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Repair and Rehabilitation of Concrete Structures Using Fiber Reinforced

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ABSTRACT

International, a exquisite deal of research is currently being carried out concerning using fiber bolstered plastic wraps, laminates and sheets inside the restore and strengthening of bolstered concrete members. Fiber-bolstered polymer (frp) software is a totally effective manner to repair and enhance systems which have end up structurally vulnerable over their lifestyles span. frp restore systems offer an economically feasible alternative to conventional restore structures and materials.

Experimental investigations at the flexural and shear conduct of rc beams bolstered using continuous glass fiber bolstered polymer (gfrp) sheets are accomplished. Externally reinforced concrete beams with epoxy-bonded gfrp sheets had been tested to failure the usage of a symmetrical factor concentrated static loading device. two sets of beams were casted for this experimental take a look at application. in set i 3 beams vulnerable in flexure have been casted, out of which one is managed beam and different two beams have been bolstered using continuous glass fiber bolstered polymer (gfrp) sheets in flexure. in set ii three beams vulnerable in shear have been casted, out of which one is the controlled beam and other beams have been strengthened the use of non-stop glass fiber strengthened polymer (gfrp) sheets in shear. The strengthening of the beams is accomplished with exclusive amount and configuration of gfrp sheets

Experimental records on load, deflection and failure modes of each of the beams were obtained. the detail manner and alertness of gfrp sheets for strengthening of rc beams is also included. The impact of range of gfrp layers and its orientation on final load sporting capability and failure mode of the beams are investigated.

INTRODUCTION

The protection, rehabilitation and upgrading of structural contributors, is perhaps one of the most vital troubles in civil engineering applications. moreover, a huge variety of systems built inside the past the usage of the older design codes in unique elements of the sector are structurally unsafe in step with the new design codes. In view that replacement of such poor elements of structures incurs a large amount of public time and money, strengthening has grow to be the suitable way of improving their load wearing ability and extending their provider lives. Infrastructure decay caused by untimely deterioration of homes and systems has cause the investigation of several tactics for repairing or strengthening functions [1]. One of the challenges in strengthening of concrete structures is choice of a strengthening method so that it will beautify the energy and serviceability of the shape even as addressing boundaries consisting of constructability, building operations, and budget. Structural strengthening can be required due to many different situations.

- Additional energy can be had to permit for better hundreds to be located at the structure. That is frequently required while using the shape adjustments and a higher load-wearing potential

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is needed. This could additionally arise if extra mechanical system, submitting structures, planters, or other objects are being delivered to a structure.

- Strengthening can be had to permit the structure to face up to masses that had been not predicted inside the unique design. This may be encountered while structural strengthening is required for hundreds due to wind and seismic forces or to improve resistance to blast loading.
- Extra electricity can be needed because of a deficiency within the shape's ability to hold the original layout loads. Deficiencies can be the result of degradation (e.g., corrosion of steel reinforcement and loss of concrete section), structural harm (e.g., vehicular impact, excessive put on, immoderate loading, and fire), or errors within the original layout or creation (e.g., out of place or lacking reinforcing metal and insufficient concrete energy).

Whilst coping with such circumstances, every assignment has its very own set of restrictions and needs. Whether or not addressing area regulations, constructability regulations, durability demands, or any number of other troubles, each assignment requires a wonderful deal of creativity in arriving at a strengthening answer [5].

Most people of structural strengthening includes enhancing the capability of the structural element to securely withstand one or more of the subsequent inner forces caused by loading: flexure, shear, axial, and torsion. Strengthening is accomplished by using either reducing the magnitude of these forces or via improving the member's resistance to them. Regular strengthening techniques such as phase growth, externally bonded reinforcement, submit- tensioning, and supplemental supports may be used to achieve improved strength and serviceability.

Strengthening structures can improve the resistance of the existing shape to internal forces in either a passive or active manner. Passive strengthening systems are commonly engaged only when additional hundreds, beyond the ones present on the time of set up, are applied to the structure. Bonding metal plates or fiber-reinforced polymer (FRP) composites on the structural contributors are examples of passive strengthening systems [3], [4]. active strengthening systems normally have interaction the shape straight away and may be achieved via introducing external forces to the member that counteract the consequences of inner forces. Examples of this consist of the usage of outside post-tensioning structures or by means of jacking the member to alleviate or switch current load. Whether passive or energetic, the primary task is to reap composite conduct among the present shape and the brand new strengthening elements.

STRENGTHENING USING FRP COMPOSITES

Only some years in the past, the construction marketplace started to apply frp for structural reinforcement, typically in combination with other creation materials such as wooden, metallic, and urban. frps showcase numerous progressed properties, which includes high energy-weight ratio, excessive stiffness-weight ratio, flexibility in design, non-corrosiveness, high fatigue energy, and simplicity of application [2]. The use of frp sheets or plates bonded to concrete beams has been studied by way of several researchers. Strengthening with adhesive bonded fiber reinforced polymers has been hooked up as an powerful method relevant to many varieties of concrete structures together with columns, beams, slabs, and walls. due to the fact the frp substances are non-corrosive, non-magnetic, and resistant to diverse sorts of chemical substances, they're increasingly being used for external reinforcement of current concrete structures. from the beyond research carried out it's been proven that externally bonded glass fiber-bolstered polymers (gfrp) can be used to decorate the flexural, shear and torsional capacity of rc beams. due to the bendy nature and simplicity of managing and application, mixed with excessive tensile energy-weight ratio and stiffness, the flexible glass fiber sheets are located to be especially powerful for strengthening of rc

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beams. the use of fiber strengthened polymers (frps) for the rehabilitation of current concrete structures has grown very rapidly over the previous couple of years. Research has proven that frp may be used very efficiently in strengthening the concrete beams susceptible in flexure, shear and torsion. Unluckily, the cutting-edge indian concrete layout requirements (is codes) do no longer encompass any provisions for the flexural, shear and torsional strengthening of structural contributors with frp substances. This loss of layout requirements brought about the formation of partnerships among the research community and industry to research and to promote the usage of frp inside the flexural, shear and torsional rehabilitation of current systems. frp is a composite material normally together with excessive strength carbon, aramid, or glass fibers in a polymeric matrix (e.g., thermosetting resin) wherein the fibers are the main load wearing detail.

ADVANTAGES AND DISADVANTAGES OF FIBER COMPOSITE STRENGTHENING

ADVANTAGES

Fiber composite strengthening materials have better ultimate electricity and lower density than steel. While taken collectively those homes result in fiber composites having a power/weight ratio better than steel plate in some instances (even though it's far frequently now not viable to apply this absolutely). The lower weight makes managing and installation substantially less complicated than metal [7]. That is particularly important whilst installing material in cramped places. Work on soffits of bridges and building floor slabs can regularly be completed from guy-get admission to platforms instead of full scaffolding. Metal plate requires heavy lifting gear and need to be held in place whilst the adhesive profits electricity. Bolts ought to be fitted via the steel plate into the figure concrete to assist the plate even as the adhesive therapies and to reduce the results of peeling on the ends. However, the software of FRP plate or sheet cloth has been related to applying wallpaper; as soon as it has been rolled on carefully to dispose of entrapped air and excess adhesive it could be left unsupported. In trendy, no bolts are required; in truth, the use of bolts would severely weaken the fabric until additional cowl plates are bonded on. moreover, due to the fact there's no want to drill into the shape to fix bolts or different mechanical anchors there's no danger of unfavourable the existing reinforcement.

Fiber composite substances are to be had in very long lengths at the same time as metal plate is typically limited to 6 m. the availability of lengthy lengths and the ability of the cloth also simplify installation:

- Laps and joints are not required
- The fabric can soak up irregularities within the shape of the concrete surface
- The material can observe a curved profile; steel plate might must be pre-bent to the required radius
- The fabric may be without problems established at the back of present offerings
- Overlapping, required while strengthening in directions, isn't a problem because the cloth is thin.

DISADVANTAGES

The principle downside of externally strengthening systems with fiber composite substances is the chance of hearth, vandalism or unintentional harm, until the strengthening is blanketed. a particular issue for bridges over roads is the hazard of soffit reinforcement being hit via over- top motors however, strengthening the usage of plates is normally supplied to carry additional stay load and the capacity of the unstrengthened structure to carry its very own self-weight is unimpaired. Damage to the plate strengthening fabric only reduces the overall issue of safety and is not likely to result in fall apart [6].

Experience of the long-term durability of fiber composites is not yet to be had. This may be a disadvantage for systems for which a totally lengthy design life is needed however can be triumph over with the aid of appropriate monitoring.

A perceived disadvantage of the usage of FRP for strengthening is the enormously high price of the

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substances. However, comparisons ought to be made on the basis of the whole strengthening exercise; in positive cases the expenses may be less than that of steel plate bonding.

A drawback inside the eyes of many clients might be the dearth of experience of the strategies and definitely qualified personnel to carry out the paintings. Subsequently, a huge downside is the dearth of widely wide-spread design requirements [5].

APPLICATIONS OF FRP STRENGTHENING

Of the programs of frp strengthening suggested inside the literature, most of the people occur in switzerland in which the idea changed into first proposed and advanced. in these instances, which can be considered in more detail by way of meier (1995), pultruded carbon fibre/epoxy laminates had been used solely. the primary stated application changed into the repair in 1991 of the ibach bridge inside the canton of lucerne, for which numerous prestressing tendons have been severed for the duration of the set up of visitors alerts. the bridge became repaired with three cfrp sheets of dimensions one hundred fifty mm wide via 5000 mm long and of thickness 1.75 mm or 2.zero mm. the entire weight of the cfrp used changed into only 6.2 kg, in comparison with the a hundred seventy five kg of metal which might had been required for the restore. in addition, all paintings turned into accomplished from a cellular platform, removing the want for costly scaffolding. a loading check with an 840 kn automobile demonstrated that the rehabilitation paintings had been first-rate. the wood bridge at sins in switzerland was stiffened in 1992 to meet expanded site visitors loading (meier et al., 1993). of the most enormously loaded move beams had been reinforced the use of 1.0mm thick cfrp laminates. the arrival of the historic shape was unaltered through the strengthening method. different cfrp strengthening programs in switzerland encompass slab reinforcement around a newly established raise shaft in the city corridor of gossaust. Gall, the upgrading of a supermarket roof the use of laminates 15.5m in period to permit the elimination of a supporting wall, ground floor strengthening of the rail terminal in zurich, and the strengthening of a multistory car park in flims. a chimney wall at the nuclear strength plant in leibstadt has also been poststrengthened for wind and seismic loading after the installation of ducts.

Rostasy et al. (1992) document using gfrp plates on the working joints of the continuous multispan box girder kattenbusch bridge in germany to lessen fatigue stresses in the prestressing tendons and transverse cracking due to thermal restraint. a representative specimen of the joint was examined within the laboratory to confirm the technique previous to field utility. ten joints required rehabilitation; eight of these were reinforced with metal plates 10mm thick, at the same time as the final two utilisedgfrp plates 30mm thick to provide the same region stiffness as the steel plates. the set up of such plates, of which twenty had been used at each joint, befell in 1987 and changed into located to lessen the pressure amplitude on the joints via 36% and the crack widths by means of around 50%.

STRUCTURAL ADHESIVE BONDING

Structural adhesives are typically conventional to be monomer composites which polymerise to give fairly stiff and strong adhesive uniting rather rigid adherends to shape a load-bearing joint (shields, 1985). the feasibility of bonding concrete with epoxy resins turned into first validated within the past due Forties (aci, 1973), and the early improvement of structural adhesives is recorded via fleming and king (1967). since the early Fifties adhesives have turn out to be widely used in civil engineering (mays, 1985). however, although the building and construction industries constitute some of the largest customers of adhesive materials, many programs are non-structural inside the sense that the bonded assemblies are not used to transmit or maintain enormous stresses (e.g. crack injection and sealing, skid-resistant layers, bonding new concrete to vintage) [8]. in reality structural utility means that the adhesive is used to offer a shear connection between comparable or varied substances, permitting the components being bonded to behave as a composite structural unit.

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A comprehensive overview of applications involving using adhesives in civil engineering is given with the aid of hewlett and shaw (1977), tabor (1982) and mays and hutchinson (1992). Assessment of an adhesive as a appropriate product for structural use should consider the design spectrum of hundreds, the strength and stiffness of the fabric underneath short term, sustained or cyclic hundreds and the impact on those homes of temperature, moisture and different environmental conditions for the duration of provider (mays, 1993).

Difficulty concerning the durability houses of adhesive joints has supposed that resistance to creep, fatigue and fracture are taken into consideration of greater significance than particularly excessive energy (vardy and hutchinson, 1986). Temperature is vital in any respect tiers inside the use and performance of adhesives, affecting viscosity and consequently workability, usable life and contact time, fee of cure, degree of go-linking and very last cured performance (tu and kruger, 1996). Controlled situations are consequently usually required in the course of bonding. This is applicable similarly at some stage in the floor remedy tactics if a durable system is to be achieved. Adhesives, which might be manageable and remedy at ambient temperatures, have been used and are able to tolerate a sure amount of moisture without a marked discount in performance. Those ought to have ok usable time beneath website online situations and a cure price which does no longer prevent the development programme [9]. Workmanship underneath conditions regularly occurring on website is much less conducive to first-rate manage than in different industries, and hence capacity to tolerate minor versions in proportioning and mixing, in addition to imperfect floor remedy, is crucial.

In addition, the goods concerned are extra toxic, require extra cautious storage and, bulk for bulk, are extensively more costly than conventional construction materials. Nondestructive test methods for assessing the integrity of bonded joints are actually available for civil engineering applications.

TYPE OF STRUCTURAL ADHESIVES

The principal structural adhesives mainly formulated for use inside the creation enterprise are epoxy and unsaturated polyester resin structures, each thermosetting polymers [10]. The method of adhesives is considered in element by way of wake (1982), whilst tabor (1978) offers steerage on the effective use of epoxy and polyester resins for civil engineering systems. -part epoxies, first developed inside the 1940s (lee and neville, 1967), encompass a resin, a hardener or cross-linking agent which reasons polymerisation, and numerous components inclusive of fillers, tougheners or flexibilisers, all of which make contributions to the bodily and mechanical houses of the resulting adhesive. formulations can be numerous to allow curing at ambient temperature, the so-referred to as cold treatment epoxies, the most common hardeners for that are aliphatic polyamines, whose use results in hardened adhesives which are inflexible and offer right resistance to chemical substances, solvents and water (mays and hutchinson, 1992). Accurate proportioning and thorough blending are vital whilst the usage of epoxy resin structures. the rate of curing doubles as the temperature will increase by way of 10°c and halves as the temperature drops by using 10 °c and many of the formulations prevent curing altogether under a temperature of 5 °c. Fillers, normally inert materials together with sand or silica, may be used to lessen price, creep and shrinkage, reduce exotherm and the coefficient of thermal expansion, and help corrosion inhibition and fireplace retardation. Fillers growth the viscosity of the freshly mixed device however impart thixotropy, which is beneficial in utility to vertical surfaces.

Unmodified epoxy systems have a tendency to be brittle whilst cleavage or peel forces are imposed. Toughening of the cured adhesive may be done through the inclusion of a dispersed rubbery section which absorbs energy and stops crack propagation. Epoxies are commonly tolerant of many surface and environmental conditions and own notably high energy. They are desired for bonding to concrete seeing that, of all adhesives, they have got a specifically excessive tolerance of the alkalinity of

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concrete, in addition to moisture. by means of suitable method, their capability to moist out the substrate surfaces can even be accomplished within the presence of water, the resin being able to disperse the water from the surface being bonded (tabor, 1978).

MATERIALS

CONCRETE

Concrete is a creation cloth composed of portland cement and water blended with sand, gravel, overwhelmed stone, or different inert material inclusive of elevated slag or vermiculite. The cement and water form a paste which hardens via chemical reaction right into a strong, stone- like mass. The inert substances are referred to as aggregates, and for economic system no greater cement paste is used than is necessary to coat all of the combination surfaces and fill all the voids. The concrete paste is plastic and easily molded into any shape or troweled to supply a smooth floor. Hardening begins at once, however precautions are taken, usually by way of covering, to avoid fast loss of moisture since the presence of water is vital to keep the chemical response and boom the energy. an excessive amount of water, but, produces a concrete that is greater porous and weaker. The quality of the paste shaped with the aid of the cement and water largely determines the individual of the concrete. Proportioning of the ingredients of concrete is called designing the mixture, and for most structural work the concrete is designed to present compressive strengths of 15 to 35 MPa [11]. A wealthy mixture for columns may be in the percentage of one volume of cement to at least one of sand and 3 of stone, even as a lean combination for foundations can be in the percentage of 1:3:6. Concrete may be produced as a dense mass which is nearly artificial rock, and chemical compounds may be introduced to make it water-resistant, or it is able to be made porous and surprisingly permeable for such use as clear out beds. An air-entraining chemical can be delivered to provide minute bubbles for porosity or mild weight. generally, the overall hardening length of concrete is at least 7 days. The slow boom in strength is due to the hydration of the tricalcium aluminates and silicates. Sand utilized in concrete turned into at first particular as roughly angular, however rounded grains are actually preferred. The stone is usually sharply broken. the weight of concrete varies with the kind and amount of rock and sand. A concrete with trap rock can also have a density of 2,483 kg/m3. Concrete is stronger in compression than in tension, and metallic bar, known as rebar or mesh is embedded in structural participants to growth the tensile and flexural strengths. further to the structural makes use of, concrete is extensively used in precast gadgets consisting of block, tile, sewer, and water pipe, and ornamental merchandise. Portland slag cement (p.c) – 43 grade (Kornak Cement) was used for the research. It became tested for its physical residences according with Indian preferred specs. The exceptional combination used on this investigation become easy river sand, passing through four.75 mm sieve with particular gravity of 2.sixty eight. The grading quarter of pleasant aggregate became zone III as in step with Indian widespread specifications. system overwhelmed granite broken stone angular in form became used as coarse mixture. The most length of coarse combination was 20 mm with unique gravity of two.seventy three. normal clean transportable water unfastened from suspended debris and chemical substances become used for both mixing and curing of concrete.

For concrete, the maximum aggregate length used was 20 mm. Nominal concrete mix of 1:1.five:3 with the aid of weight is used to acquire the energy of 20 N/mm2. The water cement ratio 0.five is used. three dice specimens were solid and examined on the time of beam take a look at (on the age of 28 days) to decide the compressive energy of concrete. The average compressive power of the concrete changed into 31N/mm2.

Cement

Cement is a material, generally in powder shape, that may be made right into a paste generally with the aid of the addition of water and, while molded or poured, will set into a solid mass. severa natural compounds used for adhering, or fastening substances, are called cements,

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however these are categorised as adhesives, and the term cement alone approach a construction material. The maximum widely used of the development cements is portland cement. it is a bluish-gray powder obtained with the aid of finely grinding the clinker made by strongly heating an intimate aggregate of calcareous and argillaceous minerals. The leader uncooked cloth is a combination of excessive-calcium limestone, referred to as cement rock, and clay or shale. Blast-furnace slag can also be used in some cements and the cement is referred to as portland slag cement (p.c). The shade of the cement is due mainly to iron oxide. inside the absence of impurities, the colour would be white, but neither the shade nor the particular gravity is a test of first-class. The unique gravity is at least three.10. Portland slag cement (p.c) – 43 grade (Kornak Cement) turned into used for the research.

Fine aggregate

Nice mixture / sand is an accumulation of grains of mineral count number derived from the disintegration of rocks. it's far outstanding from gravel handiest through the dimensions of the grains or particles, however is distinct from clays which incorporate organic substances. Sands which have been looked after out and separated from the organic cloth with the aid of the action of currents of water or by means of winds across arid lands are commonly quite uniform in size of grains. generally business sand is acquired from river beds or from sand dunes initially shaped by way of the action of winds. a good deal of the earth's surface is sandy, and those sands are commonly quartz and different siliceous materials. The most useful commercially are silica sands, frequently above 98% natural. seashore sands commonly have smooth, spherical to ovaloid debris from the abrasive movement of waves and tides and are free of natural depend. The white seaside sands are largely silica but may also be of zircon, monazite, garnet, and other minerals, and are used for extracting numerous factors.

Sand is used for making mortar and urban and for polishing and sandblasting. Sands containing a touch clay are used for making molds in foundries. Clean sands are hired for filtering water. Sand is offered via the cubic backyard (0.76 m3) or ton (zero.ninety one metric ton) but is always shipped via weight. the burden varies from 1,538 to one,842 kg/m3, depending on the composition and length of grain. construction sand is not shipped extraordinary distances, and the pleasant of sands used for this purpose varies consistent with neighborhood deliver. widespread sand is a silica sand used in making concrete and cement exams. The first-rate aggregate received from river mattress of Koel, clear from all forms of natural impurities turned into used in this experimental software. The satisfactory aggregate become passing thru 4.seventy five mm sieve and had a selected gravity of two.68. The grading region of excellent aggregate changed into quarter III as per Indian preferred specs.

Coarse aggregate

Coarse aggregate are the crushed stone is used for making concrete. the industrial stone is quarried, crushed, and graded. lots of the beaten stone used is granite, limestone, and entice rock. The final is a term used to designate basalt, gabbro, diorite, and other darkish-coloured, quality-grained igneous rocks. Graded crushed stone typically consists of only one form of rock and is damaged with sharp edges. The sizes are from 0.25 to 2.five in (zero.64 to six.35 cm),even though larger sizes may be used for big concrete aggregate. Gadget beaten granite broken stone angular in form become used as coarse combination. The most size of coarse combination changed into 20 mm and unique gravity of 2.78. Granite is a coarse-grained, igneous rock having a fair texture and consisting in large part of quartz and feldspar with frequently small amounts of mica and other minerals. There are many sorts. Granite may be very tough and compact, and it takes a quality polish, showing the splendor of the crystals. Granite is the maximum vital building stone. Granite is extremely long lasting, and since it does now not soak up moisture, as limestone and sandstone do, it does no longer climate or crack as those stones do. the colors are generally reddish, greenish, or gray. Rainbow granite may

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A Peer Reviewed Open Access International Journal

additionally have a black or dark-inexperienced heritage with crimson, yellowish, and reddish mottling; or it can have a red or lavender heritage with darkish mottling. The density is two,723 kg/m3, the precise gravity 2.72, and the crushing power 158 to 220 MPa

Water

Water healthy for drinking is generally considered in shape for making concrete. water must be loose from acids, oils, alkalies, vegetables or other natural impurities. gentle waters also produce weaker concrete. Water has features in a concrete blend. First of all, it reacts chemically with the cement to shape a cement paste in which the inert aggregates are held in suspension till the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the combination of best aggregates and cement.

REINFORCEMENT

The longitudinal reinforcements used were high-yield electricity deformed bars of 12 mm diameter. the stirrups had been made from slight metallic bars with 6 mm diameter. the yield strength of metal reinforcements used on this experimental software turned into determined by way of acting the same old tensile test at the three specimens of each bar. the common proof stress at 0.2 % stress of 12 mm φ bars became 437 n/mm2 and that of 6 mm φ bars became 240 n/mm2.

FIBER REINFORCED POLYMER (FRP)

Continuous fiber-reinforced substances with polymeric matrix (FRP) can be considered as composite, heterogeneous, and anisotropic substances with a common linear elastic conduct as much as failure. They're broadly used for strengthening of civil systems. There are numerous benefits of the usage of FRPs: lightweight, accurate mechanical properties, corrosion-resistant, and so on. Composites for structural strengthening are to be had in numerous geometries from laminates used for strengthening of participants with everyday floor to bi-directional fabric effortlessly adaptable to the form of the member to be bolstered. Composites also are suitable for programs in which the cultured of the unique systems wishes to be preserved (homes of ancient or creative hobby) or where strengthening with traditional strategies can't be efficaciously hired.

Fiber bolstered polymer (FRP) is a composite material made by combining or greater substances to give a brand new mixture of homes. but, FRP is different from different composites in that its constituent substances are distinctive on the molecular stage and are routinely separable. The mechanical and physical residences of FRP are managed with the aid of its constituent residences and by structural configurations at micro stage. Consequently, the design and evaluation of any FRP structural member requires a terrific knowledge of the material residences, which can be depending on the manufacturing system and the properties of constituent materials [5].

FRP composite is a two phased fabric, consequently its anisotropic residences. it is composed of fiber and matrix, that are bonded at interface. each of these unique phases has to perform its required feature based on mechanical properties, so that the composite machine plays satisfactorily as an entire. In this example, the reinforcing fiber presents FRP composite with strength and stiffness, while the matrix offers rigidity and environmental safety.

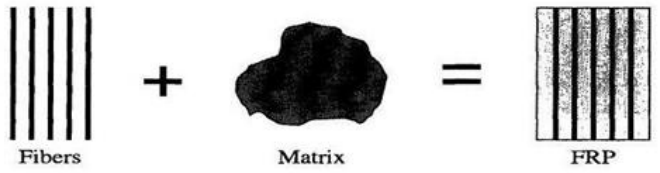

Fig. 3.1 Formation of Fiber Reinforced Polymer Composite

Reinforcement materials

A first rate majority of substances are more potent ad stiffer in fibrous shape than as bulk materials. A high fiber element ratio (duration: diameter ratio) lets in very effective switch of load through matrix substances to the fibers, accordingly taking gain of there tremendous

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houses. Therefore, fibers are very effective and appealing reinforcement substances.

Fiber

A fiber is a cloth made into an extended filament with a diameter usually inside the order of 10 tm. the issue ratio of duration and diameter can be ranging from thousand to infinity in non- stop fibers. the primary features of the fibers are to carry the load and provide stiffness, strength, thermal stability, and different structural homes within the frp.

To perform those suitable features, the fibers in frp composite need to have:

i) High modulus of elasticity to be used as reinforcement;

ii) High closing energy;

iii) Low variation of energy among fibers;

iv)High stability of their electricity at some stage in managing; and

v) Excessive uniformity of diameter and floor measurement among fibers.

There are 3 sorts of fiber dominating in civil engineering industry-glass, carbon and aramid fibers, each of which has its very own benefits and drawbacks.

Material	Density (g/cm^3)	Tensile Modulus (E) (GPa)	Tensile Strength (σ) (GPa)	Specific Modulus (E/σ)	Specific Strength	Relative Cost
E-glass	2.54	70	3.45	27	1.35	Low
S-glass	2.50	86	4.50	34.5	1.8	Moderate
Graphite, high modulus	1.9	400	1.8	200	0.9	High
Graphite, high strength	1.7	240	2.6	140	1.5	High
Boron	2.6	400	3.5	155	1.3	High
Kevlar 29	1.45	80	2.8	55.5	1.9	Moderate
Kevlar 49	1.45	130	2.8	89.5	1.9	Moderate

Table 3.1 Properties of different fibers

Types of fibers used in fiber reinforced polymer composites

- Glass fibers
- Carbon fibers
- Aramid fibers

Glass fibers

These are fibers normally used inside the naval and commercial fields to produce composites of medium-high overall performance. Their strange feature is their excessive electricity. Glass is in particular product of silicon (sio2) with a tetrahedral shape (sio4). somealuminium oxides and other steel ions are then brought in diverse proportions to either ease the running operations or regulate some homes (e.g., s-glass fibers showcase a better tensile energy than e- glass).

	E-glass	S-glass
Silicon oxide	54.3	64.20
Aluminium oxide	15.2	24.80
Iron oxide	-	0.21
Calcium oxide	17.2	0.01
Magnesium oxide	4.7	10.27
Sodium oxide	0.6	0.27
Boron oxide	8.0	0.01
Barium oxide	-	0.20
Various	-	0.03

Table 3.2 Typical composition of fiberglass (% in weight)

The manufacturing generation of fiberglass is largely primarily based on spinning a batch manufactured from sand, alumina, and limestone. the elements are dry blended and brought to melting (about 1260 °c) in a tank. the melted glass is carried at once on platinum bushings and, by means of gravity, passes via advert hoc holes located on the bottom. the filaments are then grouped to shape a strand generally made of 204 filaments. the unmarried filament has a median diameter of 10 µm and is usually included with a sizing. the yarns are then bundled, in most instances with out twisting, in a roving.

Glass fibers are also to be had as skinny sheets, known as mats. a mat may be fabricated from both long non-stop and brief fibers (e.g., discontinuous fibers with a typical duration among 25 and 50 mm), randomly arranged and kept collectively through a chemical bond. the width of such mats is variable between 5 cm and 2 m, their density being roughly 0.5 kg/m2.

Glass fibers commonly have a young modulus of elasticity (70 gpa for e-glass) lower than carbon or aramid fibers and their abrasion resistance is highly negative; therefore, warning in their manipulation is required. in addition, they are vulnerable to creep and feature low fatigue electricity. to beautify the bond between fibers and matrix, as well as to shield the fibers itself towards alkaline retailers and moisture, fibers undergo sizing remedies performing as coupling

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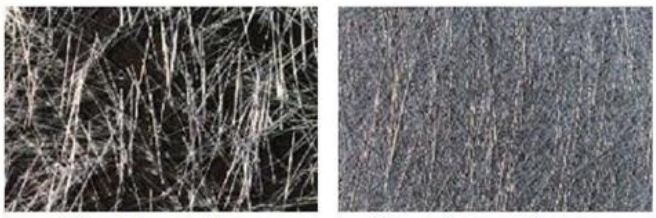
marketers. such remedies are beneficial to enhance durability and fatigue performance (static and dynamic) of the composite material. frp composites based on fiberglass are typically denoted as .GFRP.



Discontinuous fibers. Discontinuous fibers *mat*.

Fig 3.2 Discontinuous Glass Fibers

Carbon fibers

Carbon fiber is the maximum highly-priced of the greater common reinforcements, however in area applications the mixture of top notch overall performance traits coupled with light weight make it fundamental reinforcement with value being of secondary importance. Carbon fibers include small crystallite of turbo stratic graphite. those resemble graphite single crystals except that the layer planes aren't packed in a everyday fashion alongside the c-axis course. In a graphite unmarried crystal the carbon atoms in a basal aircraft are arranged in hexagonal arrays andheld together by means of sturdy covalent bonds. among the basal planes only weak Van-der-waal forces exist. Therefore the single crystals are fairly anisotropic with the aircraft moduli of the order of one hundred GPa while the molecules perpendicular to the basal aircraft are most effective about 75 GPa. it is for that reason obvious that to provide excessive modulus and high strength fibers, the basal planes of the graphite ought to be parallel to the fiber axis. they've lower thermal enlargement coefficients than both the glass and aramid fibers. The carbon fiber is an anisotropic material, and its transverse modulus is an order of value less than its longitudinal modulus. The fabric has a completely high fatigue and creep resistance. Since its tensile power decreases with growing modulus, its pressure at rupture will are also a great deal decrease. because of the cloth brittleness at higher modulus, it becomes critical in joint and connection information, which can have excessive strain concentrations. because of this phenomenon, carbon composite laminates are more powerful with adhesive bonding that removes mechanicalfasteners.

Typical Properties	Density (g/cm^3)	Young's Modulus (GPa)	Tensile Strength (GPa)	Tensile Elongation (%)
High Strength	1.8	230	2.48	1.1
High Modulus	1.9	370	1.79	0.5
Ultra-High Modulus	2.0 - 2.1	520 – 620	1.03 - 1.31	0.2

Table 3.3 Typical properties of Carbon Fiber

Kevlar fibers

kevlar (poly-paraphenyleneterephthalamide) is the dupont agency's emblem call for a artificial cloth built of para-aramid fibers that the business enterprise claims is five instances more potent than the identical weight of metallic,at the same time as being lightweight, bendy and cozy. it's also very heat resistant and decomposes above four hundred °c without melting. it turned into invented via stephaniekwolek of dupont from research into highperformance polymers, and patented by means of her in 1966 and first marketed in 1971. kevlar is a registered trademark of e.i. du pont de nemours and employer.at the beginning supposed to update the metallic belts in tires, it might be the most well known call in soft armor (bulletproof vests). it is also used in intense sports activities gadget, high-tension drumhead applications, animal managing protection, composite plane production, fire suits, yacht sails, and as an asbestos alternative. When this polymer is spun within the identical manner that a spider spins a web, the resulting industrial para-aramid fiber has extremely good power, and is heat and cut resistant. para-aramid fibers do not rust or corrode, and their energy is unaffected through immersion in water. while woven collectively, they shape a terrific cloth for mooring strains and other underwater items [3]. However, unless particularly waterproofed, para-aramid fiber's capacity to forestall bullets and other projectiles is degraded when moist. kevlar is a kind of aramid that consists of lengthy polymeric chains with a parallel orientation. kevlar derives its strength from inter-molecular hydrogen bonds and fragrant stacking interactions between aromatic businesses in neighboring strands.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
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These properties bring about its high mechanical electricity and its excellent warmth resistance. because it is notably unsaturated, i.e. the ratio of carbon to hydrogen atoms is pretty high, it has a low flammability. kevlar molecules have polar agencies handy for hydrogen bonding. water that enters the indoors of the fiber can take the location of bonding among molecules and decrease the cloth's electricity, even as the to be had organizations on the surface result in top wetting properties. that is important for bonding the fibers to other kinds of polymer, forming a fiber reinforced plastic. this same property also makes the fibers feel greater herbal and "sticky" compared to non-polar polymers like polyethylene. in structural applications, kevlar fibers can be bonded to each other or to different materials to form a composite. kevlar's principal weaknesses are that it decomposes underneath alkaline situations or whilst exposed to chlorine. even as it is able to have a great tensile energy, on occasion in excess of four.zerogpa, like several fibers it has a tendency to buckle in compression.

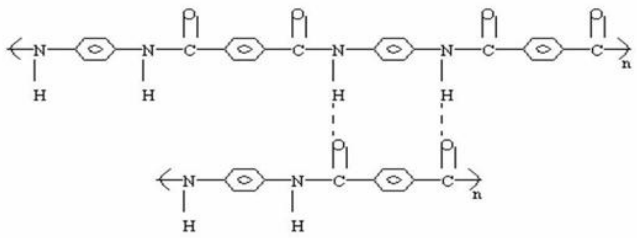

Fig. 3.3 Structure of aramid fiber

Fiber sheet

Fiber sheet used on this experimental research changed into E-Glass, Bi directional woven roving mat. It turned into no longer susceptible to atmospheric agents. It changed into also chemically resistive and anticorrosive.

TYPES OF MATRIX MATERIALS

Fibers, on the grounds that they can not transmit masses from one to every other, have restrained use in engineering programs. whilst they're embedded in a matrix fabric, to form a composite, the matrix serves to bind the fibers together, switch masses to the fibers, and harm because of dealing with. The matrix has a robust affect on several mechanical properties of the composite inclusive of transverse modulus and strength,shear homes, and homes in compression. physical and chemical characteristics of the matrix such as melting or curing temperature, viscosity, and reactivity with fibers have an effect on the preference of fabrication procedure. The matrix fabric for a composite device is chosen, keeping in view these kinds of elements. There most resins are the most normally used matrices for production of FRP materials. they're typically available in a partially polymerized nation with fluid or pasty consistency at room temperature. whilst mixed with a proper reagent, they polymerize to come to be a strong, vitreous material. The reaction can be extended with the aid of adjusting the temperature. There most resin have numerous blessings, inclusive of low viscosity that lets in for a relative smooth fiber impregnation, proper adhesive properties, room temperature polymerization traits, proper resistance to chemical sellers, absence of melting temperature, and many others. negative aspects are restrained range of running temperatures, with the upper bound restriction given by way of the glass transition temperature, bad sturdiness with recognize to fracture (“brittle” behavior), and sensitivity to moisture throughout area packages. The most not unusual thermosetting resins for civil engineering are the epoxy resin. Polyester or vinylester resins also are used. considering that the cloth is blended without delay at the development site and obtains its very last structural characteristics thru a chemical reaction, it need to usually be dealt with through specialized personnel. usually used matrix substances are described below

Epoxy resin

Epoxy resins are noticeably low molecular weight pre-polymers succesful of being processed under a variety of conditions. two critical advantages of those resins are over unsaturated polyester resins are: first, they can be in part cured and saved in that kingdom, and 2d they show off low shrinkage at some point of cure. but, the viscosity of conventional epoxy resins is higher and they're greater highly-priced as compared to polyester resins. The cured resins have excessive chemical, corrosion resistance, right mechanical and thermal

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International Journal & Magazine of Engineering, Technology, Management and Research
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residences, tremendous adhesion to a ramification of substrates, and desirable and electrical residences. about forty five% of the overall quantity of epoxy resins produced is utilized in protective coatings while the remaining is utilized in structural programs such as laminates and composites, tooling, moulding, casting, production, adhesives, and so forth.

Epoxy resins are characterized by means of the presence of a three-membered ring containing two carbons and an oxygen (epoxy group or epoxide or oxirane ring). Epoxy is the first liquid response product of bisphenol-A with extra of epichlorohidrin and this resin is known as diglycidylether of bisphenol A (DGEBA). DGEBA is used appreciably in industry because of its high fluidity, processing ease, and precise physical homes of the cured of resin.

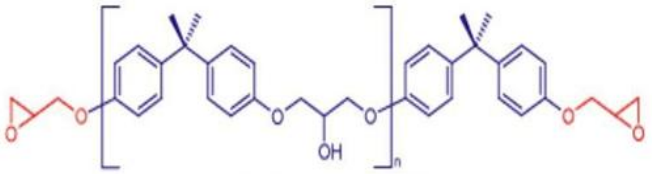

Fig. 3.4 Structure of DGEBA

A number epoxy resins is now available, varying from highly hard low temperature epoxies to be used in production industry to brittle epoxies for use in construction industry to brittle epoxies beneficial in aerospace zone. this vast application of epoxy resin is generally because of the availability of resins with extraordinary spine structures and molecular weights to offer products with low viscosity (beverages) to low melting factor solids. the ease of processibility, appropriate melting characteristics, first rate adhesion to various kinds of substrates, low shrinkage all through treatment, superior mechanical properties of cured resin, and desirable thermal and chemical resistance have made epoxy resin a material of desire in advanced fiber bolstered composites. ethylenediamines are most extensively used aliphatic amines for cured epoxy resins. those are especially reactive, low molecular weight curing retailers that result in tightly move-linked community. one number one amino group reacts with epoxy groups. the primary and secondary amines are reactive curing sellers. the number one amino group is extra reactive closer to epoxy than secondary amino organizations are ate up (95%), while best 28% of secondary amino organizations are consumed.

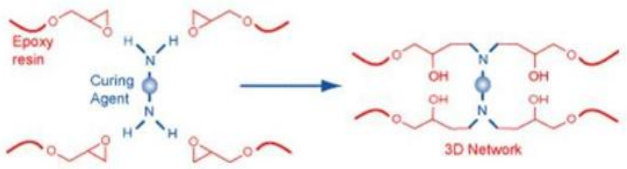

Fig. 3.5 The curing of epoxy resin with primary amines

The number one amino-epoxy response consequences in linear polymerization even as secondary amino-epoxy response results in branching and cross-linking.the cured epoxy resins find a ramification of applications as adhesives, laminates, sealants, coatings, and many others. the most fulfilling curing temperature and the thermal balance of epoxy resin depend upon the type of curing agent. the anhydride cured epoxy resins have terrific electrical, chemical, and mechanical residences and are used for electric and electronic packages. Epoxies are used as binders in substances for construction. filling of cracks in concrete systems is done by using epoxies. in creation enterprise, for bonding and coating functions, low temperature curing of epoxies is achieved with the aid of the use of thiols that exhibit higher curing fees. Epoxy primarily based prepregs have been used in severa aircraft additives such as rudders, stabilizers, elevators, wing hints, launching equipment doors, radomes, ailerons, and so on. The composite substances represent three- 9% of general structural weight of the economic aircrafts including boeing 767 or boeing 777. composite and laminate enterprise makes use of 28% of epoxy resins produced. besides these programs, the applications, the foremost person of epoxy is coatingindustry.

Property	
Density, g/cm^3	1.2-1.3
Tensile modulus, MPa	55-130
Tensile modulus, GPa	2.75-4.10
Thermal expansion, 10^{-6}/°C	45-65
Water absorption, %in 24h	0.08-0.15

Table 3.4 Properties of epoxy resin

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

The achievement of the strengthening approach significantly depends at the overall performance of the epoxy resin used. numerous sorts of epoxy resins with a huge variety of mechanical properties are commercially available. those epoxy resins are generally component systems, a resin and a hardener. the resin and hardener are used on this take a look at is araldite ly 556 and hardener hy 951, respectively. araldite ly-556, an unmodified epoxy resin primarily based on bisphenol-a and the hardener (ciba-geig, india) hy 951 (8% of overall epoxy taken) an aliphatic primary amine, were combined nicely.

CASTING OF BEAMS

Sets of beams had been casted for this experimental take a look at software. In SET I 3 beams (F1, F2 and F3) susceptible in flexure had been casted using identical grade of concrete and reinforcement detailing. In SET II 3 beams (S1, S2 and S3) susceptible in shear had been casted using identical grade of concrete and reinforcement detailing. the scale of all the specimens are same. The pass sectional dimensions of the each the set of beams is 250 mm via 200 mm and length is 2300 mm. In SET I beams 2, 12 mm φ bars are furnished as the main longitudinal reinforcement and 6 mm φ bars as stirrups at a spacing of seventy five mm middle to center where as in SET II beams 3, 12 mm φ bars are furnished as the primary longitudinal reinforcement and without anystirrups.

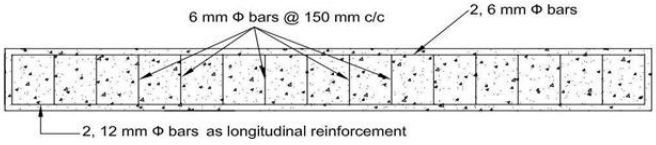

Fig. 3.6 Reinforcement details of SET I beams

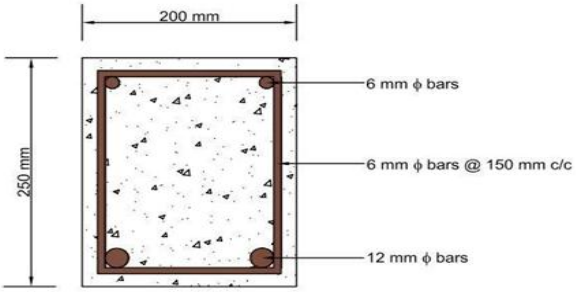

Fig. 3.7 Section of SET I beams

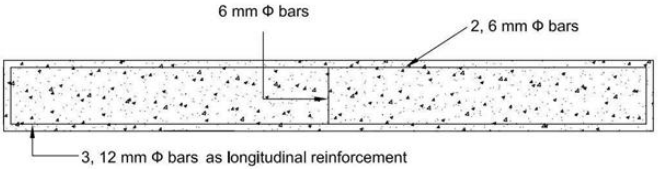

Fig. 3.8 Reinforcement details of SET II beams

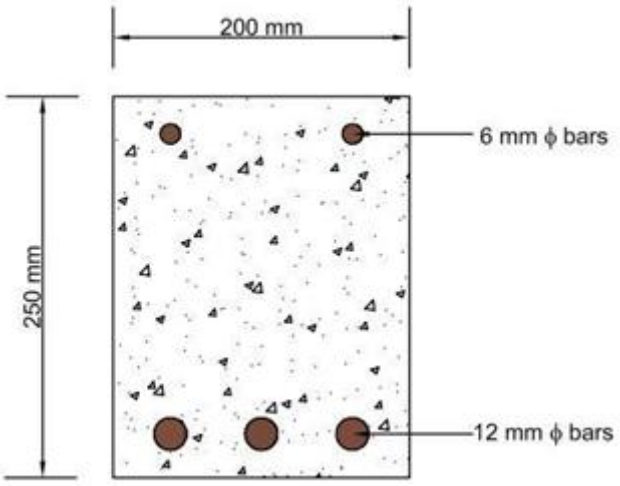

Fig. 3.9 Section of SET II beams

STRENGTHENING OF BEAMS

Before bonding the composite fabric onto the concrete floor, the required area of concrete floor changed into made difficult using a coarse sand paper texture and wiped clean with an air blower to dispose of all dirt and debris. once the surface become prepared to the desired popular, the epoxy resin was blended according with producer's instructions. mixing changed into achieved in a plastic container (Araldite LY 556 – a hundred components through weight and Hardener HY 951 – eight parts by weight) and turned into endured until the mixture changed into in uniform shade. While this changed into completed and the fabric were reduce to length, the epoxy resin was applied to the concrete surface. The composite cloth was then placed on top of epoxy resin coating and the resin turned into squeezed through the roving of the fabric with the curler. Air bubbles entrapped at the epoxy/concrete or epoxy/fabric interface had been to be removed. Then the second layer of the epoxy resin become applied and GFRP sheet changed into then positioned on top of epoxy resin coating and the resin changed into squeezed through the

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

roving of the fabric with the roller and the above technique was repeated. in the course of hardening of the epoxy, a constant uniform strain turned into applied at the composite material surface on the way to extrude the excess epoxy resin and to make sure accurate touch between the epoxy, the concrete and the material. This operation become achieved at room temperature. Concrete beams strengthened with glass fiber fabric have been cured for twenty-four hours at room temperature earlier than testing

Fig. 3.10 Application of epoxy and hardener on the beam

Fig. 3.11 Fixing of GFRP sheet on the beam

Fig. 3.12 Roller used for removal of air bubble

RESULTS

LOAD DEFLECTION HISTORY

The load deflection history of all the beams was recorded. The mid-span deflection of each beam was compared with that of their respective control beams. Also the load deflection behavior was compared between two wrapping schemes having the same reinforcement. It was noted that the behaviour of the flexure and shear deficient beams when bonded with GFRP sheets were better than their corresponding control beams. The mid-span deflections were much lower when bonded externally with GFRP sheets. The graphs comparing the mid-span deflection of flexure and shear deficient beams and their corresponding control beams are shown in Figs 5.4 and 5.8. The use of GFRP sheet had effect in delaying the growth of crack formation. In SET I when both the wrapping schemes were considered it was found that the beam F3 with GFRP sheet up to the neutral axis along with the soffit had a better load deflection behaviour when compared to the beam F2 with GFRP sheet only at the soffit of the beam. In SET II when both the wrapping schemes were considered it was found that the beam S3 with U wrapping of GFRP sheet had a better load deflection behaviour when compared to the beam S2 with GFRP sheet only at the sides of the beam.

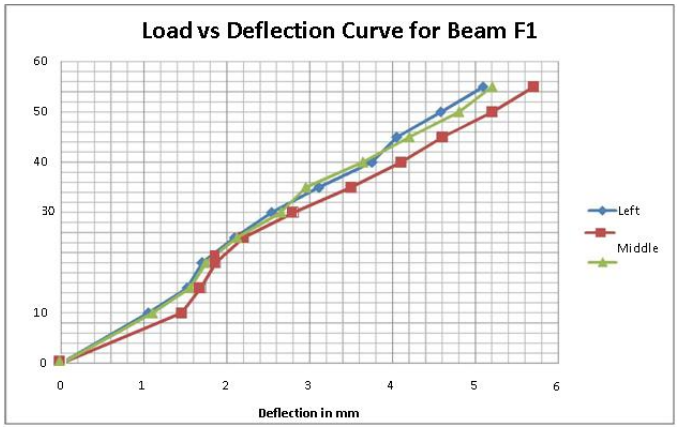

Fig. 5.1 Load vs Deflection Curve for Beam F1

Beam F1 was the control beam of SET I beams which were weak in flexure but strong in shear. In beam F1 strengthening was not done. Two point static loading was done on the beam and at the each increment of the load, deflection at the left, right and middle dial gauges

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
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were taken. Using this load and deflection of data, load vs deflection curve is ploted. At the load of 30 KN initial cracks started coming on the beams. Further with increase in loading propagation of the cracks took place. The beam F1 failed completely in flexure.

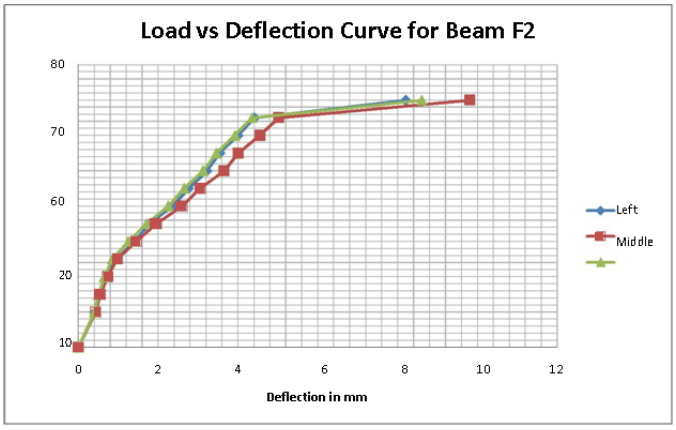

Fig. 5.2 Load vs Deflection Curve for Beam F2

Beam F2 of SET I beams which were weak in flexure but strong in shear. In beam F2 strengthening is done by application of GFRP sheet only at the soffit of the beam. Two point static loading was done on the beam and at the each increment of the load, deflection at the left, right and middle dial gauges were taken. Using this load and deflection of data, load vs deflection curve is ploted. At the load of 34 KN initial cracks started coming on the beams. Initial cracks started at a higher load in beam F2 compared to beam F1. Further with increase in loading propagation of the cracks took place. The beam F2 failed in flexural shear. Beam F2 carried a higher ultimate load compared to beam F1.

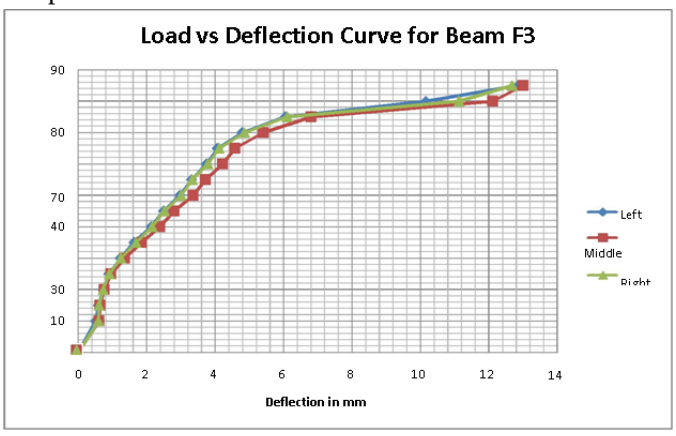

Fig. 5.3 Load vs Deflection Curve for Beam F3

Beam F3 of SET I beams which were weak in flexure but strong in shear. In beam F3 strengthening is done by application of GFRP sheet upto the neutral axis along with the soffit of the beam. Two point static loading was done on the beam and at the each increment of the load, deflection at the left, right and middle dial gauges were taken. Using this load and deflection of data, load vs deflection curve is ploted. Initial cracks are not visible on the beams. Further with increase in loading propagation of the cracks took place but it had poor visibility of cracks due to the covering of the GFRP sheet. The beam F3 also failed in flexural shear like beam F2 but beam F3 carried a higher ultimate load compared to both beam F1 and F2.

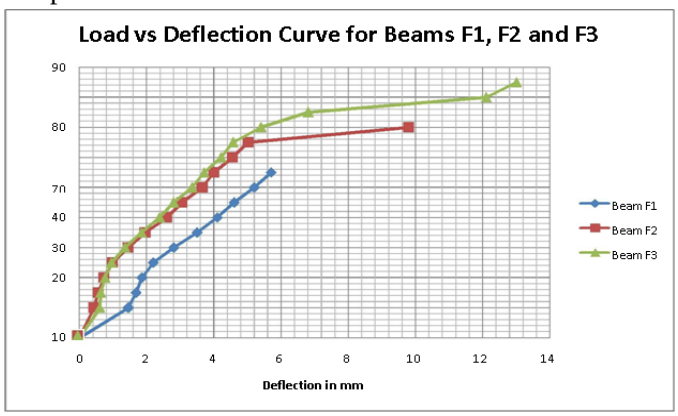

Fig. 5.4 Load vs Deflection Curves for Beams F1, F2 and F3.

From the load and deflection of data of SET I beams F1, F2 and F3, load vs deflection curve is ploted for all the three beams. From this load vs deflection curve, it is clear that beam F1 has lower ultimate load carrying capacity compared to beams F2 and F3. Beam F1 had also undergone higher deflection compared to beams F2 and F3 at the same load. Beam F2 had higher ultimate load carrying capacity compared to the controlled beam F1 but lower than beam F3. Beam F3 had higher ultimate load carrying capacity compared to the beams F1 and F2. Both the beams F2 and F3 had undergone almost same deflection upto 65 KN load. After 65 KN load beam F3 had undergone same deflection as beam F2 but at a higher load compared to beam F2. The deflection undergone by beam F3 is highest. Beam F2 had undergone higher deflection than beam F1.

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International Journal & Magazine of Engineering, Technology, Management and Research
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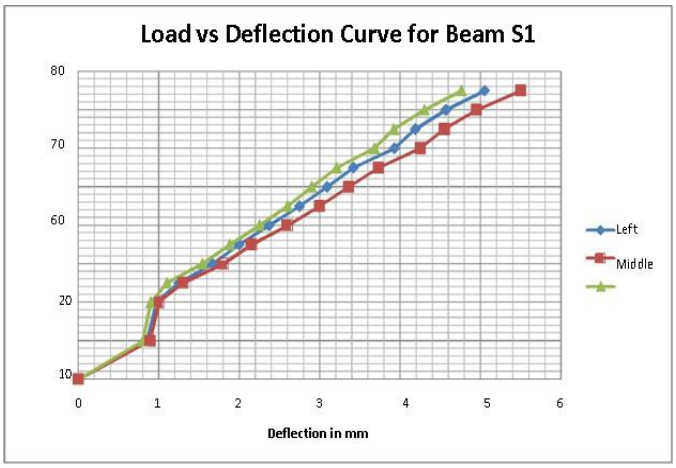

Fig. 5.5 Load vs Deflection Curve for Beam S1

Beam S1 was the control beam of SET II beams which were weak in shear but strong in flexure. In beam S1 strengthening was not done. Two point static loading was done on the beam and at the each increment of the load, deflection at the left, right and middle dial gauges were taken. Using this load and deflection of data, load vs deflection curve is ploted. At the load of 35 KN initial cracks started coming on the beams. Further with increase in loading propagation of the cracks took place.

At first in beam S1 only flexural cracks were developed but ultimately the beam failed in shear.

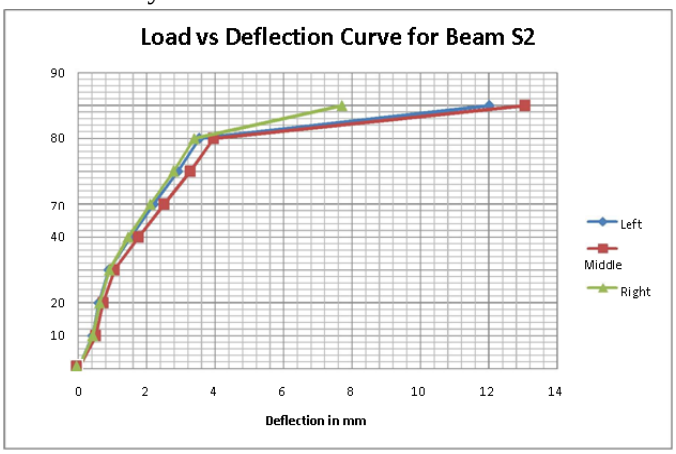

Fig. 5.6 Load vs Deflection Curve for Beam S2

Beam S2 of SET II beams which were weak in shear but strong in flexure. In beam S2 strengthening is done by application of GFRP sheet only on the two sides of the beam. Two point static loading was done on the beam and at the each increment of the load, deflection at the left, right and middle dial gauges were taken. Using this load and deflection of data, load vs deflection curve is ploted. At the load of 39 KN initial cracks started coming on the beams. Initial cracks started at a higher load in beam S2 compared to beam S1. Further with increase in loading propagation of the cracks took place.

In beam S2 only flexural cracks were developed and finally the beam failed by flexural failure and crushing of concrete. Beam S2 carried a ultimate load higher than beam S1 but lower than beam S3.

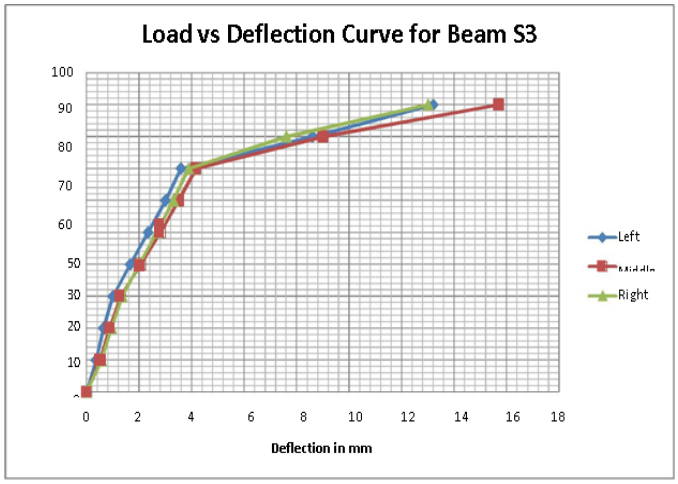

Fig. 5.7 Load vs Deflection Curve for Beam S3

Beam S3 of SET II beams which were weak in shear but strong in flexure. In beam S3 strengthening is done by application of GFRP sheet as U-wrap on the beam. Two point static loading was done on the beam and at the each increment of the load, deflection at the left, right and middle dial gauges were taken. Using this load and deflection of data, load vs deflection curve is ploted. At the load of 39 KN initial cracks started coming on the beams. Initial cracks started at a higher load in beam S3 compared to beams S1 and S2.

Further with increase in loading propagation of the cracks took place. In beam S3 similar to beam S2 only flexural cracks were developed and finally the beam failed by flexural failure and crushing of concrete, but beam S3 carried a higher ultimate load compared to both beam S1 and S2.

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International Journal & Magazine of Engineering, Technology, Management and Research
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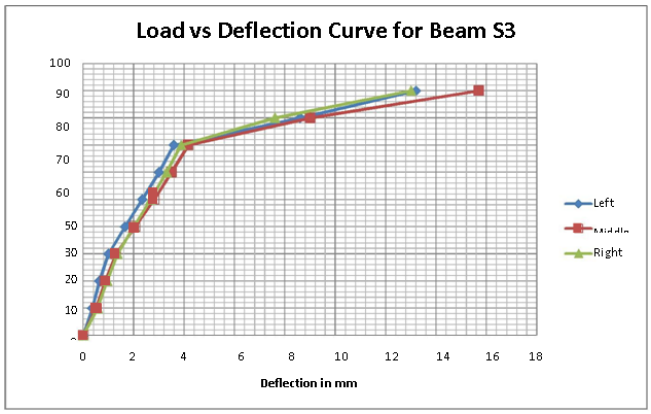

Fig. 5.8 Load vs Deflection Curves for Beams S1, S2 and S3.

From the load and deflection of data of SET II beams S1, S2 and S3, load vs deflection curve is ploted for all the three beams. From this load vs deflection curve, it is clear that beam S1 has lower ultimate load carrying capacity compared to beams S2 and S3. Beam S1 had also undergone higher deflection compared to beams S2 and S3 at the same load. Beam S2 had higher ultimate load carrying capacity compared to the controlled beam S1 but lower than beam S3. Beam S3 had higher ultimate load carrying capacity compared to the beams S1 and S2. Both the beams S2 and S3 had undergone almost same deflection upto 70 KN load. After 70 KN load beam S3 had undergone same deflection as beam S2 but at a higher load compared to beam S2. The deflection undergone by beam S3 is highest. Beam S2 had undergone higher deflection than beam S1.

CONCLUSIONS

In this experimental investigation the flexural and shear behaviour of reinforced concrete beams strengthened by GFRP sheets are studied. Two sets of reinforced concrete (RC) beams, in SET I three beams weak in flexure and in SET II three beams weak in shear were casted and tested. From the test results and calculated strength values, the following conclusions are drawn:

A) SET I Beams (F1, F2 and F3)

1. Initial flexural cracks appear at a higher load by strengthening the beam at soffit. The ultimate load carrying capacity of the strengthen beam F2 is 33 % more than the controlled beam F1.
2. Load at initial cracks is further increased by strengthening the beam at the soffit as well as on the two sides of the beam up to the neutral axis from the soffit. The ultimate load carrying capacity of the strengthen beam F3 is 43 % more than the controlled beam F1 and 7 % more than the strengthen beam F2.
3. Analytical analysis is also carried out to find the ultimate moment carrying capacity and compared with the experimental results. It was found that analytical analysis predicts lower value than the experimental findings.
4.When the beam is not strengthen, it failed in flexure but after strengthening the beam in flexure, then flexure-shear failure of the beam takes place which is more dangerous than the flexural failure of the beam as it does not give much warning before failure. Therefore it is recommended to check the shear strength of the beam and carry out shear strengthening along with flexural strengthening if required.
5. Flexural strengthening up to the neutral axis of the beam increases the ultimate load carrying capacity, but the cracks developed were not visible up to a higher load. Due to invisibility of the initial cracks, it gives less warning compared to the beams strengthen only at the soffit of the beam.
6.By strengthening up to the neutral axis of the beam, increase in the ultimate load carrying capacity of the beam is not significant and cost involvement is almost three times compared to the beam strengthen by GFRP sheet at the soffit only.

B) SET II Beams (S1, S2 and S3)

1. The control beam S1 failed in shear as it was made intentionally weak in shear.
2. The initial cracks in the strengthen beams S2 and S3 appears at higher load compared to the un-strengthen beam S1.
3. After strengthening the shear zone of the beam the initial cracks appears at the flexural zone of the beam and the crack widens and propagates towards the neutral axis with increase of the load. The final failure is flexural failure which indicates that the GFRP sheets increase the shear strength of the beam. The ultimate

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International Journal & Magazine of Engineering, Technology, Management and Research
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load carrying capacity of the strengthen beam S2 is 31 % more than the controlled beam S1.

4.When the beam is strengthen by U-wrapping in the shear zone, the ultimate load carrying capacity is increased by 48 % compared to the control beam S1 and by 13% compared the beam S2 strengthen by bonding the GFRP sheets on the vertical sides alone in the shear zone of the beam.

5. When the beam is strengthen in shear, then only flexural failure takes place which gives sufficient warning compared to the brittle shear failure which is catastrophic failure of beams.

6. The bonding between GFRP sheet and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to GFRP sheet.

7. Restoring or upgrading the shear strength of beams using GFRP sheet can result in increased shear strength and stiffness with no visible shear cracks. Restoring the shear strength of beams using GFRP is a highly effective technique.

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