Experimental study and finite element modeling of concrete beam confined with FRP sheets in flexure

A Project Report

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Title Bending behaviour of RCC beams with FRP wrapping.

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ABSTRACT

This project enumerates the outcome of detailed experimental investigations carried out to ascertain the feasibility of concrete for GFRP flexural members. FRP composites have wide applications in civil engineering infrastructure. Application of FRP composite in construction industry includes strengthening of existing beams with external FRP composite reinforcement and construction of new FRP composite structures. In this experimental work, three numbers of reinforced concrete beams were cast and test under pure bending. This work mainly destined to examine experimentally the external bonding of E-Glass fiber (woven rovings) bonded with epoxy resin to strengthen the RCC beam. This is also to evaluate the effect on both load carrying and flexural behavior with respect to number of E-Glass fiber layers wrapped around the RCC beam. Depending on the E-Glass fiber layers wrapped around the beam, the variation in strength, deflection were determined. The experimental results obtained were compared with FEM modelling of RCC beams with GFRP wrappings using ANSYS software

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LIST OF SYMBOLS & ABBREVIATIONS

FRP	Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
CFRP	Carbon Fiber Reinforced Polymer
WR	Woven roving
F_{ck}	Characteristic compressive strength of concrete
F_a	Fine aggregate
Ca	Coarse aggregate
1	Control specimen
1 (A)	Beam with single layer wrapping
1 (B)	Beam with double layer wrapping

CHAPTER 1

1.0 INTRODUCTION

1.1 GENERAL

Strengthening of Structures

Strengthening of existing (Concrete) structures has become increasingly important in the construction industry lately. Our demands to existing buildings are changing increasingly faster, resulting in an increased need to alter existing structures. Most of the structures is in most cases a better alternative than demolishing and subsequently rebuilding. One of the recent developments in this field is the strengthening of Reinforced Concrete (RC) structures with externally bonded Fibre Reinforced polymer (FRP) reinforcement.The strengthening of the concrete structures is widely very important in the field of civil engineering and the reasons are increasing in load factors, design, construction faults, change of structural system etc. The bonding of glass fiber reinforced polymers is found to be a competitive method for strengthening of existing structures.

For rehabilitation and strengthening of the concrete structures, fiber reinforced polymer (FRP) sheets and strips have been recently established. FRP has the advantage as the external reinforcement of rehabilitation of R.C.C structures. Another method for the strengthening of R.C.C structure is to bond FRP sheets on the surface of structural members. The advantage of FRP are light weight, ease to installation and high strength. Due to this reason it is adopted for rehabilitation and strengthening projects. Many experimental investigations have been reported on the behavior of concrete beams strengthened for flexure using externally bonded FRP sheets or fabrics, plates which shows that bonded FRP has significantly increase the load carrying capacity of the member

In the recent years,large scale general –purpose finite element codes have developed rapidly and their functions are more and more perfect.This makes it possible to apply finite element analysis on different structures.Now the higher version of ANSYS provides many new functions that can stimulate,analyze and compute the bending behaviour of structures more accurately.in this thesis paper bending behaviour of beams with number of GFRP wrappings details were simulated and analysed by using ANSYS.

1.2 FIBER REINFORCED POLYMERS

The strengthening or retrofitting of existing concrete structures to resist higher design loads, correct deterioration-related damage, or increase ductility has traditionally been accomplished using conventional materials and construction techniques. Externally bonded steel plates, steel or concrete jackets and external post-tensioning are just some of the many traditional techniques available.

Composite materials made of fibers in a polymeric resin, also known as fiber-reinforced polymers (FRP), have emerged as an alternative to traditional materials and techniques. For the purposes of this document, an FRP system is defined as all the fibers and resins used to create the composite laminate, all applicable resins used to create the composite laminate, all applicable resins used to bond it to the concrete substrate, and all applied coatings used to protect the constituent materials. Coatings used exclusively for aesthetic reasons are not considered part of an FRP system.

FRP materials are lightweight, no corrosive, and exhibit high tensile strength. Additionally, these materials are readily available in several forms ranging from factory made laminates to dry fiber sheets that can be wrapped to confirm to the geometry of a structure before adding the polymer resin. The relatively thin profiles of cured FRP systems are often desirable in applications where aesthetics or access is a concern.

This provides guidance for the selection, design, and installation of FRP systems for externally strengthening concrete structures. Information on material properties, design, installation, quality control, and maintenance of FRP systems used as external reinforcement is presented. This information can be used to select an FRP system for increasing the strength and stiffness of reinforced concrete beams or the ductility of columns, and other applications.

1.3 Types of manmade fibers –

- ARAMID
- BORON
- CARBON/GRAPHITE
- GLASS
- NYLON
- POLYESTER
- POLYETHYLENE
- POLYPROPYLENE

1.4 Forms of Glass Fiber Reinforcements

Glass fiber-re-inforced composites contain fibers having lengths far greater than their cross sectional dimensions (aspect ratios > 10:1). The largest commercially produced glass fiber diameter is a "T" fiber filament having a nominal diameter of 22.86 to 24.12 microns. A number of fiber forms are available.

Rovings

This is the basic form of commercial continuous fiber. Rovings are a grouping of a number of strands, or in the case of so-

called "direct pull" rovings, the entire roving is formed at one time. This result in a more uniform product and eliminates catenary associated with roving groups of strands under unequal tension.

COMPOSITIONAL RANGES FOR COMMERCIAL GLASS FIBERS (UNITS = PERCENT BY WEIGHT) TABLE NO. 1

	E-Glass range	S- Glass range	C-glass range
Silicon dioxide	52-56	65	64-68
Aluminum oxide	12-16	25	3-5
Boric oxide	5-10	-	4-6
Sodium oxide and potassium oxide	0-2	-	7-10
Magnesium oxide	0-5	10	2-4
Calcium oxide	16-25	-	11-25
Barium oxide	-	-	0-1
Zinc oxide	-	-	-
Titanium oxide	0-1.5	-	-
Zirconium oxide	-	-	-
Iron oxide	0-0.8	-	0-0.8
Iron	0-1	-	-

Woven roving

The same roving product mentioned above is also used as input to woven roving reinforcement. The product is defined by weave type, which can be at 0 and 90 deg; at 0 deg, +45deg, -45deg, and other orientations depending on the manufacturing process.

Mats

These are two-dimensional random arrays of chopped strands. The fiber strands are deposited onto a continuous conveyor and pass through a region where thermosetting resin is dusted on them. This resin is heat set and holds the mat together. The binder resin dissolves in the polyester or vinyl ester matrix thereby allowing the mat to conform to the shape of the mold.

Combined products

It is also possible to combine a woven roving with a chopped strand mat. There are several techniques for accomplishing this. One technique bonds the two reinforcements together with a thermosetting resin similar to that in the chopped strand approach. Another approach starts with the woven roving but has the chopped strand fibers deposited onto the surface of the woven roving, which is followed immediately by a stitching process to secure the chopped fibers. There are several variations on this theme.

Cloth

Cloth reinforcement is made in several weights as measured in ounces-per-square-yard. It is made from continuous strand filaments that are twisted and plied and then woven in conventional textile processes.

All composite reinforcing fibers, including glass, will be anisotropic with respect to their length. There are fiber placement techniques and textile-type operations that can further arrange fibers to approach a significant degree of quasi-isotropic composite performance. Glass fibers and virtually all other composite fibers are also available in a range of fabric-like forms including braided needle punched, stitched, knitted, bonded, multi-axial, and multiple-ply materials.

1.5 Behavior of glass fibers under load

Glass fibers are elastic until failure and exhibit negligible creep under controlled dry conditions. Generally, it is agreed that the modulus of elasticity of mono-filament E-glass is approximately 73GPa. The ultimate fracture strain is in the range of 2.5 to 3.5 percent. The fracture of the actual strand is a cumulative in which the weakest fiber fails first and the load is then transferred to the remaining stronger fibers which fail in succession.

Glass fibers are much stronger than a comparable glass formulation in bulk form such as window glass, or bottle glass. There strength of glass fibers is well-retained if the fibers are protected from moisture and air-borne or contact contamination.

When glass fibers are held under a constant load at stresses below the instantaneous static strength, they will fail at some point as long as the stress is maintained above a minimum value. This is called “creep rupture.” Atmospheric conditions play a role, with water vapor being most deleterious. It has been theorized that the surface of glass contains submicroscopic voids that act as stress concentrations. Moist air can contain weakly acidic carbon dioxide. The corrosive effect of such exposure can affect the stress in the void regions for glass fiber filaments until failure occurs. In addition, exposure to high pH environments may cause aging or a rupture associated with time.

These potential problems were recognized in the early years of glass fiber manufacture and have been the object of continuing development of protective treatments. Such treatments are universally applied at the fiber-forming stage of manufacture. A number of special organo-silane functional treatments have been developed for this purpose. Both multi-functional and environmental-specific chemistries have been developed for the classes of matrix materials in current use.

Depending upon the resin matrix used, the result of these developments has been to limit the loss of strength to 5 to 10 percent after a 4-hr water boil test.

1.6 Suitability of FRP for Uses in Structural Engineering

The strength properties of FRPs collectively make up one of the primary reasons for which civil engineers select them in the design of structures. A material's strength is governed by its ability to sustain a load without excessive deformation or failure. When an FRP specimen is tested in axial tension, the applied force per unit cross-sectional area (stress) is proportional to the ratio of change in a specimen's length to its original length (strain). When the applied load is removed, FRP returns to its original shape or length. In other words, FRP responds linear-elastically to axial stress.

The response of FRP to axial compression is reliant on the relative proportion in volume of fibers, the properties of the fiber and resin, and the interface bond strength. FRP composite compression failure occurs when the fibers exhibit extreme (often sudden and dramatic) lateral or sides-way deflection called fiber buckling.

FRP's response to transverse tensile stress is very much dependent on the properties of the fiber and matrix, the interaction between the fiber and matrix, and the strength of the fiber-matrix interface. Generally, however, tensile strength in this direction is very poor.

Shear stress is induced in the plane of an area when external loads tend to cause two segments of a body to slide over one another. The shear strength of FRP is difficult to quantify. Generally, failure will occur within the matrix material parallel to the fibers.

Among FRP's high strength properties, the most relevant features include excellent durability and corrosion resistance. Furthermore, their high strength-to-weight ratio is of significant benefit; a member composed of FRP can support larger live loads since its dead weight does not contribute significantly to the loads that it must bear. Other features include ease of installation, versatility, anti-seismic behaviour, electromagnetic neutrality, excellent fatigue behaviour, and fire resistance.

However, like most structural materials, FRPs have a few drawbacks that would create some hesitancy in civil engineers to use it for all applications: high cost, brittle behaviour, susceptibility to deformation under long-term loads, UV degradation, photo-degradation (from exposure to light), temperature and moisture effects, lack of design codes, and most importantly, lack of awareness.

FRP systems can be used to rehabilitate or restore the strength of a deteriorated structural member, to retrofit or strengthen a sound structural member to resist increased loads due to changes in use of the structure, or to address design or construction errors. The engineer should determine if an FRP system is a suitable strengthening technique before selecting the type of FRP system.

The use of FRP systems developed through material characterization and structural testing, including well-documented proprietary systems, is recommended. The use of untested combinations of fibers and resins should be avoided. A comprehensive set of test standards for FRP systems is being developed by several organizations, including ASTM, ACI, and the Intelligent Sensing for Innovative Structures organization (ISIS).

1.7 Applications of FRP

Composites in Construction

There are three broad divisions into which applications of FRP in civil engineering can be classified: applications for new construction, repair and rehabilitation applications, and architectural applications. FRPs have been used widely by civil engineers in the design of new construction. Structures such as bridges and columns built completely out of FRP composites have demonstrated exceptional durability, and effective resistance to effects of environmental exposure. Pre-stressing tendons, reinforcing bars, grid reinforcement , and dowels are all examples of the many diverse applications of FRP in new structures. One of the most common uses for FRP involves the repair and rehabilitation of damaged or deteriorating structures. Several companies across the world are beginning to wrap damaged bridge piers to prevent collapse and steel-reinforced columns to improve the structural integrity and to prevent buckling of the reinforcement.

Architects have also discovered the many applications for which FRP can be used. These include structures such as siding/cladding, roofing, flooring and partitions.

1.8 Current Research on FRP

A serious matter relating to the use of FRPs in civil applications is the lack of design codes and specifications. For nearly a decade now, researchers from Canada, Europe, and Japan have been collaborating their efforts in hope of developing such documents to provide guidance for engineers designing FRP structure

CHAPTER-2

2.0 OBJECTIVE AND SCOPE

2.1 OBJECTIVES OF THE THESIS

- Many type of research works have been done on flexural behaviour of concrete beams with fiber reinforced polymer .But most of them are using glass fibers, and the beams were reinforced in tension zone with GFRP reinforcement.
- In the present work a study on behaviour of RCC beams with externally bonded GFRP wrapping in flexure is carried out.
- FEM modelling of RCC beams with GFRP wrappings was done using ANSYS software
- The experimental results obtained were compared with that of the FEM models developed by the author.

2.2 SCOPE

Following characteristic studies are of interest

1. Comparison of experimental results,for beams without FRP,with single layer FRP and double layer FRP by testing the beams in flexure.
2. To prepare the load vs deflection curve using the experimental values.
3. FEM modelling of FRP beams using ANSYS software

CHAPTER-3

3.0 LITERATURE REVIEW:

Viswanath K.G., D.S.Prakash and K.B.Prakash,(2008) reported that an experimental investigation on the flexural behaviour of hybrid fibre reinforced concrete beams with GFRP wrappings and without any wrappings. Beams of 700 mm x 150 mm x 150 mm were used. The mix design procedure using Indian Standard code of practice for M 30 grade of concrete yielded a proportion of 1 : 1.21 : 2.15 by weight with a water – cement ratio of 0.42.[12] The ingredients of concrete were weighed accordingly and dry mixed. Calculated quantity of hybrid fibres were added to the ingredients and the mass was thoroughly mixed,. Next, approx, 80 % of the calculated quantity of water was added while continuing the mixing. Finally, superplastisiser (1% by weight of cement) was added with the remaining water an the concrete was homogeneously mixed. The beam specimens were kept under wet gunny bags of 24 hours and then demoulded and cured for 28 days under water. The wrapping was done on three sides of the beams following the procedure of hand lay – up. To secure a proper bond between concrete and GFRP, steel plates smeared with releaser were kept over the beams. The plates were removed after setting of GFRP was achieved. The wrapped beams were further air cured for one day before testing. A load controlled universal testing machine was used to test the beams using two point loading as shown. The mid span deflection was recorded using a dial gauge having least count of 0.01 mm. The load deflection curve was plotted. Flexural strength corresponding to the maximum load was calculated from the curve. In general, it can be concluded that the hybrid fibres can be effectively used in beams to derive additional benefits. It can also be concluded that GFRP wrapping (either single wrapping or sandwich wrapping) of beams offer an effective confinement system which enhances the strength characteristics and energy absorption characteristics.

Hota Ganga Rao, V.S and Vijay P.V,(1998) Reinforced concrete structures deteriorate over time due to environmental aging, fatigue and other reasons. Strengthening and rehabilitation those concrete structures by wrapping them with carbon fabric are one of several economic engineering solutions. The intent of study is to evaluate the increase in flexural strength of reinforced concrete beams after wrapping them with carbon fabrics. In this study, 24 reinforced concrete beams strengthened with carbon fiber wraps were experimentally evaluated to determine to improvements in flexural strengths. In addition, bending test results from the wrapped beams were compared with those of other identical concrete beams strengthened with bonded steel plates. Four different carbon wrap configurations were used for strengthening beams and for evaluation and comparison of experimental data. Static responses of all the concrete beams were evaluated in terms of strength, stiffness, compositeness between wrap and concrete, and associated failure modes. Factors governing the percentage increase in the ultimate strength are discussed. Wrapped beams were analyzed considering conventional force equilibrium equations and compared with the experimental results.

Ernst L. Klamer, Dick A. Hordijk and Michael C.J. Hermes,(2008) One of the topics for which further research is required, is the influence of service temperature on the debonding behaviour of service temperature on the debonding behaviour of externally bonded FRP The twelve beams were tested in a four point bending test setup. The beams were loaded with two hydraulic jacks at 650 mm from midspan. The beams measured 200x450x400mm^3 and spanned 3.8m. four reinforcement bars Ø12 mm were applied in the compressive zone Stirrups Ø8 mm were applied for all beams at a 100mm centre-to-centre distance, except for the part at was applied. One CFRP laminate of 1.2 mm thickness was glued to the soffit of each beam after sandblasting and cleaning of the concrete surface. The beams were first heated up in the isolated chamber until the entire beam reached the test temperature. This took about 6 hours for the beams tested at 50^0C and 30 hours for the beams tested at 70^0C. The significant difference in heating time was caused by the fact that heating of the beams was not allowed during night. After heating, the beams were loaded by two hydraulic jacks with a speed of 6.6kN/min until yielding of the internal steel reinforcement. From that point on, loading speed was reduced to 3.3 kN/min until failure of the beam occurred. In the investigation, four different CFRP strengthened RC beams that were designed to fail by four different debonding mechanisms have been investigated at 20^0C, 50^0C and 70^0C. For all the beams tested at 50^0C no change in the type of debonding was observed compared to the beams tested at 20^0C. The failure load was also not (significantly) affected at 50^0C , compared to room temperature, despite the reduction of the Young's modulus of the adhesive and bond strength of the concrete surface. The effect on the failure load was however only small, probably due to the positive effect of the reduced Young's modulus and time dependent creep behaviour of the adhesive, which reduces the stress concentrations at the plate

Piyong Yu, Pedro F. Silva, and Antonio Nanni,(2008) The objective of this investigation is to study the effectiveness of externally bonded CFRP sheets or fabric in increasing the flexural strength of concrete beams. Four-point bending flexural tests are conducted up to failure on nine concrete beams strengthened with different layouts of CFRP sheets and fabric, and three beams with different layouts of anchored CFRP sheets. An analytical procedure, based on compatibility of deformations and equilibrium of forces, is presented to predict the flexural behavior of beams strengthened with FRP sheets and fabric. Comparisons are made between the test results and the analytical calculations. Results of the testing showed that the flexural strength is increased up to 40% on beams strengthened with two layers of CFRP fabric, 49% for beams strengthened with two 1.42 mm thick CFRP sheets, and 58% on beams strengthened with two anchored 4.78 mm CFRP sheets.

Laurent Massam,(2001) The objective of the experimental program presented in th's thesis is to investigate the shear capacity and size effect in concrete beams reinforced with varying amounts of longitudinal and transverse GFRP reinforcement. To better understand the behaviour of GFRP reinforced beams in shear and. To evaluate the accuracy of the new GFRP design methods, a series of nine beams comprising 13 test specimens were designed. To investigate the influence of varied levels of longitudinal reinforcement on the failure shear stress in each size of beam, two levels of longitudinal reinforcement, *0.5%* and 26. were used. In addition, two different nansverse shear reinforcement spacing of 200mm and 400mm were tested to investigate the behaviour of lightly to heavily reinforced sections. The concrete used to build the beams was normal strength concrete with a maximum aggregate size of IOmm. The concrete varied in strength from 36MPa to 45MPa Both the transverse and longitudinal reinforcement was made of Aslan 100 GFRP reinforcing bar.The experimental results and size effect analysis indicated that beams reinforced with GFRP are verysensitive to both the depth of the member and the

!onginidinal reinforcement ratio. The size effect was considerably more pronounced in beams with low levels of longitudinal reinforcement.

Songklanakarin J,(2004), This paper presents a non-linear finite element analysis of reinforced concrete beam strengthened with externally bonded FRP plates. The finite element modeling of FRP-strengthened beams is demonstrated. Concrete and reinforcing bars are modeled together as 8-node isoparametric 2D RC element. The FRP plate is modeled as 8-node isoparametric 2D elastic element. The glue is modeled as perfect compatibility by directly connecting the nodes of FRP with those of concrete since there is no failure at the glue layer. The key to the analysis is the correct material models of concrete, steel and FRP. Cracks and steel bars are modeled as smeared over the entire element. Stress-strain properties of cracked concrete consist of tensile stress model normal to crack, compressive stress model parallel to crack and shear stress model tangential to crack. Stressstrain property of reinforcement is assumed to be elastic-hardening to account for the bond between concrete and steel bars. FRP is modeled as elastic-brittle material. From the analysis, it is found that FEM can predict the load-displacement relation, ultimate load and failure mode of the beam correctly. It can also capture the cracking process for both shear-flexural peeling and end peeling modes similar to the experiment.

S.A.EI-Rafaie A.F.Ashour,and S.W.Garrity,(2003), This paper reports the testing of 11 reinforced concrete (RC) two span beams strengthened in flexure with externally bonded carbon fiber-reinforced polymer (CFRP) sheets the beams were classified into two groups according to the arrangement of the internal steel reinforcement. Each group included one unstrengthened control beam. The main parameters studied were the position, length and number of CFRP layers. An external strengthening using CFRP sheet was found to increase beam load capacity. All strengthened beam exhibited less ductility compared with the unstrengthened control beams, however, and showed undesirable sudden failure modes. There was an optimum number of CFRP layers beyond which there no further enhancement in the beam capacity. Extending the CFRP sheet length to cover the entire hogging or sagging zones did not prevent peeling failure of the CFRP sheets, which was the dominant failure mode of beams tested.

M.R.Islam, M.A.Mansur and M.Maalej,(2006) This study therefore explores the prospect of strengthening structurally deficient deep beams by using an externally bonded fibre reinforced polymer (FRP) system. Six identical beams were fabricated and tested to failure for this purpose. One of these beams was tested in its virgin condition to serve as reference, while the remaining five beams were tested after being strengthened using carbon fibre wrap, strip or grids. The results of these tests are presented and discussed in this paper. Test results have shown that the use of a bonded FRP system leads to a much slower growth of the critical diagonal cracks and enhances the load-carrying capacity of the beam to a level quite sufficient to meet most of the practical upgrading requirements.

CHAPTER – 4

4.0 PROPERTIES OF MATERIALS

4.1 Materials

4.1.1 Cement

Portland pozzilona cement was used for casting all the specimens.

Specific gravity - 3.13

4.1.2 Fine aggregate

The clean dry river sand was used as fine aggregate. The sand was sieved to remove all the pebbles.

Specific gravity - 2.72
Fineness modulus - 2.85

4.1.3 Coarse aggregate

Hard granite broken stone of 20 mm was used as coarse aggregate.

Specific gravity - 2.82
Fineness modulus - 7.48

4.1.4 Water

Water of good quality was used through out the work.

4.1.5 Steel

Two numbers of 12 mm diameter bars were used as bottom reinforcement and two numbers of 12 mm diameter bars were used as top reinforcement. Stirrups of 8 mm diameter bars were used.

4.2 E- Glass fiber:

E-Glass or Electrical Grade Glass Fiber – It was originally developed for insulating electrical wiring and later found to have excellent fiber forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fiberglass.

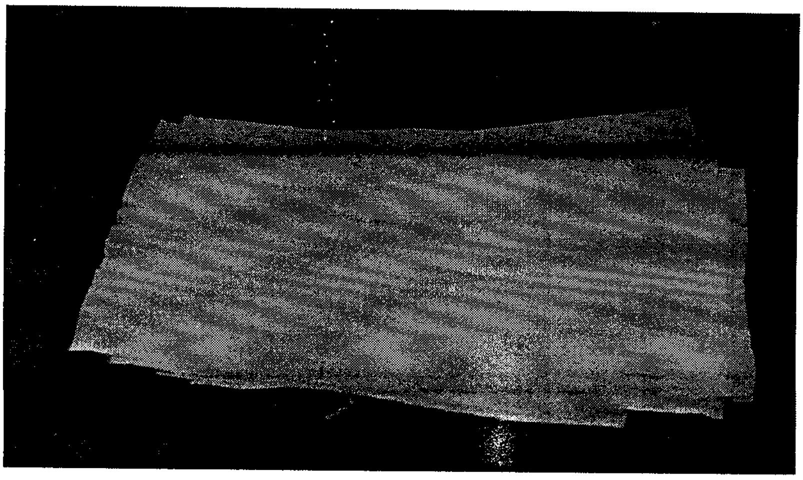

Fig. 4.1 woven roving

4.2.1 Properties of E-Glass fiber

1. High tensile strength
2. High stiffness
3. Low density
4. Non- flammable
5. Resistant to heat
6. Good chemical resistance
7. Good electrical insulation
8. Low cost
9. Relatively insensitive to moisture
10. Able to maintain strength properties over a wide range of conditions

4.2.2 Chemical and physical properties

E- GLASS is a glass with a very low alkaline content. The chemical and physical properties of the fiber are listed in Table 4.1 & 4.2.

TABLE 4.1: CHEMICAL PROPERTIES

SiO_2	53-57%
Al_2O_3	12-15%
$CaO + MgO$	22-26%
B_2O_3	5-8%
F_2	0-0.6%
$Na_2O + K_2O$	<1%
Fe_2O_3	0.5%

TABLE 4.2: PHYSICAL PROPERTIES

Density in g/cm^3	1.57
Tensile strength in MPa	195.00
Flexural modulus	11.10 GPa
Water absorption in %	0.22

4.3 Epoxy Resin

Epoxy resins are excellent binding agents with high tensile strength. The epoxy components are mixed just prior to application. The product is of low viscosity and can be injected in small cracks too. The higher viscosity epoxy resin can be used for surface coating or filling larger cracks or holes. The epoxy mixture strength is dependent upon the temperature of curing (lower strength for higher temperature) and the method of application.The type of chemical used is given below.Mix ratio is 2:1

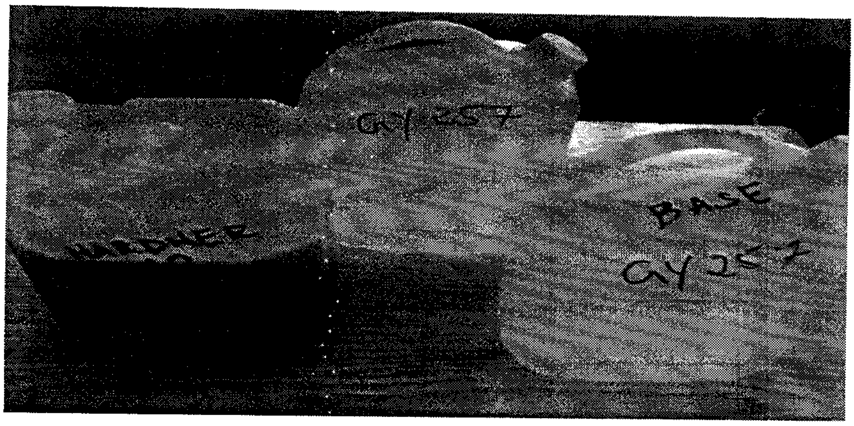

Fig.4.2 Epoxy resin

- **BASE - Araldite GY 257**
- **HARDNER - Aradur HY 140**

4.3.1 Properties of Epoxy Resin

The properties of Epoxy resin are shown in Table 4.3

TABLE 4.3 PROPERTIES OF EPOXY RESIN

Material Properties in N/mm^2	Epoxy resin
Compressive Strength	80
Tensile Strength	17
Young's modulus	5000
Flexural strength	28
Bond to concrete	>4

CHAPTER – 5

5.0 MIX DESIGN

Mix proportions:

a) Design stipulations

Characteristic compressive strength required = 20 N/mm^2

Maximum size of the aggregate = 20mm

Workability = 0.9

Degree of quality control = Good

Type of exposure = mild

b) Test data of materials

Specific Gravity of cement = 3.15

Specific Gravity of Fine Aggregate = 2.82

Specific Gravity of Coarse Aggregate = 2.72

1. Target mean strength $= F_{ck} + 1.65\ S$

$= 20 + 1.65 \times (4)$

$= 26.6\ N/mm^2$

2. Water cement ratio = 0.5

3. Selection of water and sand content:

Water content per cubic metre of concrete = 191.6kg

Sand content as % of total aggregate by absolute volume = 35%

Change in condition	W.C in %	% of sand in total aggregate
For decrease in W/C ratio By 0.6-0.5	0	-2
Increase in compaction	3	0
For zone iii	0	-1.5
	3%	-3.5%

Required sand content = 35-3.5

= 31.5%

Required water content = 186+5.58

= 191.61 lit /m^3

4. Determination of cement content:

W/c ratio = 0.5

Cement = 191.6 / 0.5

= 383kg/ m^3

5. Determination of coarse and fine aggregate content:

$$V = \left[W + \frac{C}{Sc} + \frac{1}{P} \times \frac{Fa}{SFa}\right] \times \frac{1}{1000}$$

$$0.98 = \left[191.6 + \frac{383}{3.15} + \frac{1}{0.315} \times \frac{Fa}{2.72}\right] \times \frac{1}{1000}$$

$$F_a = 572 \text{ kg/m}^3$$

$$V = \left[W + \frac{C}{Sc} + \frac{1}{1-P} \times \frac{Ca}{SCa}\right] \times \frac{1}{1000}$$

$$980 = \left[191.6 + \Im\frac{383}{3.15} + \frac{1}{0.685} \times \frac{Ca}{2.82}\right]$$

$$C_a = 1289.6 \text{ kg/m}^3$$

Water	Cement	Fine aggregate	coarse aggregate
191.6	383	572	1289.6
0.5	1	1.5	3.36

CHAPTER -6

6.0 EXPERIMENTAL PROGRAM

6.1 Casting of beams

Beam were designed as an under reinforced section having dimension 150x220x2100 mm. Totally 3 beams were casted.

6.2 Curing

The mould is stripped after 24 hours. The demoulding of the specimens were done simultaneously. The specimens were cured for 28 days.

6.3 Number of Specimens Prepared

Beam witout wrapping (1 no)

Beam with single layer of woven roving (1 no)

Beam with double layer woven roving (1 no)

6.4 FRP Wrapping

Totally 3 rectangular beams were cast and strengthened using commercially available E-Glass fiber (woven rovings), with the goal of increasing their flexural capacity. The composite will have to carry high loads. So it is important that a good bond between fiber and concrete. The concrete surface must be even enough and sand blasted before commencing of the FRP wrapping work. It is then cleaned with acetone to remove dirt. The following procedure was adopted for hand laying of fiber in the experimental work.

6.4.1 Procedure for FRP wrapping (woven rovings)

The two sides and the surface of the beam were roughened by chipping and rubbing.

1. Air blowing technique was used to clean the debris.
2. Coat of base mixed with hardener (mix ratio is 2:1) was applied.
3. Wrap the woven rovings having proper dimensions.

4. Additional coat of epoxy was applied and subsequent wrapping was done.

6.5 Strength Tests:

Following tests were conducted for evaluating the strength properties.

1. Compressive strength test
2. Flexural strength test

6.5.1 Compressive Strength test:

The cube specimens of size is 150x150x150mm . During casting the cubes were mechanically vibrated. After 24 hours the specimens were removed from the mould and subjected to water curing for 28 days. After specified period of curing, the specimens were tested using compressive testing machine.

The cube compressive strength is calculated by

Compressive strength = Load at failure / Cross sectional area in N/mm^2

6.5.2 Flexural Strength test:

Test set-up:

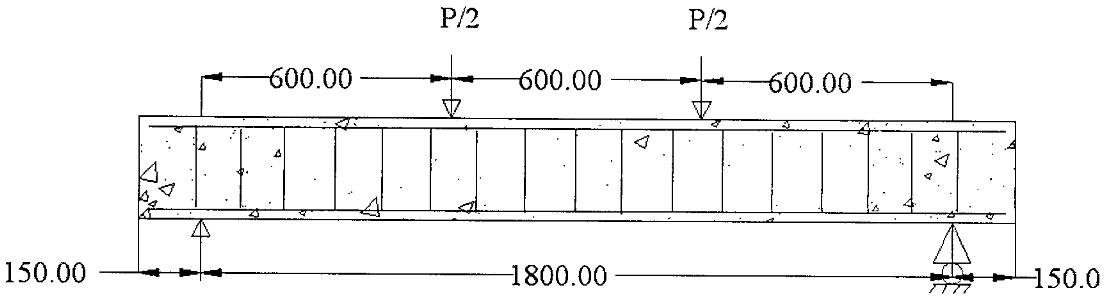

Fig.4.3Layout out of test set up

All the specimens were tested under two point loading system. The beams were white washed before testing. Two concentrated loads at one third spans were applied on the beam by means of 30 tones capacity. Three dial gauges having a least count of 0.01mm were placed under the beam. One dial gauge were placed at the centre of the beam while the other two were placed under the concentrated loads to record the deflections at these threepositions. .

CHAPTER-7

FINITE ELEMENT ANALYSIS

7.0 General

The finite element method is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. A finite element model of a problem gives a piecewise approximation to the governing equations. The basic premise of the finite element method is that a solution region can be analytically modelled or approximated by replacing it with an assemblage of discrete elements. Since these elements can be put together in a variety of ways, they can be used to represent exceedingly complex shapes.

7.1 Advantages of FEM

The Finite Element Method has many advantages of its own. Some of them are given below.

- Various types of boundary conditions are automatically handled in the formulation. They are systematically enforced just before the solution, for the nodal values of the field variables are obtained.
- Material anisotropy and in homogeneity can be treated without much difficulty,
- Any type of loading can be handled,
- Higher order elements may be implemented with relative ease.
- The method can efficiently be applied to cater irregular geometry
- Spacing of nodes need not follow a pattern or rule

7.2 Disadvantages of FEM

The Finite Element Method has its own limitations. They are listed below.

- There are many types of problems where some other method of analysis may prove more efficient than the FEM,
- There are some trouble spots such as "Aspect Ratio" (ratio of longer to smaller dimensions), which may affect the final results,
- The cost involved in the solution of the problem is high

7.3 STAGES IN FINITE ELEMENT SOLUTION

In general, a finite element solution may be broken in to the following three stages.

1.Preprocessing: defining the problem

- Define keypoints/ lines/ areas/ volumes
- Define element type and material/ geometric properties
- Mesh lines/ areas / volumes as required

Different sections of this module are;

1. Defining the parameters-Element types, Real constant, Material properties.
2. Geometry of the structure
3. Meshing.

DEFINING THE PARAMETERS

Element Type

- In ANSYS program, the element used for analysis is **SOLID 65 ,10 Noded Tetrahedral Structural Solid, and shell element**

SOLID 65

- ■ It is used for three-dimensional modeling of solids with or without reinforcing bars
- ■ Element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x,y, and z directions.

SHELL

- Has both bending and member capabilities
- Both in-plane and normal loads are permitted
- The element has six degrees of freedom at each node: translations in nodal x,y,z directions and rotations about nodal x,y,z axes

Real Constants

The real contants of the element are the properties that are specific to a given element type such as the cross sectional properties.

Material Properties

Materials properties which are frequently used are Youngs Modulus, Density, Possons ratio, etc.

2.Geomentry of the structure

The ultimate purpose of the finite element analysis is to create an accurate mathematical model of a physical prototype. Model generation is the process of defining the geometric configuration of the model nodes and elements. The model used for my analysis is Solid Model.

3.Meshing

Meshing consists of three steps,

Setting of element attributes.
Mesh control.
Shape

Free meshing is used for my analysis

4.Solutions-assigning loads, constraints and solving.

5.Post-Processing: further processing and viewing of the results

In this work, three beams were analysed. The size of the beam is 150mm x 250x2100mm and the of beam is 4nos of 12mm dia bars with 2nos at bottom and 2nos at top with a stirrups spacing of 100mmc/c .Three numbers of RCC beams are one plain RCC beam ,one RCC beam with single FRP wrapping and one RCC beam with double FRP wrapping were analysed.

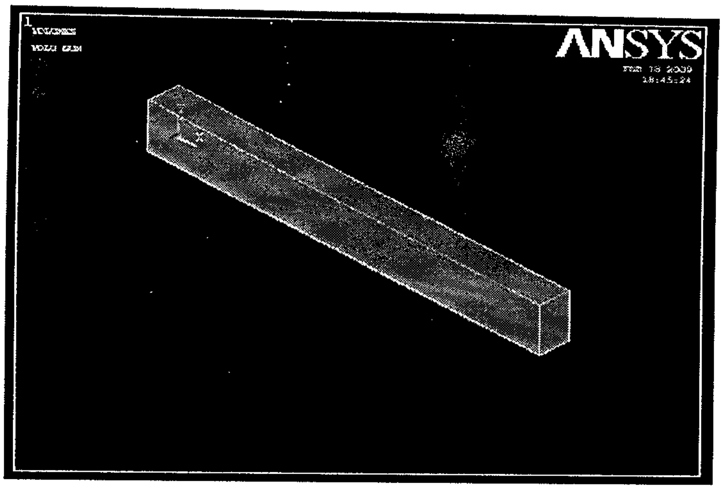

Fig.7.1 Modelling of beam

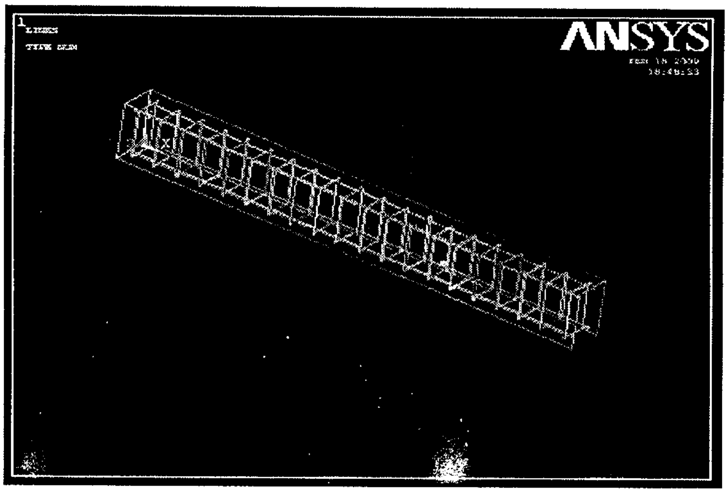

Fig.7.2 Modelling with Reinforcement

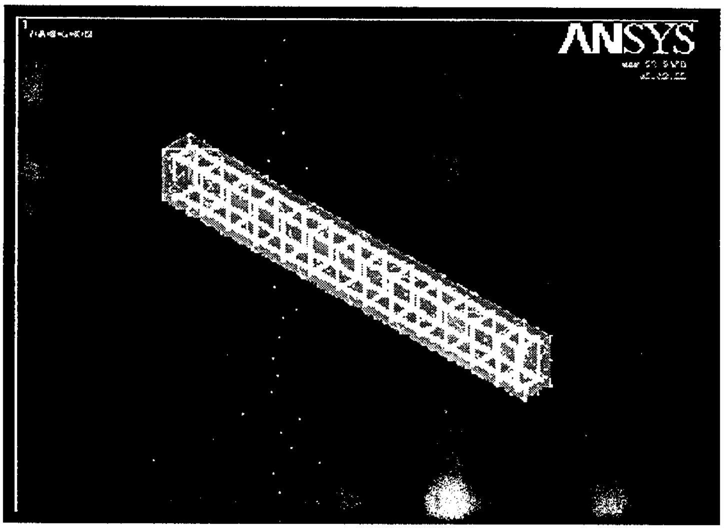

Fig.7.2 Modelling with Reinforcement

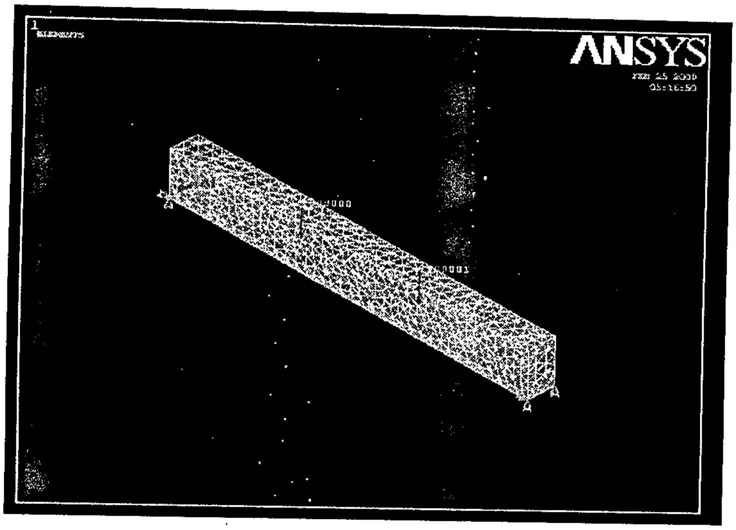

Fig.7.3 Mesh generation of specimen with load & support

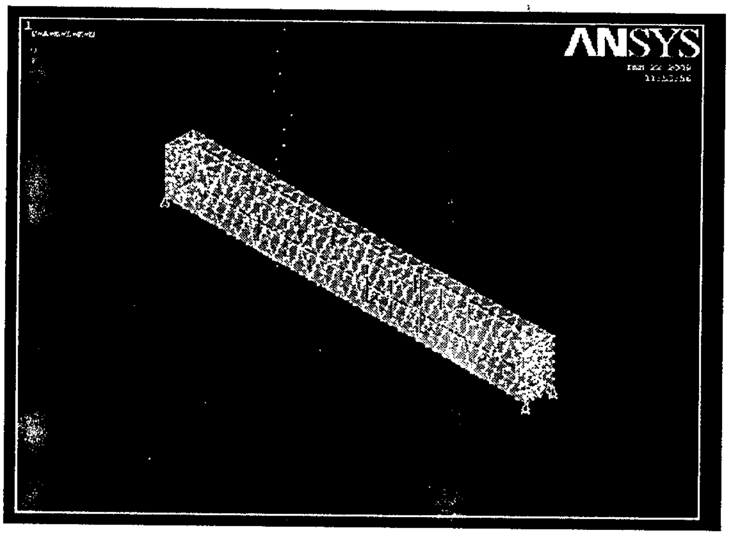

Fig.7.4 Mesh generation of specimen with reinforcement

CHAPTER – 8

8.0 TEST RESULTS AND DISCUSSIONS

Compressive Strength Test

The compressive strength test was conducted for finding the characteristic compressive strength of concrete at 28 days of curing.

TABLE 8.1: TEST RESULTS FOR CUBES

Specimen	7days strength (Mpa)	28 days strength (Mpa)
Cube	18.2 17.65 17.1	24.3 23.75 23.2

Flexural Strength Test

Failure loads for various types of RC beams

1. R.C. beam without wrapping = 38 KN
2. Beam with 1 layer of GFRP wrapping = 48 KN
3. Beam with 2 layer of GFRP wrapping = 53 KN

`TABLE 8.2:COMPARISON OF EXPERIMENTAL RESULTS

Beam	Moment at first crack Mcr (KNm)	Ultimate moment Mu(KNm)	% of increase in ultimate moment (Mu)	% of increase in cracking moment(Mcr)
Without wrapping	8.33	13.3		
Single layer wrapping	10.66	16.8	26.3	27.97
Double layer wrapping	12.66	18.5	39.0	51.98

8.1 Failure Mechanism

8.1.1 Conventional Ductile Flexural Failure:

Conventional Ductile Flexural Failure occurred due to yielding of the internal tensile steel reinforcement followed by concrete crushing at mid span section for control beam. Sagging flexural failure of control beam occurred as a result of the yielding of the tensile steel reinforcement at the beam mid span.

8.1.2 Tensile Rupture of the GFRP Sheets

Tensile Rupture of the GFRP Sheets was followed by flexural failure in the beam. Rupture of the GFRP Sheets was sudden and accompanied by a loud noise indicating a rapid release of energy, a total loss of load capacity, and resulted in immediate beam failure.

8.1.3 De-bonding failure:

This type of failure usually occurred in the beam at the level adjacent to the external GFRP composite strengthened beam is the test program. It is termed as a premature failure of FRP due to de-bonding. It is seems to be a non-ductile behaviour. However before failure it provided adequate warning about impending failure. A thin layer of concrete was attached to the separated part of the GFRP sheet. In beams GFRP separation without concrete attached was also occurred along the GFRP sheet adhesive interfaces.

8.2 Measured Responses of Beams:

TABLE 8.3: SPECIMEN 1

Sl. no	Load In KN	Deflection in mm		
		Left	Middle	Right
1	0	0	0	0
2	5	0.68	0.8	0.64
3	10	1.57	1.92	1.78
4	15	3.59	3.71	3.24
5	20	5.75	5.84	5.58
6	25	7.64	8.04	7.44
7	30	9.44	10.56	9.11
8	35	12.66	13.2	12.45
9	38	13.11	14.1	13.24

The specimen 1 was control specimen. The deflection at the mid span and the points of application of load were noticed throughout the test. The ultimate load of this specimen was 38 KN. The beam was failed by yielding of steel reinforcement followed by compression failure of concrete at mid span.

TABLE 8.4: SPECIMEN 1 [A]

Sl. no	Load in KN	Deflection in mm		
		Left	Middle	Right
1	0	0	0	0
2	5	0.47	0.62	1.08
3	10	1.11	1.23	1.08
4	15	1.56	1.75	1.52
5	20	2.22	2.69	2.32
6	25	3.46	3.94	3.51
7	30	4.32	5.54	4.21
8	35	5.12	7.85	5.32
9	40	6.42	9.11	6.78
10	45	8.87	10.32	8.97
11	48	10.23	12.12	10.31

The specimen 1 [A] was pasted with one layer of woven rovings. The beam was failed at a load of 48 KN due to the yielding of steel reinforcement. It was termed as conventional flexural tensile failure. The deflection of the beam was less for each load case compared to the control beam. This eventually shows the considerable increment in stiffness.

TABLE 8.5: SPECIMEN 1 [B]

Sl. no	Load in KN	Deflection in mm		
		Left	Middle	Right
1	0	0	0	0
2	5	0.54	0.58	0.55
3	10	0.94	0.98	0.91
4	15	1.22	1.32	1.26
5	20	2.10	2.2	2.13
6	25	2.79	2.9	2.8
7	30	3.32	3.57	3.33
8	35	4.22	4.71	4.32
9	40	5.87	6.23	5.78
10	45	6.23	7.26	6.15
11	50	7.22	8.64	7.11
12	53	8.02	9.61	8.12

The specimen 1 [B] was wrapped with 2 layers of woven roving. The ultimate load was found to be 53 KN. The deflection of the beam was less for each load case compared to the control beam and single layer wrapping .The mode of failure was pure conventional flexural tensile failure.

Photograph of Tested Beams

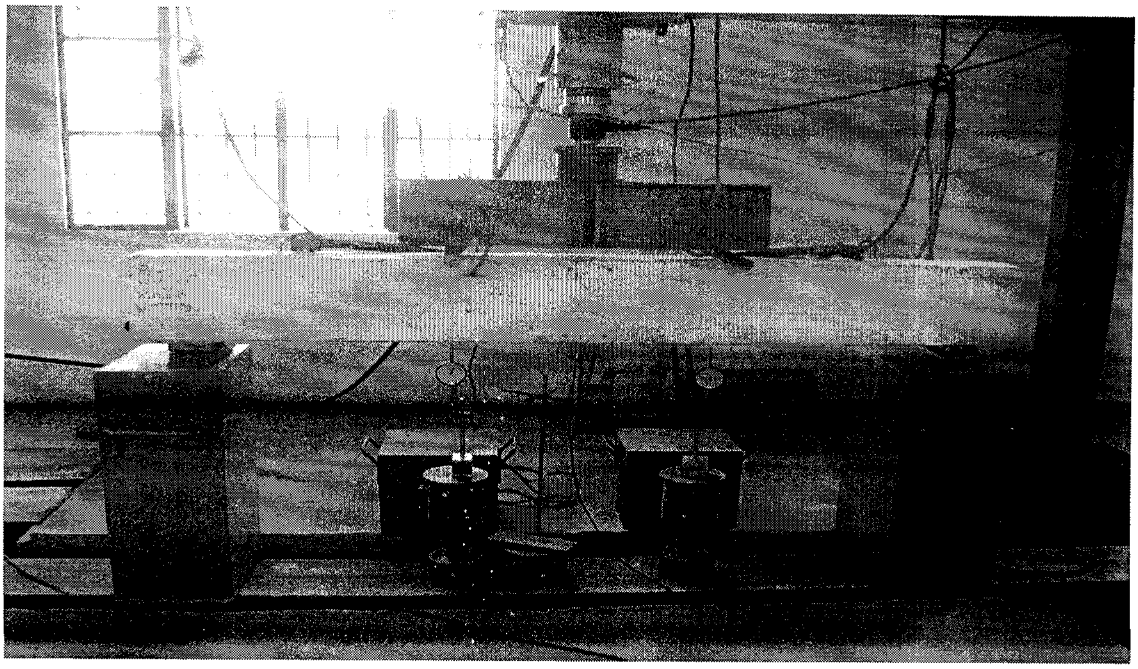

Fig.8.1 Testing of beam without wrapping

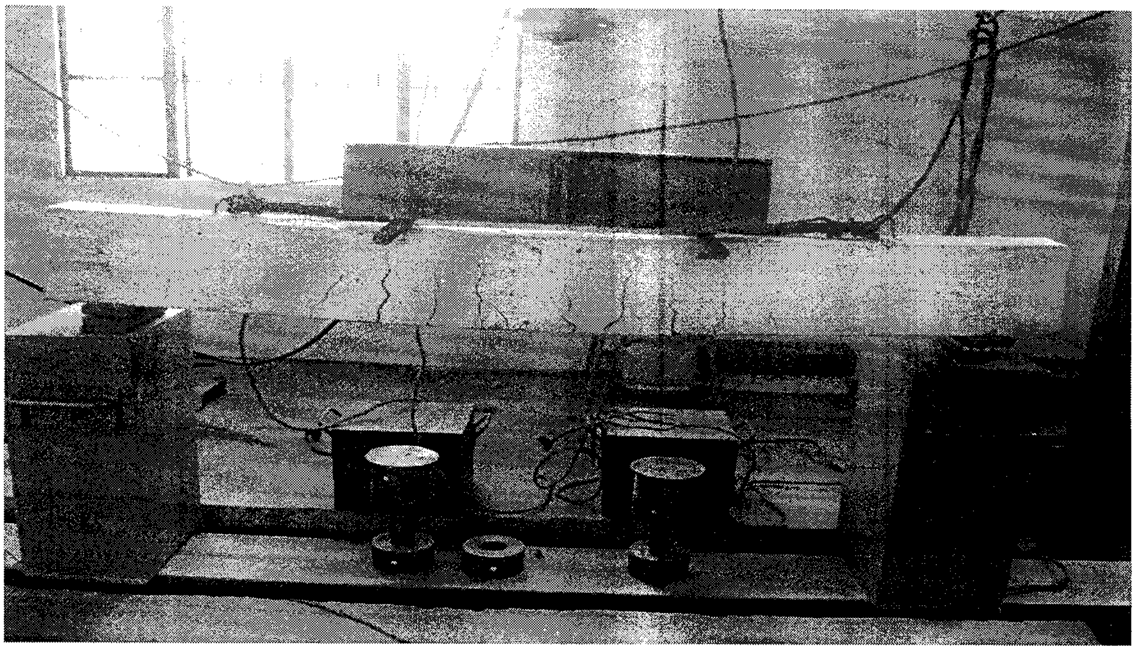

Fig.8.2 Typical failure of beam without wrapping

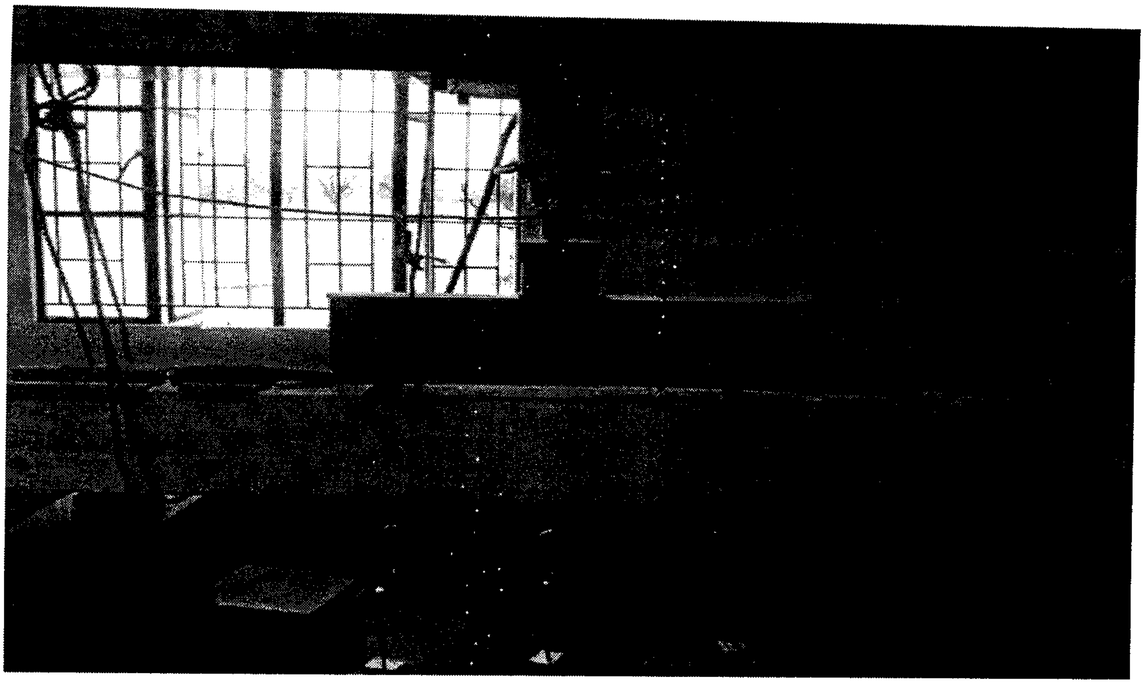

Fig.8.3 Testing of beam with 1 layer of woven rovings 1(A)

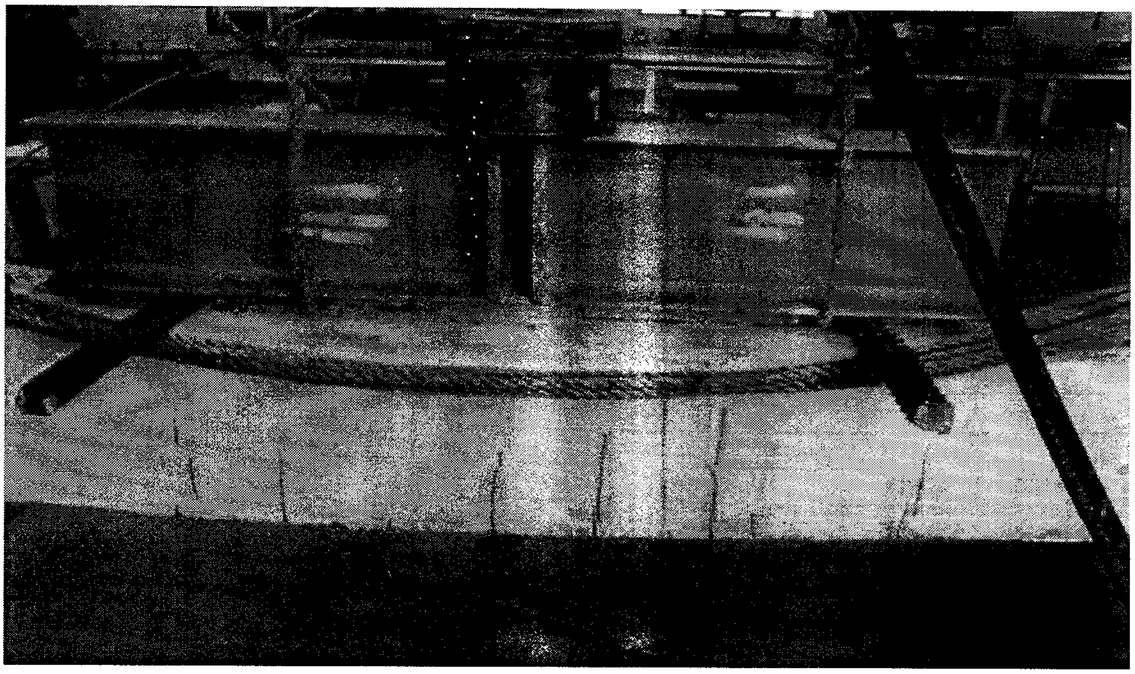

Fig .8.4 Typical failure of beam with 1 layer of woven rovings 1(A)

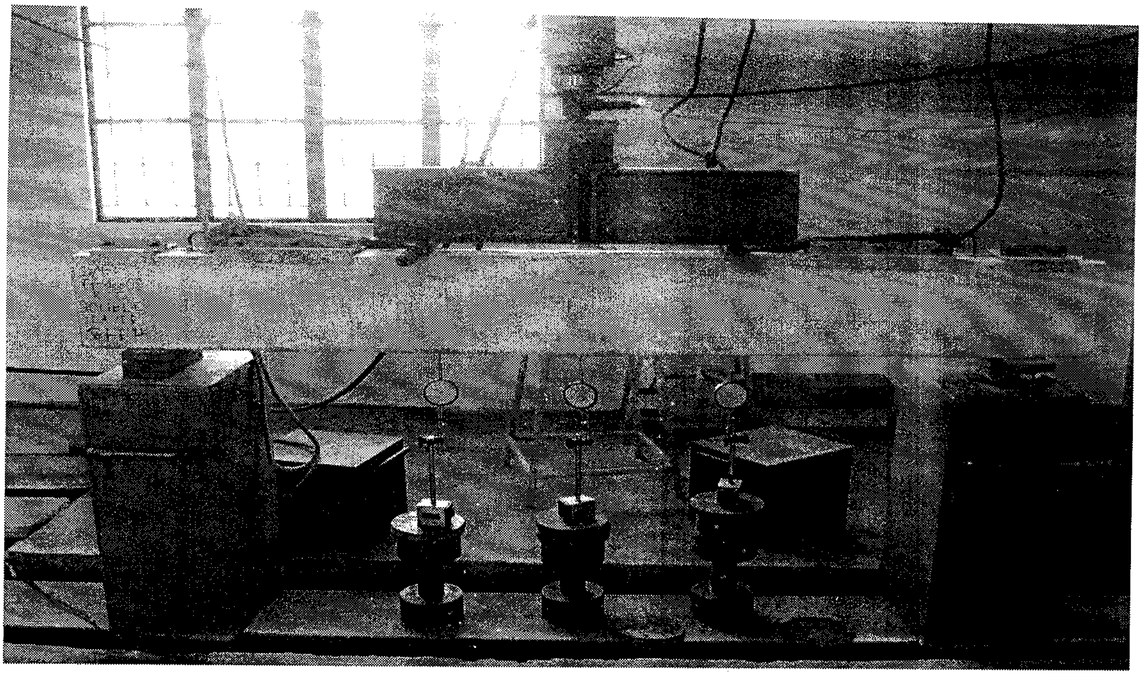

Fig.8.5 Testing of beam with 2 layers of woven rovings 1(B)

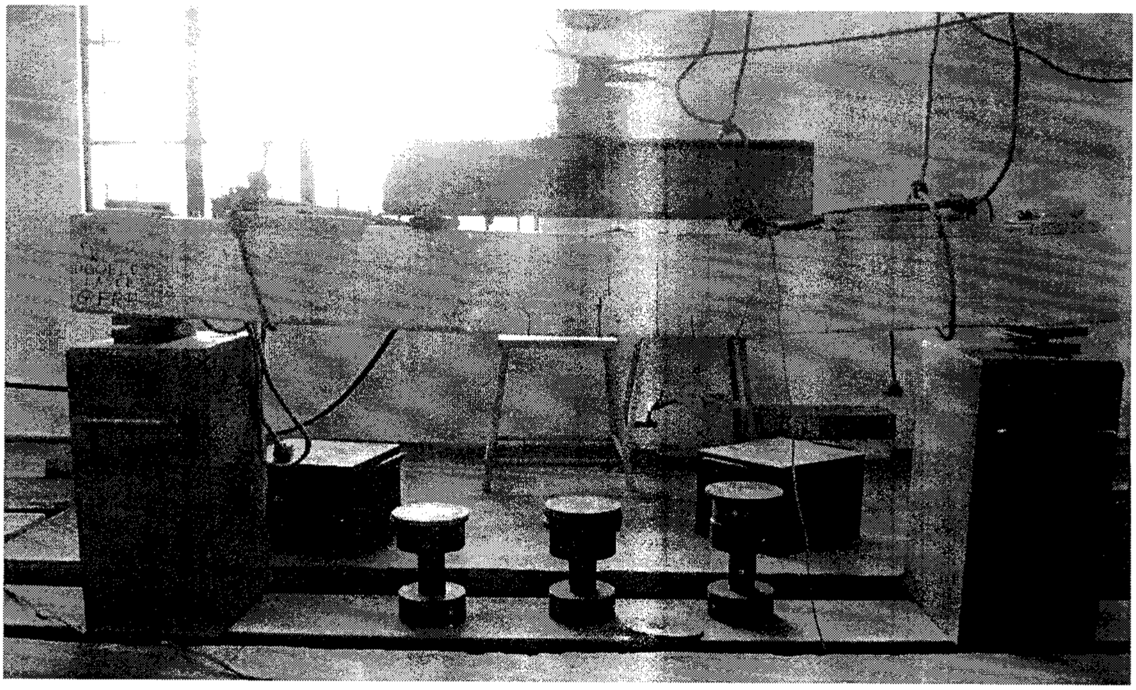

Fig.8.6 Typical failure of beam with 2 layer of woven rovings 1(B)

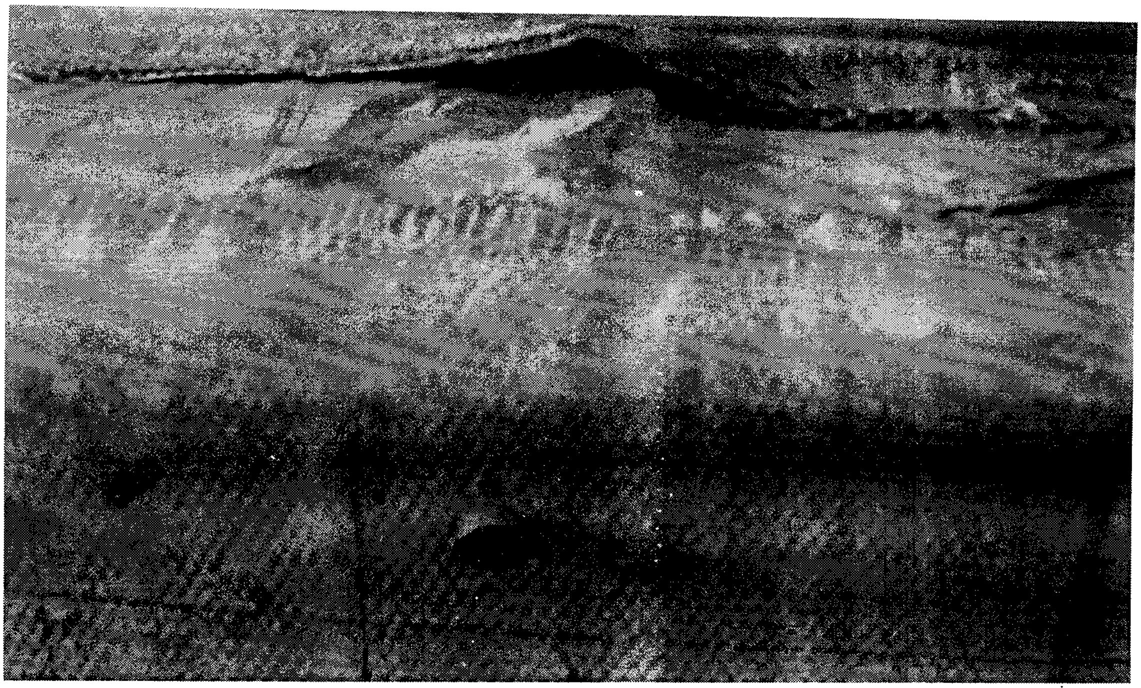

Fig.8.7 Typical De-bonding failure of beam with 2 layers of woven rovings

8.2.1 Load-Deflection Characteristics:

The strength and deformation capacity of the tested specimens varied significantly depending on the number of layers of E-glass fiber. The measured response of the specimens wrapped with different layers was shown in fig. . All the wrapped specimens failed at the displacement levels that were considerably less than the capacity of the control beams.

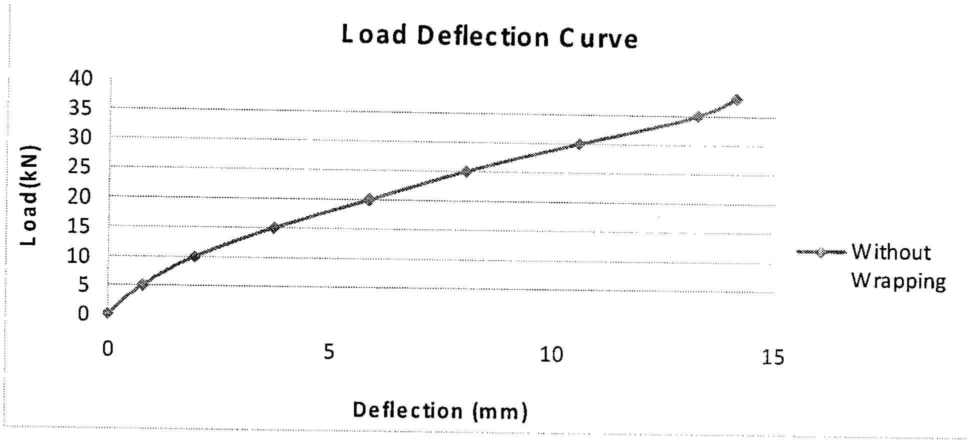

Fig. 8.8 Load Vs mid Span Deflection Graph for Control Specimen

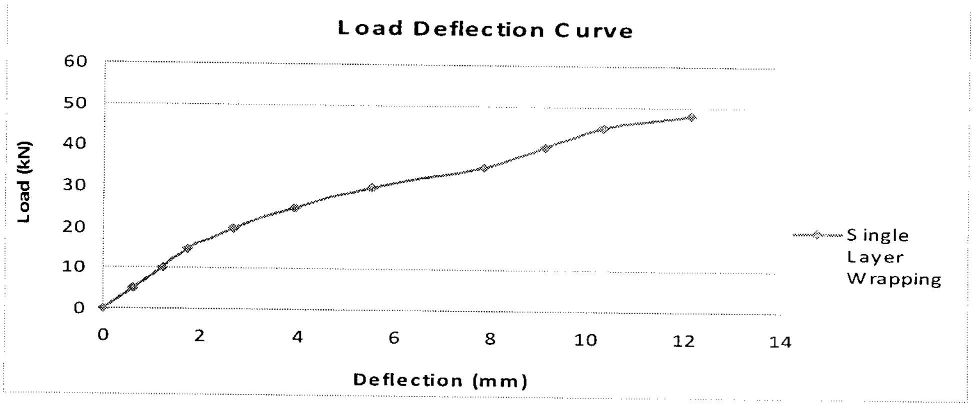

Fig. 8.9 Load Vs mid Span Deflection Graph for Single wrapped Specimen

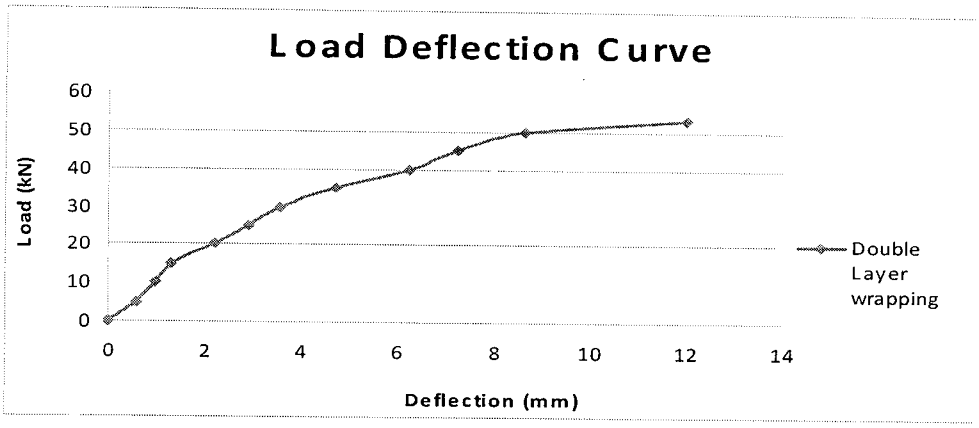

Fig.8.10 Load Vs mid Span Deflection Graph for Control Specimen

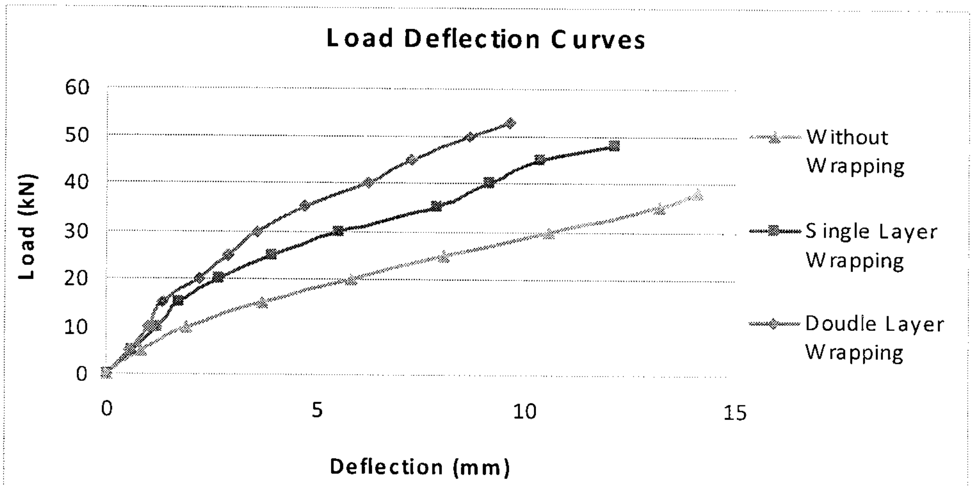

Fig.8.11 Comparision of load deflection curves

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