value of material is essential for inducing a lowest mean strength known as characteristic strength which will be decided by the structural designer. It is also depended on the measure of quality control but it is certain that the quality control add on to the value of the concrete.

The range of quality control is generally an economic understanding and hinge on the type and size of the work. Depending on the mix workability the wage of labour is decided.

4.3.2 Requirement Of Concrete Mix Design

For the mix design, the requirement of the selection of ingredients and proportion of ingredients are

- From the structural consideration the required maximum compressive strength is taken.
- The compacting equipment is used for full compaction for the efficient workability.
- For the specific site conditions Maximum water cement ratio is required to concede the efficient durability.
- To prevent shrinkage cracking because of the temperature cycle the maximum cement content is required.

4.3.3 Types Of Mix

Nominal mix

The mixes prepared for concrete that is fixed cement-aggregate ratio which secure efficient strength are named as nominal mix. These provide integrity and in normal situation, it has a brim of strength which is specified above. Moreover, because of the difference in mixing ingredients the nominal concrete for the provided workability also differs largely in strength.

Standard mix

The nominal mix of determined cement aggregate ratio differs largely in strength and may lead to under rich mix or over rich mix. Because of this, many specifications were included with the minimum compressive strength. These mixes are known to be standard mix.

In the code IS 456-2000, the concrete mix are designed as a quota of grades from M15 to M40. In this standard mix, the mix is denoted by the letter M and the number next to the letter M is denoted as the cube strength of mix in N/mm^2 which is cured for 28 days. The mixes of grades M10 will be approximately to the mix proportion (1:3:6), M15 to be (1:2:4), M20 to be (1:1.5:3) and so on.

Design mix

In design mix the concrete is decided by the designer for staging but the proportion of mix are determining by the one who makes the concrete. In this is mix the selection of mix proportions with required material which have more or less certain characteristic moreover, the design mix do not serves as a guide because this does not gives the exact mix proportions for the expected performance of the concrete. For nominal or standard mixes of concrete is given by the codes for per meter cube how much quantity of dry ingredients and slump which is used only for small works when the curing of 28 days compressive strength of concrete does not go over 30N/mm^2 . There is No need for control testing.

4.3.4 Factors Affecting The Choice Of Mix Proportions

Compressive strength

Compressive strength is one of the important concrete properties and it also has the influence on the other hardened concrete properties. The mean compressive strength obtained from the cubes at a defined age of 28 days, it will decide the nominal water cement ratio of mix. Another factor which affects the strength of concrete at a specified age is cured at a given temperature to the compaction degree. Abraham's law states that the strength of the compacted concrete is inversely proportional to the water cement ratio.

Workability

The workability of the concrete depends on three factors they are the quantity of reinforcement, the size of the concrete section and the method of compaction. The section which is complicated, narrow and inaccessible with many corners, the concrete should pass through all the section so it should have a medium workability so that it can be fully compacted. It is also suitable to the embedded steel section. The equipment available at the site for compacting is used to get desired workability.

Maximum nominal size of aggregate

Generally, if the size of the aggregate gets larger then the cement requirement will be less for the required water cement ratio. However, when the size of the aggregate decreases it will increase the compressive strength. The code books IS10262-1982 and IS 456- 2000 recommended that the size of aggregate should be as large.

Grading and type of aggregate

The aggregate grading makes effect on the proportion of mix for a defined water cement ratio and workability. The mix can be used will be leaner when the grading is coarse.

The aggregate strongly influence the specified water cement ratio and the aggregate cement ratio for the defined workability specified. A most important

parameter of an aggregate is the grading which can be gained by mixing various size fractions.

Durability

The ability of concrete to resist the aggressive environmental conditions is known as the durability of concrete. Generally, the concrete low strength is less durable than the concrete with High strength. In a situation such that when the concrete with high strength is not necessary but the exposure conditions which needs the necessity then the concrete with high strength is mandatory, However the water-cement ratio is used to determine the durability requirement.

Quality Control

From the variation of the test results the degree of control shall be estimated. If the cement-content required should be less, then the variation between the minimum strength and mean strength should be low. The factor governing these variations is known as quality control.

4.3.5 Mix Design Procedure

The mix design was done based on the Indian Standard Recommended Method (IS 10262-2009). Conventional mix proportion was showed in Table 4.5.

PROVISION FOR PROPORTIONING

Grade of concrete	= M40
Aggregate type	= Crushed angular aggregates
Size of aggregate	= 20 mm
Cement type	= OPC 53 Grade
Cement content (minimum)	= 360 kg/m ³
Cement content (maximum)	= 420 kg/m ³
Workability (slump)	= 100 – 120 mm
Water to cement ratio	= 0.40
Degree of supervision	= Good
Exposure condition	= Moderate

MATERIAL TEST DATA

Specific gravity of cement	= 3.15
Specific gravity of coarse aggregate	= 2.67
Specific gravity of Fine aggregate	= 2.65
Water absorption of coarse aggregate	= 0.5%
Water absorption of fine aggregate	= 2.5%

TARGET STRENGTH OF THE MIX

$$f'_{ck} = f_{ck} + 1.65s$$

Where,

f_{ck} = Compressive strength achieved at 28 days

f'_{ck} = Targeted Compressive strength achieved at 28 days

s = Standard deviation (From table 1 of IS 10262:2009) = 5 N/mm²

$$\text{Targeted Compressive strength } (f'_{ck}) = 40 + (1.65 \times 5) = 48.25 \text{ N/mm}^2$$

WATER CEMENT RATIO SELECTION

Water cement ratio adopted = 0.36

From table 5 of IS 456,

Water cement ratio (Very severe exposure) = 0.40

$$0.36 < 0.46$$

Hence okay.

WATER CONTENT SELECTION

From table 2 of IS 10262-2009

Maximum water content (20 mm aggregate) (For 25 to 50 mm slump) = 186 litre

Maximum water content expected for 100 mm slump = 186 + (6/186) = 197 litre

CEMENT CONTENT CALCULATION

Water cement ratio adopted = 0.36

$$\text{Cement content} = 151/0.36 = 420 \text{ Kg/m}^3$$

From table 5 of IS 456,

Minimum cement content (Very severe exposure) = 360 Kg/m³

$$420 \text{ Kg/m}^3 > 360 \text{ Kg/m}^3$$

Hence okay.

PROPORTION OF COARSE AGGREGATE AND FINE AGGREGATE

From table 3 of IS 10262-2009

Volume of coarse aggregate (size 20 mm) corresponding to fine aggregate (zone II) for water cement ratio of 0.50 = 0.62

In this mix the water cement ratio = 0.44

Corrected proportion of coarse aggregate for the water cement ratio of 0.44 = 0.65

Volume of the coarse aggregate = $0.65 \times 0.9 = 0.585 \text{ m}^3$

Volume of fine aggregate = $1 - 0.585 = 0.415 \text{ m}^3$

MIX CALCULATION

The mix calculation for a unit volume of concrete is given below

Concrete volume = 1 m^3

Cement volume = (Mass of cement) / (specific gravity of cement x 1000)
= $(420) / (3.15 \times 1000) = 0.1333 \text{ m}^3$

Volume of water = (Mass of water) / (specific gravity of water x 1000)
= $(151) / (1 \times 1000) = 0.151 \text{ m}^3$

Volume of chemical admixture = $1.89 \text{ litres} / \text{m}^3$

Volume of aggregate = $[1 - (0.1333 + 0.151 + 0.0045)] = 0.7115 \text{ m}^3$

Mass of coarse aggregate = $0.7115 \times 0.585 \times 2.67 \times 1000 = 1111 \text{ Kg/m}^3$

Mass of fine aggregate = $0.7115 \times 0.415 \times 2.60 \times 1000 = 768 \text{ Kg/m}^3$

MIX PROPORTION OF THE CONCRETE

Cement = 336 Kg/m^3

Water = 151 l/m^3

Fine aggregate = 768 Kg/m^3

Coarse aggregate = 889 Kg/m^3

Chemical admixture = 1.89 Kg/m^3

Density of concrete = 2451 Kg/m^3

Water cement ratio = 0.41

Mix proportion = 1:1.83:2.65

Table 4.5 Conventional mix proportion

Cement	Fine aggregate	Coarse aggregate	Water
336 kg/m ³	768 kg/m ³	890 kg/m ³	168 kg/m ³
1	1.83	2.65	0.5

Mix proportion for a cube

Cube size	= 150 x 150 x 150 mm
Volume of the cube	= 0.003375 m ³
Quantity of cement required	= 0.003375 x 336 = 1.134 kg
Quantity of fine aggregate required	= 0.003375 x 768 = 2.6 Kg
Quantity of coarse aggregate required	= 0.003375 x 890 = 3.2 Kg
Quantity of water required	= 0.003375 x 168 = 0.56 liter

Mix proportion for a beam

Beam size	= 750 x 150 x 150 mm
Volume of the cube	= 0.016875 m ³
Quantity of cement required	= 0.016875 x 336 = 5.67 kg
Quantity of fine aggregate required	= 0.016875 x 768 = 12.96 Kg
Quantity of coarse aggregate required	= 0.016875 x 890 = 15.3 Kg
Quantity of water required	= 0.016875 x 168 = 2.8 liter

Table 4.6 Test specimen for experimental analysis

TEST	NO OF SPECIMENS
Flexural strength test	4 beams
Compression strength test	18 cubes
Water penetration test	4 cubes
Rapid chloride penetration test	2 cubes

4.4 EXPERIMENTAL INVESTIGATION

4.4.1 General

In this chapter the experimental investigation carried out in the test samples to study the flexural characteristic between steel reinforced concrete and GFRP reinforced concrete. This experiment such as compression strength, flexural strength, water permeability, rapid chloride penetration test is conducted on the test samples to discover the properties of the concrete specimens. Each specimen is tested as per the Indian standards.

4.4.2 Slump Cone Test

Slump cone test on concrete is to find out the workability which is a property of the fresh concrete. Workability is the property of the fresh concrete which means it is easy to place and the workable concrete is the concrete which shall be placed and compacted with ease and without any segregation. Workability is the capable of working without any extra labour and strength loss. The concrete strength depends upon the water percentage. Water percentage and slump are taken from this slump test. It is the vertical height of the fresh concrete compared to its mould height.



Fig 4.7 Measuring the slump of concrete

The workability is determined by using slump cone test in fresh concrete. The code book IS: 1199-1959 is referred. Slump measurement was shown in Fig 4.7.

Apparatus required

- slump cone
- tamping rod
- metallic sheet

Procedure

- The mould is cleaned thoroughly and the inner surface should be free from the moisture and the attached old concrete is cleared before the test is started.
- The mould is placed on a smooth and clean surface and compacted for every layer.
- Then the concrete layer was tamped 25 times by means of the tamping rod which helps to distribute the strokes. The remaining concrete is cleared using the trowel to level.
- The mould is removed in vertical direction from the concrete by raising the mould slowly and with care.
- The fresh concrete is allowed to subside. This form of concrete is termed as slump.
- The height between the top of the slump cone and the top of the deformed concrete is measured and noted. The height difference in mm is known as the slump of the fresh concrete.
- The slump of the fresh concrete indicates the concrete characteristics with the slump value. If the fresh concrete slumps evenly then it is called as true slump. If one half of the fresh concrete slides down then it is called as shear slump. In shear slump, the variation in height between the top of the mould and the average value of the slump is measured as the slump value. The value of the slump cone test was shown in the Table 4.6.

Table 4.7 Slump cone test

Nominal mix	Slump value (mm)
M40	115

4.4.3 Compression Strength Test

The cube specimen of size 150 mm x 150 mm x 150mm is subjected to the compressive strength test. The concrete cubes are cured in potable water and saline solution for 7 days, 14 days, 21 days respectively. The concrete cubes were tested using compression testing machine. The load was applied gradually till the concrete cube fails. The reading in which the load goes reverse that instant load is the ultimate load. The test setup is shown in the Fig 4.8.



Fig 4.8 Compression strength test

4.4.4 Water Penetration Test

The water penetration test was leaded on the cube specimen of size 150 mm x 150 mm x 150mm to determine the depth of the water penetrated in the test samples. The middle portion of the cube specimens was roughened and the remaining portion is sealed with cement paste. Then the specimens are cured for 21 days and then water pressure is applied on the middle roughened portion so that water can penetrate inside the concrete. The specimens are split to perceive the rate of penetration of water in the concrete specimens. The specimens are split by using compression testing machine and the specimens are subjected to concentrated load at two diagonally opposite points which is a bit away from the central axis. The test setup is shown in the Fig 4.9 to Fig 4.11.



Fig 4.9 Water penetration equipment



Fig 4.10 Splitting of the concrete sample for the Water penetration test



Fig 4.11 Measuring the depth of water penetration

4.4.5 Rapid Chloride Penetration Test

The Rapid chloride permeability test is leaded on the concrete cylinder specimen of size 100 mm diameter which is core cut from the cube of size 150 mm x 150 mm x 150mm. This experimental test is conducted on the concrete cylinder specimen to determine the ability to resist chloride ion penetration. The concrete cylinder samples are placed in the specimen cells which contains 3.0 % of sodium chloride solution and 0.3 molar of sodium hydroxide solution. The voltage is allowed to pass through both the edge of the specimens (60 V DC). A qualitative rating was made for concrete permeability based on the charge passed (Coulombs). The range of the charge passed and the test set up are shown in Fig 4.12 and Table 4.7 respectively.

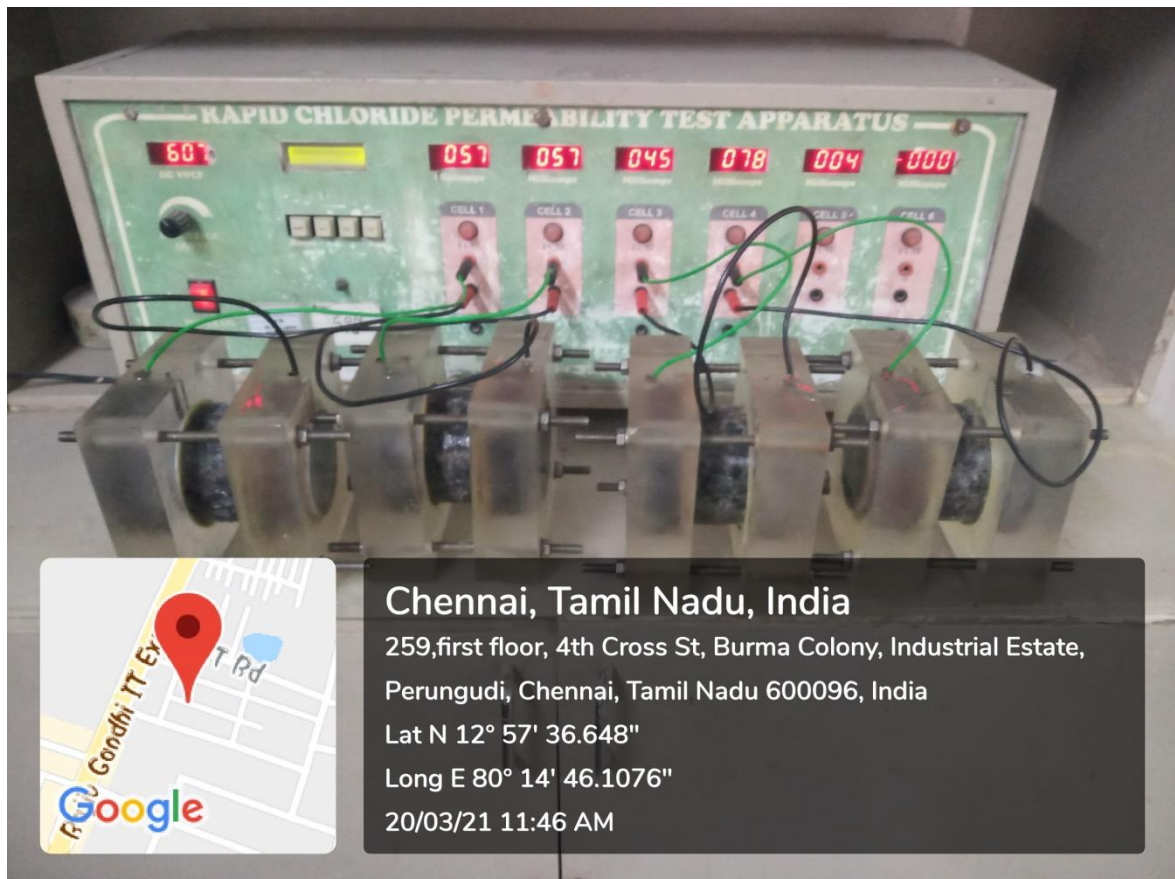


Fig 4.12 Rapid chloride penetration test equipment

Table 4.8 range of Water penetration

Charge passed (coulombs)	Chloride permeability
>4000	High permeable concrete
2000 - 4000	Moderate
1000 - 2000	Low
100 - 1000	Very low
<100	Negligible

4.4.6 Flexural Strength Test

The flexural strength test is leaded on the concrete beam specimens reinforced with GFRP bar and steel bar of size 700 mm X 150 mm X 150 mm. To compare the strength characteristic of both the concrete beam specimens they were cured in saline solution for 21 days. Then the beams are placed in the UTM machine and subjected to three point loading. The load was applied gradually till the concrete beam specimen fails and the deflection is noted. The reading in which the load go reverse that instant load is the ultimate load. The test setup is shown in the Fig 4.13.



Fig 4.13 Beam subjected to three point loading

4.4.7 Tension Test

To compare the strength characteristic of steel rebar and GFRP rebar of 12mm diameter, tension test were conducted. To determine the tensile strength of the rods UTM machine is used. The rod is placed firmly so that the rod fits the top base of the machine, when the bar is placed, the jaws of the UTM machine is locked. Then the load is applied gradually so that the bars elongates and fails. After the bar specimen is broken the tensile strength, ductility and yield strength are calculated. The test setup for steel rod and GFRP rod are shown in the fig 4.14 and 4.15 respectively.

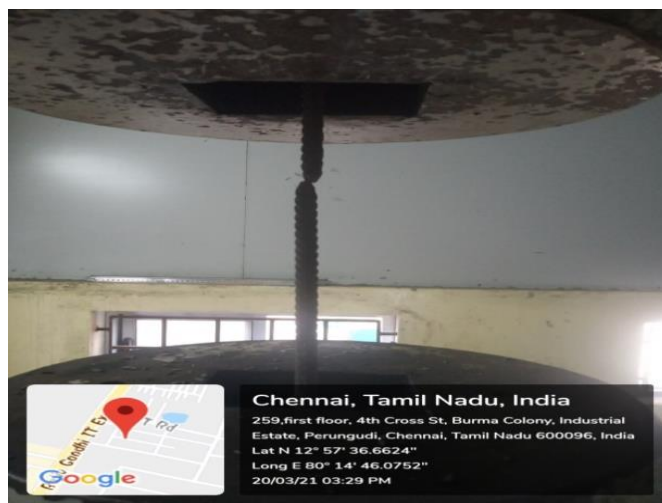


Fig 4.14 Tension test conducted on steel rebar

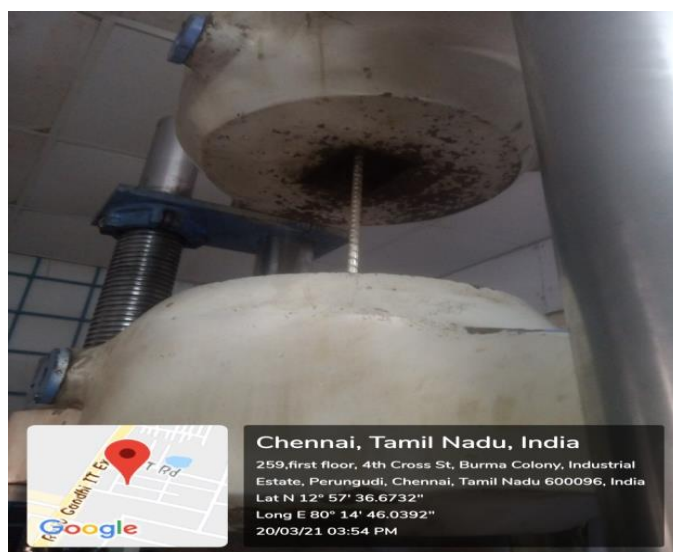


Fig 4.15 Tension test conducted on GFRP rebar

4.5 NUMERICAL INVESTIGATION

4.5.1 General

The ANSYS 2020 Workbench software is an advanced finite element analysis which coexists with other design software. Thermal, electromagnetic and structural analysis was also performed by ANSYS 2020 Workbench. In this project the focus is on the geometry creation, meshing, finite element model setup, solving and reviewing the obtained results.

The ANSYS 2020 Workbench was generally used by engineers to interact with the domains such as fluid dynamics, electromagnetic, vibration, structural and heat transfer so that it can be used in these domains. With the pre properties capability the geometry can form easily. After the geometry is formed the mesh is generated the loads are defined and analyzed so that it can be viewed geometrically and numerically.

4.5.2 Ansys Model Description

In this numerical study a FEM beam model is evolved by using ANSYS 2020 Workbench to analyze a steel reinforced beam and a GFRP reinforced beam as in 3 point loading setup. The created model has the size of 700 x 150 x 150 mm and reinforcements with main rods and stirrups having diameter 12 mm and 8 mm respectively.

4.5.3 Ansys Modelling Procedure

The beam analyses is followed in step by step procedure such as,

- Setting up engineering data
- Geometry of the model is created
- Meshing the beam model
- Solving the beam model
- Results of the beam model

4.5.3.1 Engineering Data

The mechanical properties of concrete, steel rebar, GFRP rebar is fed in engineering data for the further analysis. The engineering data of the steel and GFRP rebar was shown in Fig 4.16 and Fig 17

Properties of Outline Row 6: Structural Steel				
	A	B	C	D E
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Density	7850	kg m ⁻³	
4	Isotropic Secant Coefficient of Thermal Expansion			
6	Isotropic Elasticity			
7	Derive from	Young's Modulus and Poisson...		
8	Young's Modulus	2E+05	MPa	
9	Poisson's Ratio	0.3		
10	Bulk Modulus	1.6667E+11	Pa	
11	Shear Modulus	7.6923E+10	Pa	
12	Tensile Yield Strength	250	MPa	
13	Compressive Yield Strength	250	MPa	
14	Tensile Ultimate Strength	460	MPa	
15	Compressive Ultimate Strength	0	MPa	

Fig 4.16 Engineering data for steel rebar

Properties of Outline Row 6: GFRP				
	A	B	C	D E
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Density	1900	kg m ⁻³	
4	Isotropic Secant Coefficient of Thermal Expansion			
6	Isotropic Elasticity			
7	Derive from	Young's Modulus and Poisson...		
8	Young's Modulus	50000	MPa	
9	Poisson's Ratio	0.3		
10	Bulk Modulus	4.1667E+10	Pa	
11	Shear Modulus	1.9231E+10	Pa	
12	Tensile Yield Strength	700	MPa	
13	Compressive Yield Strength	540	MPa	
14	Tensile Ultimate Strength	740	MPa	
15	Compressive Ultimate Strength	580	MPa	

Fig 4.17 Engineering data for GFRP rebar

4.5.3.2 Geometry Creation

In this numerical study a beam size of 700mm x 150mm x 150 mm is created. The model beam was shown in fig 4.18.

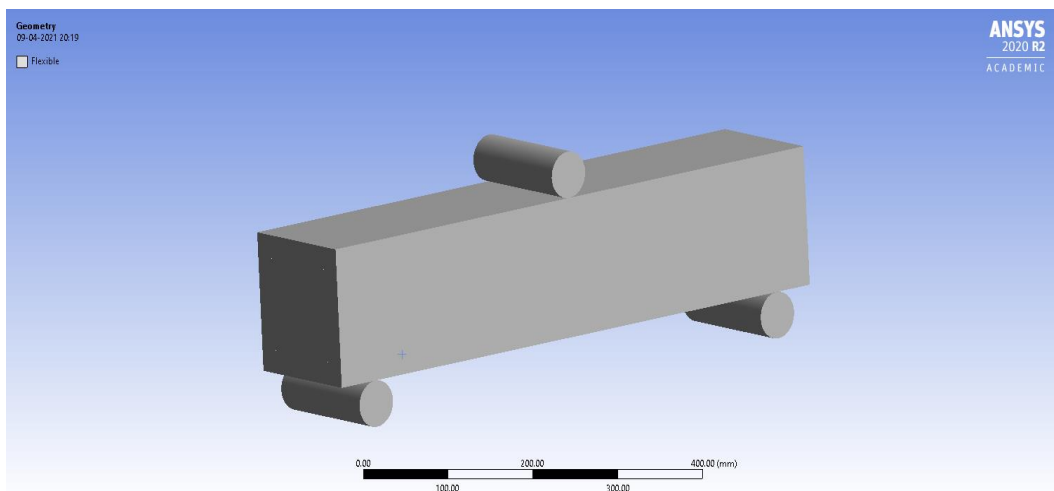


Fig 4.18 Beam model create

4.5.3.3 Assigning The Section Properties

The properties of the section are defined throughout the model. These methods are used to assign the properties in there model.

- The part of the model is selected and the properties is assigned
- A tool set is created containing the part of the model and the properties of the section are assigned.

4.5.3.4 Setting Up The Finite Element Model

The geometry model of the beam is formed then in the modelling phase the material properties were assigned for all the sections. Then the mesh should be generated in finite element method in the model which helps to solve the model analysis and the results are obtained.

4.5.3.5 Material Properties

The material data should be imported to the workbench data so that it can be assigned properly and the results obtained to be accurate. Table 4.8 shows the material properties which was used as an input in the Ansys.

Table 4.9 Material properties

Material	Density (Kg/m3)	Modulus of elasticity (Mpa)	Poisson ratio
Concrete	2400	31	0.2
Steel	7850	2×10^5	0.3
GFRP	1900	5×10^4	0.34

4.5.3.6 Mesh Generation

Meshing is a process which is also called as discretization which generates nodes. The large sections are converted into small nodes in this process. In the mesh generation process the loads will be distributed all over the section. The meshing of the beam was shown in fig 4.19.

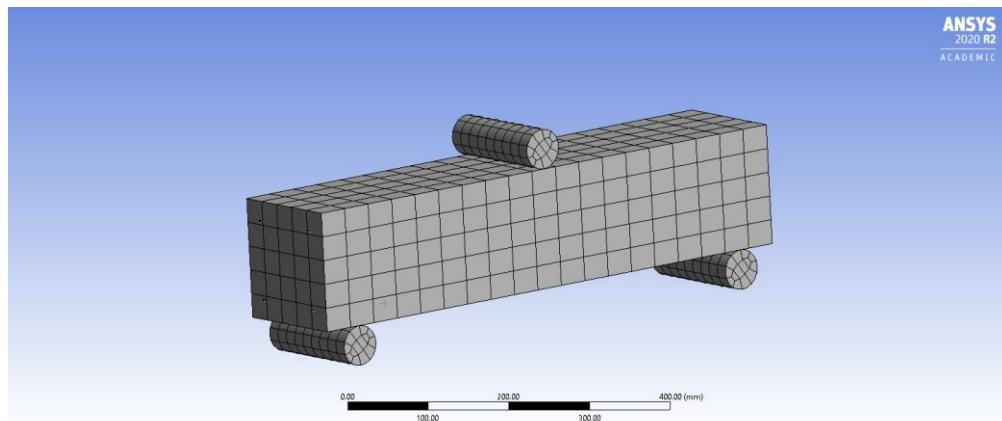


Fig 4.19 Mesh generation of beam model

4.5.3.7 loading Pattern

The generated beam model which is reinforced with steel rebar and GFRP rebar are subjected to three point loading to examine the failure modes. The loading pattern of the beam was shown in fig 4.20.

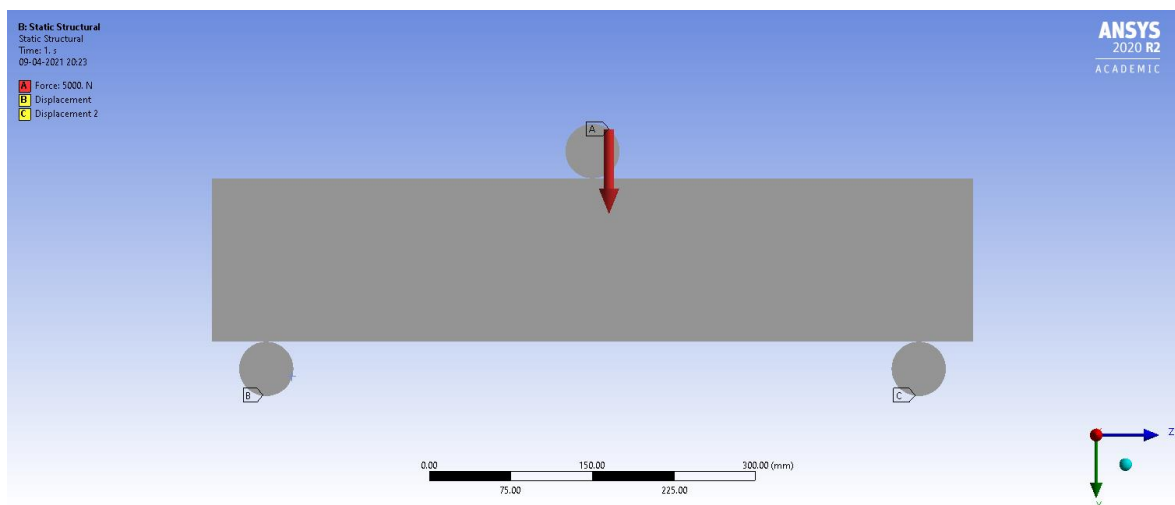


Fig 4.20 Loading pattern

CHAPTER 5

RESULT AND DISCUSSION

5.1 EXPERIMENTAL RESULTS

This chapter presents the test result and discussion on the compression strength, water penetration, and rapid chloride penetration test on concrete cubes. Then the flexural strength test on GFRP and steel reinforced concrete beams and the tensile strength test on the GFRP and steel bars.

5.1.1 Compression Strength Test

- Totally 18 concrete cube specimens of M40 grade and of size 150 mm x 150mm X 150 mm were casted and cured in both potable water and saline solution for 7 days, 14 days and 21 days then the test is conducted using compressive testing machine.
- The concrete cube specimen were dried before placing it in the space between bearing surfaces and it was aligned properly with the centre of thrust in the testing machine plates.
- When the load was applied constantly on the concrete cube specimens, it started to crack and finally the breakdown of the concrete cube specimen was noted.
- In this experimental study, the compressive strength of 21 days of M40 concrete cubes were cured in portable water was 44.13 N/mm² whereas in the cubes cured in saline solution 41.83 N/mm². Though the variation is very minor over the period of time, it is evident that the structures exposed to the marine environment will affect the strength characteristics. Table 5.1 shows the Compression strength test result.

Table 5.1 Compression strength test result

COMPRESSION TEST (N/mm²)					
POTABLE WATER			SALINE SOLUTION		
7 DAYS	14 DAYS	21 DAYS	7 DAYS	14 DAYS	21 DAYS
26.25	36.3	46.54	25.36	35.7	40.36
25.83	37.48	43.53	28.62	37.35	41.53
27.2	38.5	42.32	29.4	36.87	43.6
Average			Average		
26.43	37.4	44.13	27.8	36.64	41.83

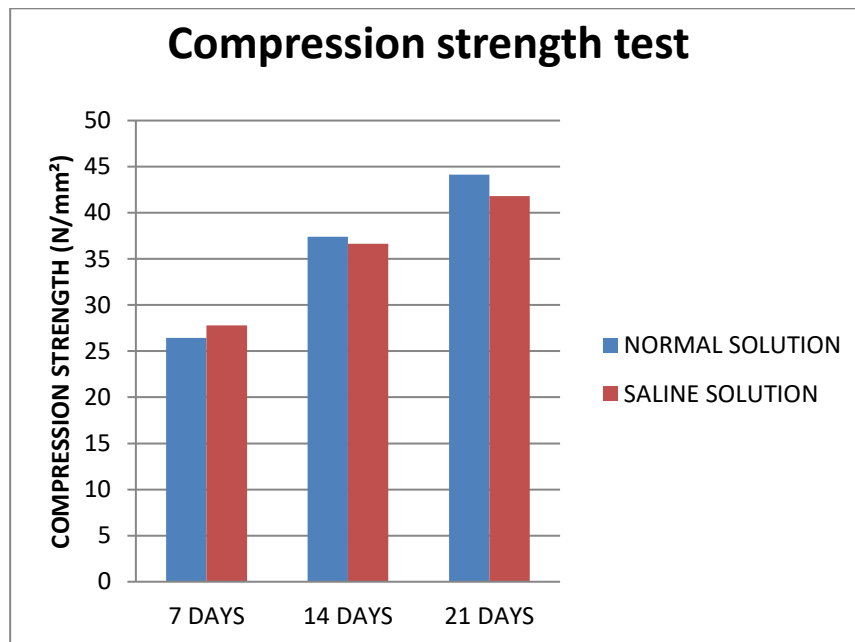


Fig 5.1 Compression strength test (7, 14, 21 days)

5.1.2 Water Penetration Test

- Four concrete cube specimens each of size 150mmX150mmX150mm are casted and after 24 hours, the middle portions of the cube specimens are roughened and the remaining portion is sealed with cement paste.
- Then the specimens are cured for 21 days and then water pressure is applied on the middle roughened portion so that water can penetrate inside the concrete. In this project two cube specimens are cured in potable water and the other two cube specimens are cured in saline solution.

- After 21 days of curing, the specimens are split to perceive the rate of penetration of water in the concrete specimens.
- The specimens are split by using compression testing machine and the specimens are subjected to concentrated load which are applied near the central axis.
- The maximum values of penetration were observed and the average is calculated.
- The penetration depth of water in concrete specimen should not be more than 25mm; if the depth of penetration exceeds 25mm then the specimens are considered to be failure in permeability test.
- In this study the depth of penetration was maximum in cubes which are cured in the saline solutions than the portable water.
- In this case, depth of saline solution penetration is 27 mm in cube specimen where as in potable water depth of penetration is 23 mm.
- It shows that the saline solution aggravates the depth of penetration, thus the structure exposed in marine environment affects the strength characteristic of concrete and its reinforcement. Table 5.2 shows the Water penetration test result.

Table 5.2 Water penetration test result

WATER PENETRATION TEST (21 days)(mm)		
Maximum depth of penetration (mm)	POTABLE WATER	SALINE SOLUTION
	21	26
	24	28
Average	23	27

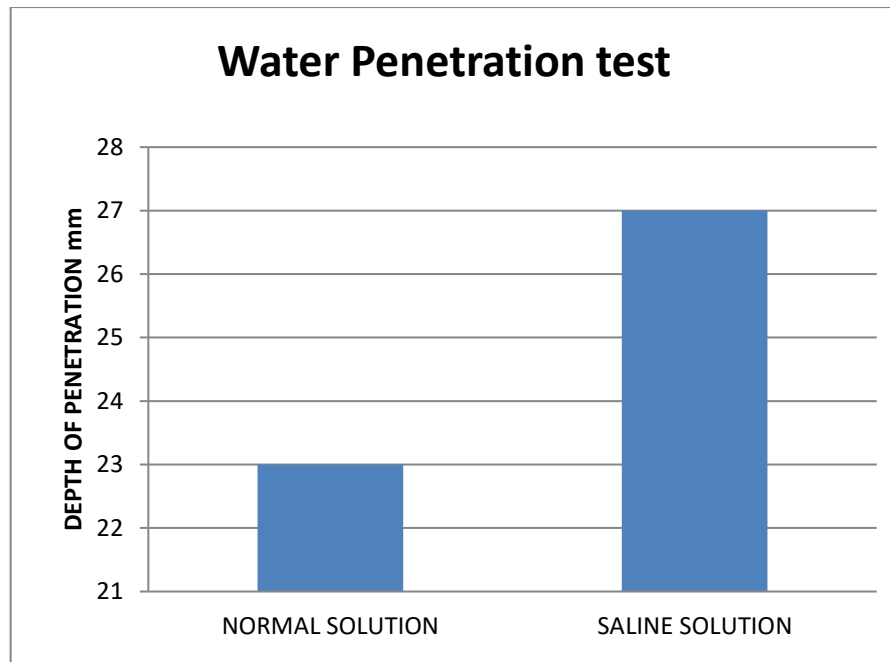


Fig 5.2 Water penetration test (21 days)

5.1.3 Rapid Chloride Penetration Test

- To evaluate the ability to resist chloride ion penetration on the concrete specimens the Rapid Chloride Permeability Test is performed.
- Test is executed by installing 100 mm diameter cylinder made up of concrete which is installed in the sample cells which contain 3.0 % sodium chloride solution and 0.3 molar sodium hydroxide solution.
- Then a voltage is passed through the ends of the specimens throughout the test for the whole 6 hours (60 V DC) and the charge that passes through the sample is recorded for every 30 minutes.
- A qualitative rating was made for concrete permeability based on the charge passed (Coulombs).
- Since the cube is cured in saline solution the chloride ions present in the saline solution reacts when the charge is passed through the cube specimen, Thus it leads to variation of charge passed in cubes cured in normal water and saline solution.
- In this experimental study, the charge passed (coulombs) through the test specimens which are cured in both normal and saline solution lies between 2000- 4000 which is moderate.

- By comparing the test results for both the specimen, the specimen cured with saline solution is subjected to increased rate of chloride ion penetration than the specimen cured with potable water.
- It shows that the structures exposed in marine environment are more prone to chloride ion penetration which induces the increased rate of corrosion effects in the reinforcement.
- Thus the present study justifies the consideration of GFRP rebar for the reinforcement in order to protect the structure from salt induced corrosion especially in marine environment. Table 5.3 shows the Rapid chloride penetration result.

Table 5.3 Rapid chloride penetration result

RAPID CHLORIDE PENETRATION TEST (21 days)		
	CHARGE PASSED (COULOMBS)	CHLORIDE ION PENETRABILITY
Potable Water	2114	MODERATE
Saline Solution	2281	MODERATE

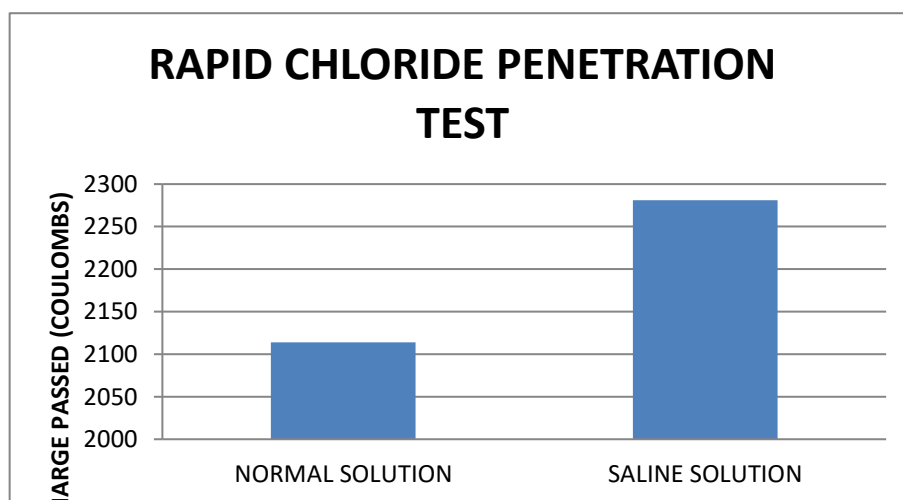


Fig 5.3 Rapid chloride penetration test (21 days)

5.1.4 Flexural Strength Test

- A total of 4 beams sized 700 mm X 150 mm X 150 mm were reinforced with both steel rebar and GFRP rebar.
- In which 2 beams are reinforced with steel bars and the other 2 beams are reinforced with GFRP bars and these 4 beams are cured in saline solution then the three-point bending flexural test were conducted on 14 days and 21 days.
- The test was performed on the universal testing machine (UTM). The beam specimen was placed on the UTM and the load was applied gradually and the deflections were noted. Fig 5.3 and 5.4 shows the flexural test conducted on the beams.



Fig 5.4 Flexural test conducted on steel reinforced beam



Fig 5.5 Flexural test conducted on GFRP reinforced beam

Formation of crack

From the results obtained from the flexural test for 14 days the first crack was observed in beam with steel rebar and GFRP rebar at load 70 KN and 35 KN respectively and for 21days the first crack was observed in beam with steel rebar and GFRP rebar at load 85 KN and 45 KN respectively.

Deflection at maximum load

In 14 days the Maximum load observed in beam with steel rebar and GFRP rebar is 117.5 KN and 75 KN respectively with 8.8mm and 13.38 mm deflection and in 21 days the Maximum load observed in beam with steel rebar and GFRP rebar is KN and 102 KN respectively with 11.75mm and 15.92 mm deflection. The maximum flexural strength was obtained in beam with steel rebar than GFRP rebar. At the maximum load, the max deflection was obtained in beam reinforced with GFRP rebar is higher than steel rebar.

Comparing the results obtained from the flexural test, the deflection of the beam was maximum for GFRP bars than the steel bars.

- The main advantage of the GFRP bar is when the structure is constructed in the marine environment the rebar will not corrode whereas steel corrodes.
- In order to attain flexural strength of the GFRP reinforced beam the micro synthetic fibres can be added to the concrete.

- Strength characteristic of GFRP reinforced beam can be modified in order to reduce the crack formation effect by using different varieties of fibres which are in practice.
- By referring the research conducted by several researchers, by adding micro synthetic fibres in the GFRP reinforced beam will improve the rigidity so that the flexural strength can be improved significantly. (Biswarup saikai et al. 2017; Pardakhe and Bajad. 2019)
- For the future study, the accelerated corrosion studies can be conducted for the beams reinforced with steel and GFRP rebar.
- The comparative analysis will show the advantages of using GFRP rebar as reinforcement.

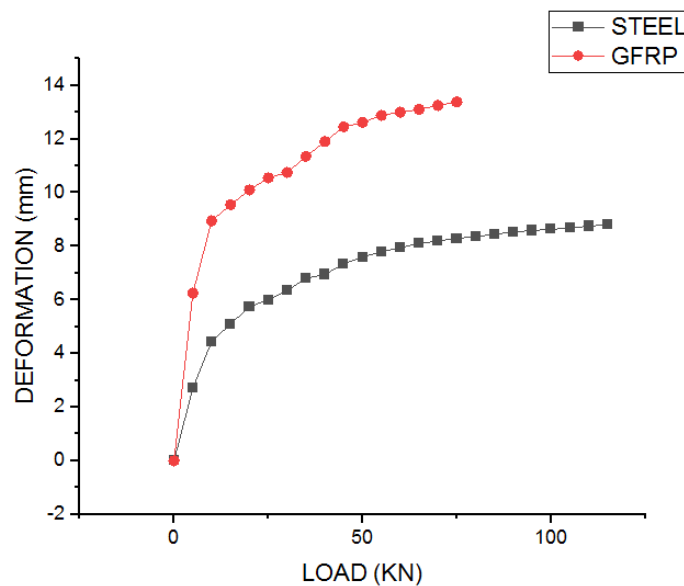


Fig 5.6 Load deflection curve (14 days)

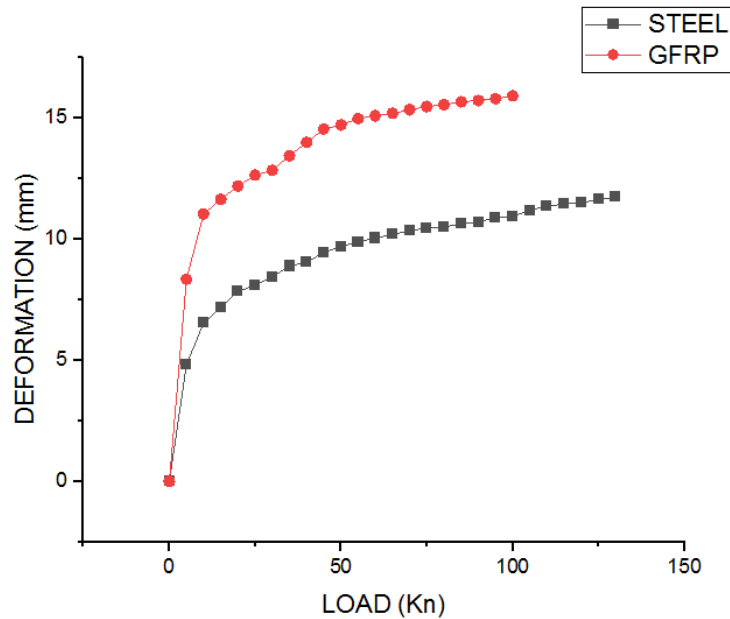


Fig 5.7 Load deflection curve (21 days)

5.1.5 Tension Test

- The steel rebar and GFRP rebar of 12 mm diameter was firmly held by top and bottom grips attached to the universal testing machine (UTM).
- During the tension test, the grips are moved away from each other at a constant rate to pull and stretch the specimen.
- The tensile strength, ductility and yield strength, are calculated after the tensile test specimen has broken.
- The test specimen is put back together to measure the final length, and then this measurement is compared to the original length to obtain elongation.
- In this experimental study, the tensile strength is achieved more in GFRP rebar than the steel rebar due to the unique material properties of GFRP. Fig 5.7 and 5.8 shows the tension test conducted on the rebar and Table 5.4 shows the results of tension test.

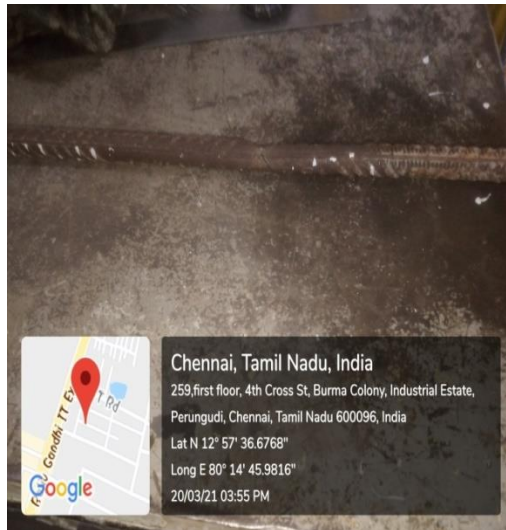


Fig 5.8 Tension test conducted on steel rebar

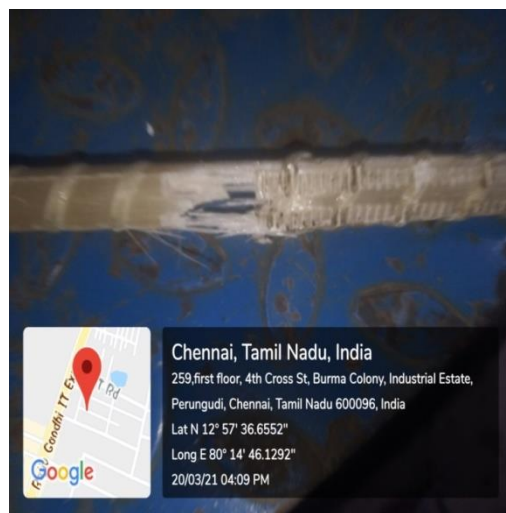


Fig 5.9 Tension test conducted on GFRP rebar

Table 5.4 Tension test result

TENSILE TEST			
SPECIMEN	DIAMETER (mm)	MASS (Kg)	TENSILE STRENGTH (Mpa)
GFRP	12	0.188	596
STEEL	12	0.857	542

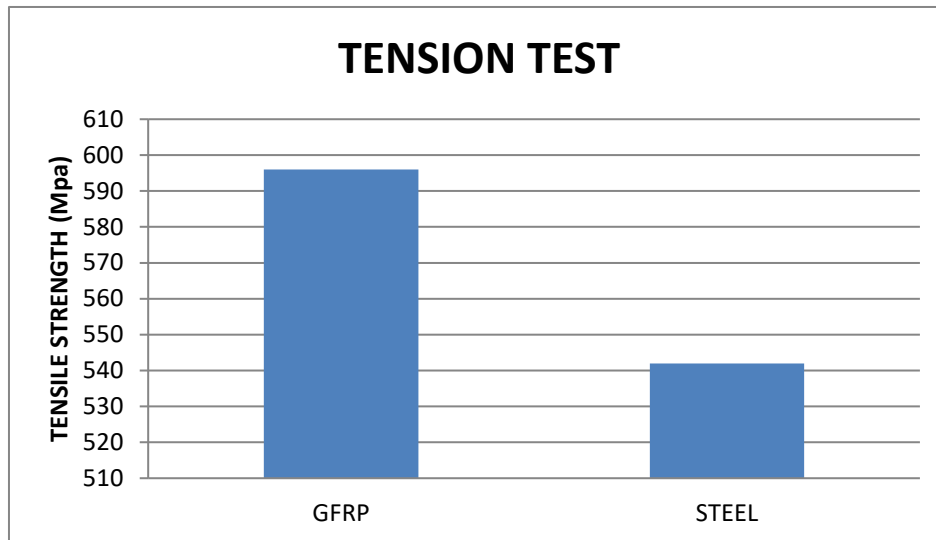


Fig 5.10 Tension test on steel and GFRP rebar

5.2 NUMERICAL RESULTS

5.2.1 Beams without Corrosion

- A total of 2 beams sized 700 mm X 150 mm X 150 mm were reinforced with steel rebar and GFRP rebar are modelled in the Ansys 2020 workbench.
- In which one beam is reinforced with steel bars and the other beam is reinforced with GFRP bars and then the three-point bending flexural load was performed in the beam model.
- The beams reinforced with GFRP rebar and steel rebar had maximum deformation of 12.58mm and 8.55 mm respectively.
- The maximum deflection was observed in beam reinforced with GFRP rebar compared to the beam reinforced with steel rebar. Fig 5.11 and 5.12 shows the maximum deflection in the GFRP and steel reinforced beams.

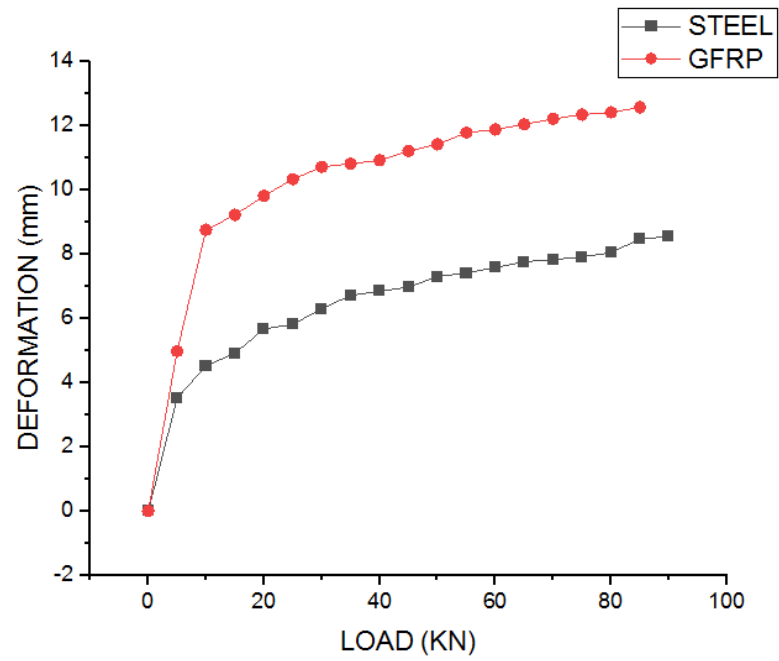


Fig 5.11 Load deflection curve of the beam in Ansys 2020

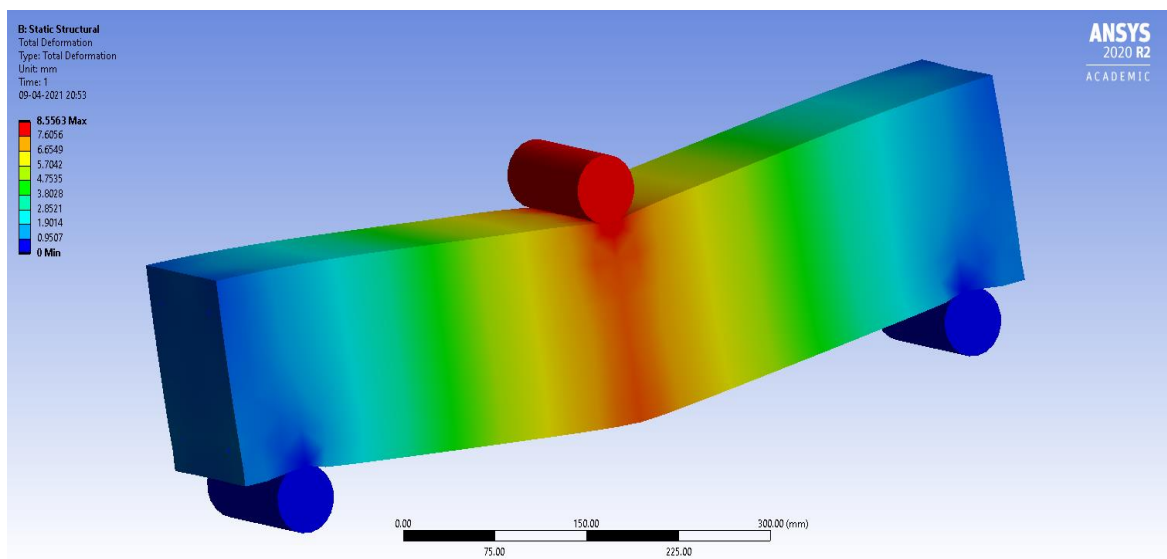


Fig 5.12 Total deflection of the steel reinforced beam

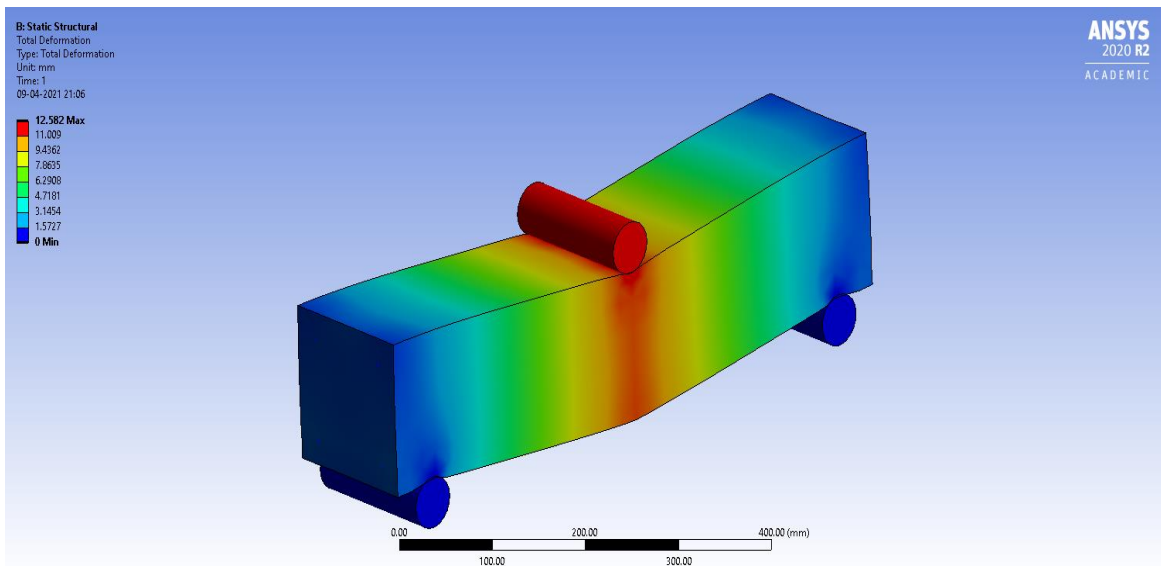


Fig 5.13 Total deflection of the GFRP reinforced beam

5.2.2 Steel Beam With 20% Corrosion

- Considering the steel beam to be 20% corroded, the cross sectional area of the reinforcement bars is reduced to 20% and analysed.
- A beam sized 700 mm X 150 mm X 150 mm were reinforced with steel rebar and modelled in the Ansys 2020 workbench.
- The beam is reinforced with steel bars in which the beam is uniformly corroded with the loss of 20%. And then the three-point bending flexural load was performed in the beam model.
- In the beam reinforced with steel rebar that is considered as corroded has total deformation of 14.73 mm and the beam reinforced with GFRP rebar has total deformation of 12.58 mm. Since in GFRP rebar corrosion does not take place the GFRP reinforced beam is compared with steel reinforced beam with corrosion.
- The maximum deflection was observed higher in beam reinforced with steel rebar that is considered to have 20% corrosion compared to the beam reinforced with GFRP rebar.

- The analysis result proves that the advantages of using GFRP rebar as reinforcement especially in the marine exposed structure.
- Fig 5.14 shows the maximum deflection in the steel reinforced beam with 20% corrosion and Fig 5.13 shows the load deflection curve of beam with 20% steel corrosion and GFRP without corrosion.

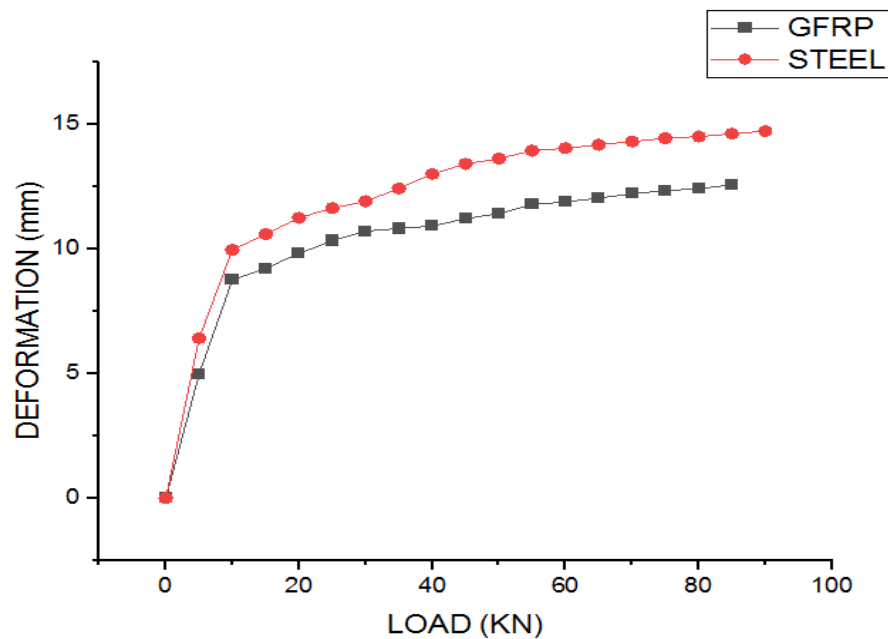


Fig 5.14 Load deflection curve of beam with 20% steel Corrosion and GFRP without corrosion in Ansys

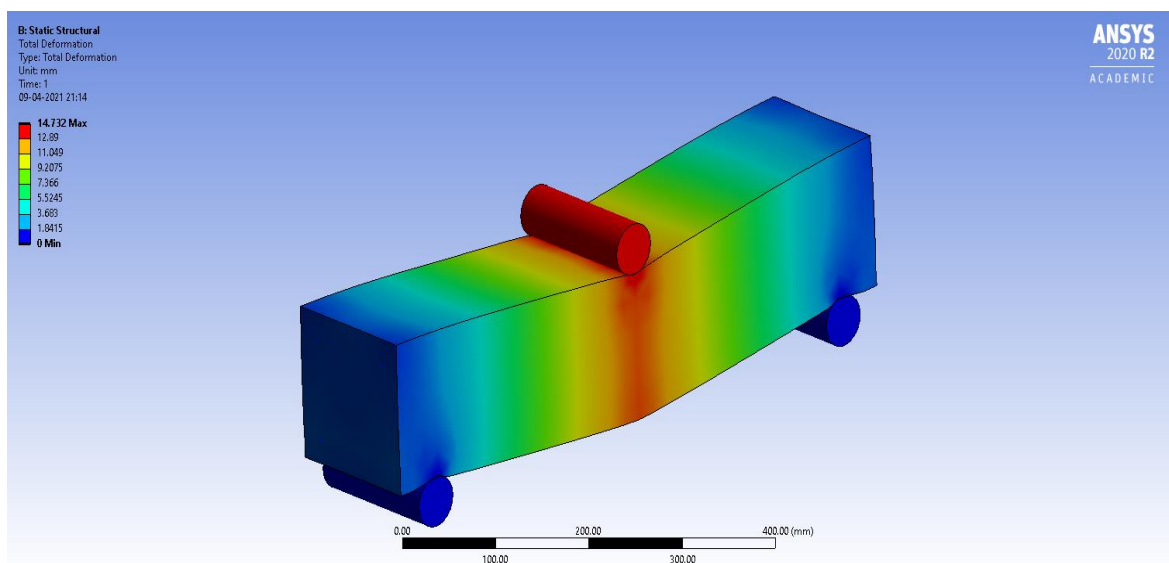


Fig 5.15 Total deflection of the steel reinforced beam with 20% corrosion

5.3 COMPARISON OF EXPERIMENTAL WITH ANALYTICAL RESULTS

- The values obtained on the total deformation in both experimental and numerical results is plotted in the Fig 5.15.
- In the beam reinforced with GFRP rebar has total deformation of 15.92mm and 12.58 mm experimental and numerical analysis respectively.
- In the beam reinforced with steel rebar has total deformation of 11.75 and 8.55 in experimental and numerical analysis respectively.
- The result which was obtained in experimental analysis was maximum.
- The results between experimental and numerical analysis varies because experimentally the beam is cured in saline solution to maintain the marine environment whereas this environment cannot be achieved in numerical analysis.

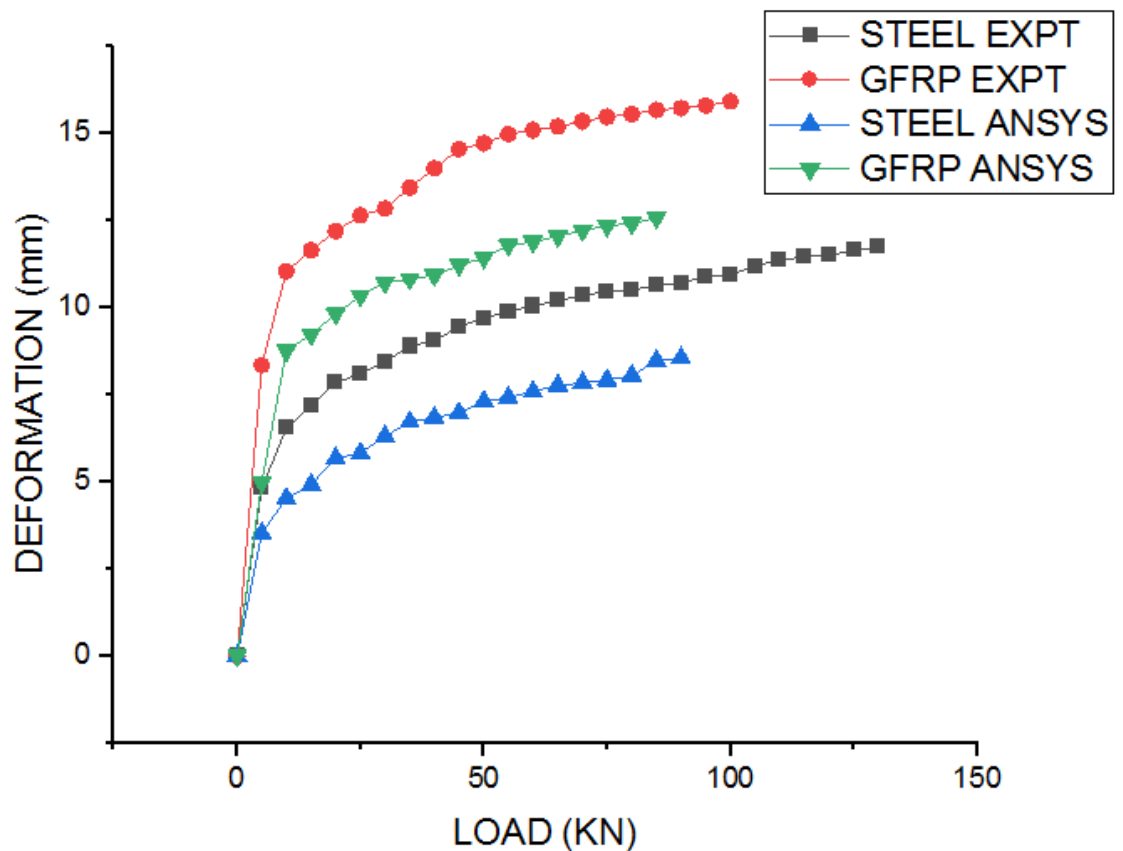


Fig 5.16 Load deflection curve (Comparison)

CHAPTER 6

SUMMARY AND CONCLUSION

GFRP bars are considered as a very important topic in recent years because of its performance. In this study the material characteristics and the properties of the GFRP bars (Mechanical) in RC structures under marine conditions. It is more obvious that GFRP and other FRP rebar are used in structures in or close to marine environment which are prone to corrosion and durability problems. Therefore, it requires to carry out the detailed study on performance of GFRP rebar and their durability effects on GFRP rebar which is embedded in concrete structures in marine conditions.

- The GFRP rebar have more tensile strength compared to the steel reinforcement.
- Maximum deflection occurs in GFRP reinforced beam compared to the Steel reinforced beam.
- From this study, the GFRP reinforced beam has less flexural strength compared to the steel reinforced beam.
- This can be minimized by using different varieties of synthetic fibres.
- From this study, though GFRP reinforced beam has less flexural strength compared to the steel reinforced beam the GFRP rebar will increase the durability behaviour when compared to steel rebar especially in the marine structures.

Thus the flexural strength of GFRP reinforced beam can be attained by the addition of micro synthetic fibres. By adopting this method the structures in the marine environment can be prevented from corrosion.

This study is evident that GFRP rebar can be effectively used for construction under marine conditions. Finally, the importance of GFRP bars in reinforced concrete construction brings new challenges for strengthening the reinforced concrete structures.

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