STUDY ON STRUCTURAL BEHAVIOUR OF GFRP LAMINATED COMPOSITE SLAB: STATE-OF-THE-ART-REVIEW

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ABSTRACT: A consists survey on the FRP laminates in the field of civil engineering is presented. This paper gives an ideaabout the need for choosing of material and its application; how they used in this field and failure modes. In this paper, collective perspectives of the previous studies were also discussed. Most of the review suggested that the application of FRP at tension side increases the strength of the member. From the studies, it is concluded that GFRP is an effective one and GFRP strips or sheets are very suitable method for strengthening the members such increases in load carrying capacity, ductility and stiffness; reduces deflection and crack propagation.

KEYWORD:RC Slab, FRP types, Resins, GFRP Lamination, Load carrying capacity, Modes of failure, Strengthening.

INTRODUCTION

1.1 Need for Innovation

In recent years, the performance of civil engineering is widely spread over the world by their infrastructure. If the structure is constructed once it will not remain same till end, so repair or rehabilitation should be done according to its modes of failure. The loadings in the structure willresults in decrease in strength and stiffness. It alsoleads to failure in the structure. Hence the structure needs to strengthen is obligatory. In some cases reconstruction is not possible due to the cost, place and other reasons. So, repair work can be done which is also economical and in the same way it also increases the strength of the structure.

[2]For these sort of work, FRP technology isproved to be effective. Other than that they additionally demonstrated to fortify the structure during the development time. It likewise offers a wide scope of remarkable advantages which are short creation and establishment time, light weight, long haul cost reserve funds, erosion opposition, and prevalent life span. An ideal material for use in almost any infrastructure project, FRP is very dynamic, making it the perfect choice for all types of infrastructure which includes pedestrian bridges, trail bridges, cantilever sidewalks, rail platforms, vehicle bridges, and waterfront frameworks. The lack of required maintenance andrepairs helps to save on expensive labour and material costs and also prevents inconvenience to end users, since repair downtime is eliminated. And, since FRP has long durability and it is corrosive resistance, thus the costs are also less. [6] An important factor in strengthening is the bond strength between FRP and the structural member.

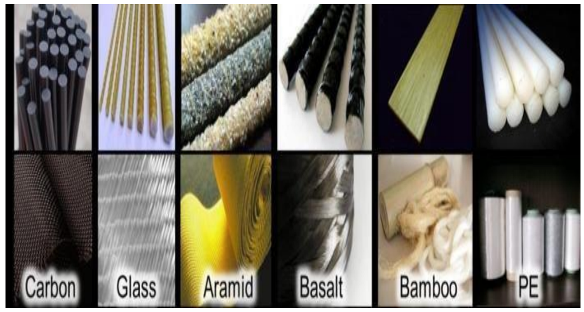

Figure 1. Types of FRP

The initial use of fibre reinforced polymer (FRP) was known as reinforcement bars in 1975 particularly in Russia. There are several types of FRP are used, some of them are mentioned below.

- Glass fibre reinforced polymer(GFRP)
- Carbon fibre reinforced polymer(CFRP)
- Basalt fibre reinforced polymer
- Amarid fibre reinforced polymer

1.2 Processing of FRP

The manufacturing process for FRP composites depends on a number of factors including: i)type of matrix and fibres used, ii)requirement of temperature form iii)shape, iv)number of products, v)the product and the process costs. Therefore, the designer needs to understand the advantages, limitations, cost, and typical uses of various manufacturing processes.

Common processes of FRP composites on the member which have potential for application incivil engineering include the following methods.

- Wet Lay-up
- Bag Moulding
- Resin Transfer Moulding
- Filament Winding
- Pultrusion

1.3 Reason for choosing GFRP

GFRP is an engineered material composedof a polyester or epoxy resin, reinforced with glassfibres. GFRP are used to increase the strength and stiffness in the member. It is mainly used when dismantling is not possible and then to strengthen the deficient structural components. It resists salt water, chemicals, and the environment - unaffected by acid rain, salts, and most chemicals. They also have high strength to weight ratio. GFRP can be used in both interior and exterior fixtures.

GFRP can be used in various fields which include transportation infrastructure, rail LRT, runways, IT and research facilities, mining and tunnelling, buildings, and waterside concrete structures such as retaining and sea walls. Waterside structures, for example, water treatment offices and seepage frameworks must bestrengthened with GFRP to ensure the solid againstunforgiving ecological conditions. GFRP- strengthened members don't rust as they can withstand tractable anxieties from freezing water. Composite channels are utilized by numerous states in light of their solidarity and strength. [13] The long-term durability in saltwater provides GFRP a clear advantage over conventional steel.

The advantages of GFRP are as follows:

- Strength/weight ratio of GFRP composite is much larger than that of steel.
- It is corrosion resistance.
- It also works for seismicstrengthening.
- It is cost effective.
- The installation process is simple.
- It requires minimum maintenance.

Figure 2. GFRP sheet

1.4 Resins Used

The polymer matrices (resins), on the other hand, are classified into two groups, namely thermosetting or thermoplastics. There are various types of resins available on the market for a the uses, which also includes composite laminating resins, floor coating resins, table coating resins and casting resins.

The major types of resins are:
- Epoxy resins
- Polyester
- Vinyl polyester
- Phenolic

Understanding the resin types which are available and their properties reading are the major part in the process of determinationof the product and making the member a high performance composites.

1.5 Failure Modes

Composite laminates may have inherent defects introduced at the manufacturing stage or may develop new damage under service loads. Since the defects or damage will ultimately affect the overall functionality of the composite member, early identification of damage characteristics in the material is of interest. Modes of failures are mainly depends on how we evaluate thestrength in a composite material.

The main three modes of failures are,
- Matrix phase of failure, which in homogeneous materials throughcrack initiation and propagation.
- Reinforcing phase failure, which is thefracture of reinforcement.
- Interface failure, in which the fibre detach from the matrix materials i.e., debonding of two constituent materials.

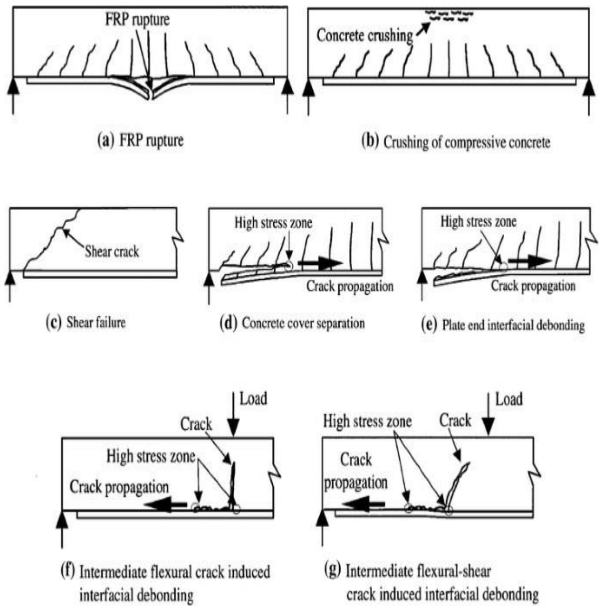

Figure 3. Modes of Failure

Usually, these Failures are through the following reasons, which are i)Concrete crushing before yielding of reinforcing steel; ii)Steel yielding followed by FRP rupture and concrete crushing; iii)Cover delamination and FRP debonding[5]. In this the most common failure is delamination failure. The major delamination problems are due to debonding failure and poor surface preparation which decreases the member capacity.

2. Reviews on Previous Studies

2.1 Review on FRP Composites

[2]**N. F. Grace, G. A. Sayed, A. K. Soliman and K. R. Saleh (1999)** In this work, they significantly addresses two concerns which are the examination of the effect of using available FRP strengthening systems with different patterns in strengthening reinforced concrete beams and the other one is evaluation of the ductility of FRP strengthened beams. This paper provide an idea about failure modes and crack patterns.The results suggests that the presence of CFRP plates have been changed the distribution of compressive strain in the concrete. The vertical layers in the member will prevent rupture. The proper combination of horizontal and vertical fibres with the bond with epoxywill double the load carrying capacity. The CFRP plateson the bottom and sides of the beam enhance the response in comparison with using CFRP plates only atthe bottom of the beam.

[4]**Ayman S. Mosallam, Khalid M. Mosalam (2003)** This paper presents an experimental and analytical study on examination of unreinforced and reinforced concrete slabs which are repaired and retrofitted with the FRP strips. In this process, miscellaneous laminates of composites are bonded to the finished concrete surfaces in the hoop and longitudinal directions for increase the member ductility and flexural and axial capacity. In the experimental program, 10 full-scale destructive tests were conducted on concrete slabs repaired and retrofitted with both carbon and E-glassy, epoxy composites. The slabs teseted were simply supported on all four sides which underwent two-way action. Computational models using the finite element (FE)method for analysing the two-way reinforced concrete slabs with and without carbon-epoxy FRP composite

external laminates were developed. The FE models consisted of eight-node quadrilateral shell elements based on isoparametric degenerated -solid approach. Conclusively in this paper, they achieved vital objective by enhancing the load distribution between the different laminates in different directions; maximizing the energy dissipation at failure; and ignore the sudden strength degradation in case of bond-line failure at certain locations of the slab. It is an apparent that the FRP systems have prevailing with regards to upgrading the structural capacity in both the slabs. The computational models were further utilized for parametric studies for the other types of loadings. The comparison between the analytical and the experimental results confirmed the validity of the computational models in capturing the experimentally determined results for both the control and the retrofitted specimens.

[6]Sing-Ping Chiew, M.ASCE; Qin Sun; and Yi Yu (2007) In this, they deals about strengthening by casting additional reinforced concrete or by dowelling with additional steel reinforcement. This process is a time consuming, so FRP composites has emerged as a preferable material in the bonding technique. In this paper, they describes the experimental and numerical study of the flexural behaviour of reinforced concrete beams strengthened with GFRP laminates. In this experimental program, beams are tested to failure under monotonic loading. The evaluation of longitudinal GFRP strain development and interfacial shear stress distribution are done. An eight-node interface element is carried out for the analysis of the RC beams with GFRP lamination. Less ductility leads to high strength and the stiffness of the strengthened beams. The beam experience excessive deflection at the moment of failure. Debonding failre occurs in all the strengthened beams with external GFRP laminates. Mainly the bond failure will start to propagate from the adhesive – concrete interface. As comparing both the beams, the strengthened one was finer and more uniformly distributed cracks. This is caused by the stress redistribution in the concrete which results in the effect of GFRP lamination. Based on the forced equilibrium, the interfacial shear stress along the GFRP and concrete beam was calculated. The numerical study on this study shows the variation effect in the bond strength which reveals higher bond strength greater stiffness, and better ductility. Conclusively, this paper will provide an information about the bonding effect, interfacial stress analysis, moment deflection characteristics on the beam. Various cracking pattern and debonding behaviour is examined. A comparison between the numerical & experimental study is provided.

[8]**Y. Zhu, Y. X. Zhang (2010**) IN this paper, a rectangular composite layered plate component and nonlinear FE method procedure are examined for nonlinear investigation of FRP-RC Slabs. Timoshenko's composite beam functions and Mindlin-Reissner plate theory are the major theories used in this model. In this research, it shows the behaviour of the FRP-reinforced slabs which was bi-linearly elastic until failure. Then, the stiffness of the CFRP- RC Slabs was reduced after propagation of cracks. A four node layered rectangularcomposite plate element is done in this paper. The reinforced composite concrete section is divided into aseries of concrete layers. It is found that when replacingFRP bars with steel bars in compression area could bear large loading with smaller deflection. FRP bars are replaced by steel bars which have increases the serviceability.

[9]**Asifuz Zaman, Saud A Gutub and Mahmoud AWafa (2013)** FRP composites are utilizedin a wide scope of uses in development on account of the advantages they give over traditional structure materials. The drawn out security of the polymer will be reliant upon its toughness in the climate into which it is set. In this paper they describe about the internal and external bonding characteristics of FRP in the structural member, in which they review about the current utilization of FRP in construction field. These materials have high strength ratio to density. The fibre makes the member more durable.

[10]**A. Leema Rose, K. Suguna, P.N. Ragunath (2014)** In this paper, the evaluation of performance of corrosion damaged reinforced concrete beams GFRP laminates. Here the different degrees of corrosion wereinduced using an accelerated corrosion technique with an impressed current. The corrosion performance of beams was examined based on the results of half-cell potential tests, chloride ion content, and mass loss and bar diameter degradation. The study shows the corrosion performance on the specimen which includes admixture type. The corrosion of specimen is done by immersing it in a NaCl

solution in which current powersupply with an output of 11Amps is directly supplied. Conclusively, bonding on tension face of RC member increases the ultimate strength. As compared with the normal beam, corroded beam strengthened with GFRP enhance the ductility and ultimate strength improved by an average of 85%. In GFRP strengthened beams, the deflection also got reduced.

[11]**Yihua Zeng, Robby Caspeele, Stijn Matthys, Luc Taerwe (2016)** In this paper, they examine the compressive membrane action of FRP. CMA effect was qualified inorder to check the parametric study and an enhancement factor in member. There are two major methods of CMA, in which one is using of plasticity theory and deformationtheory and the other method accounts for the ultimate load of laterally restrained members by taking the sum of the bending capacity and the additional three-hinge arch load due to CMA. This research has shown that CMA is beneficial in both strength enhancement and serviceability behaviour for laterally restrained concrete flexural members. The presence of the FRP reinforcement is expected to cause a difference in the CMA between conventional RC members and FRP strengthened RC members. FRP debonding failure is shows high vulnerability, it is suggested that failures should be prevented in the CMA. For the solution of delamination, U strips are provided. It is recommended that in the design process such beneficial effect of CMA can be incorporated during the verification of ultimate limit state to realize a more optimized design. Results additionally demonstrate that the impact of CMA increments with the expansion of FRP area, steel proportion, strength and extreme strain of cement however diminishes with expanding length to depth ratio.

[12]**Tejendra Tank, C D Modhera (2017)** In this paper the detailed analysis on retrofitted RC Slab strengthened with GFRP in bidirectional is done. For the retrofitting work FRP is considered to be the best alternative. The effectiveness of FRP is improved by proper bonding on laminates. ANSYS Multi-Physics module under static structural analysis system was used. Conclusively, it gives an evident that analytical results show more correlation with the experimental results. Cracks are caused due to drying shrinkage. The deflection values shown by ANSYS are moreover similar to the experimental results. The flexural capacity of the slab increases by lamination of GFRP.

[13]**Ben Abey Alex, Ben Abey Alex (2018)** Structural performance, availability and applicability makes FRP laminates most preferred item as a rehabilitating material for RC elements. The main objective of this project is to study the GFRP sheet effects with arrangements as strengthening technique for RC slabs. Glass fibre reinforced polymers is the simplest and modest method for retrofitting. The experimental and nonlinear Finite Element analysis concludes that the strengthening of slabs with CFRP increases the flexural strength. The load versus Deflection curve was plotted. It proves that Strip shape lamination is more efficient than full lamination i.e, less deflection is noted in strip shape lamination. The load carrying capacity increases in strengthened RC slabs.

[14]**Agnieszka Wiater, Tomasz Siwowski (2020)** In this, the major part is the comparison between the Normal concrete slab and Light weight concrete slabs. It aimed in evaluation of the static performance of LWC slabs reinforced with GFRP bars for flexure without shear reinforcement. It gives an evident that, GFRP reinforcement provision at compression zone can influence the slab performance. The important output of this research regarding limit state is there is no clear influence of the reinforcement ratio on the number of cracks. In the post cracking behaviour, the influence of reinforcement ratio is observed in the stiffness degradation. Furthermore, the reinforcement ratio increase in the LWC slabs resulted in different mode of failure: the slab with lower reinforcement ratio exhibited flexural failure and the slabs with higher reinforcement ratio exhibited shear failure. The research revealed the considerable differences between the test results and ACI code prediction, greater for the LWC slabs and much smaller for the NWC ones. Stiffness is decreased after the propagation of first crack. LWC fails in shear and NWC fails in flexure. Accurate analysis on the influence of some variables on the structural behaviour of LWC slabs reinforced with GFRP bars is still required. Thusby comparing both, NWC is better than LWC.

2.2 Review on Bond Behaviour

[3]**Kasumassa Nakaba, Toshiyuki Kanakubo, Tomoki Furuta, and Hiroyuki Yoshizawa (2001)** The anchorage between concrete and FRP laminates plays an important role in design of reinforcement. Since FRP is a brittle material it lacks in ductility. After yielding the failure was startedThe main purpose of this research is to propose a bond stress- versus-slip model that can provide the effective bond length and the bondstrength for externally bonded FRP laminates to concrete. To reach this objective, double-face shear type bond test is conducted. A numerical analysis is also performed to compare the proposed model with experimental results. In this research, a local bond stress – slip model was proposed. This paper gives information about the evaluation of the effective bond length, Load – displacement relationships, Strain distribution and when the stiffness of FRP increases, the load carrying capacity is increased.

2.3 Review on Failure Modes

[5]**Oral Buyukozturk, Oguz Gunes, Endem Karca (2004)** In this paper they gives an idea about the debonding failure progress in the structural member. Failures in FRP strengthened RC and steel flexural members may occur. Debonding happens in regions of high stress concentrations, which regularly related with material discontinuities and crack propagation. Conclusively we can say that, debonding failure leads to major decrease in strength of the FRP member. Experimental and theoretical research on cyclic load performance of FRP strengthened RC and steel members has been done to check the parameters. Installation quality should be checked. Various loadingeffects such as cyclic loading effects, environmental effects are tested. So, proper characterisation of this problem should be analysed.

[7]**Walid Elsayed; Usama A. Ebead; and Kenneth W. Neale, M.ASCE (2007)** In past decades, theoretical analysis that properly account for the interfacial behaviour between the concrete and bonded FRP are lacking. Subsequently in this paper, theinterfacial conduct between the FRP laminates and the concrete is represented by presenting suitable slip models for the interface in a nonlinear analysis. The numerical analysis is carried out using the FE software ADINA. A finite-element mesh is used for this work. The various strengthening configurations considered. Conclusively, this suggests that a punching shear failure associated with debonding of the FRP material initiating in the central region of the slab. In the examination, the beginning at the point of bonding surface occurs when the local slip becomes equal to the parameter. The mathematical examinations gave helpful understanding into the impacts of different parameters. This study gives various alternative strengthening techniques for the performance of the member. The provision of transverse anchorage laminates at the ends of the FRP strips could be an effective means to enhance bond behaviour.

3. Conclusion

From these studies, the use of FRP as strengthening materials has been gaining the interest of many researchers. FRP is a composite system composed of a matrix of polymer strengthened with fibres. They are generally used as an effective alternative.

- Generally, this material is selected mainly used to strengthen any concrete member.
- FRP laminate provision at tension side increases the strength of the member.
- [14]The work on Slab laminated with GFRP is limited, because of its delamination failure. Hence beams and columns are widely used. This is mainly due to insufficient development length at its ends.[10]Thus provision of U-strips as the wrap in the member decreases thedelamination failure.
- [7]FRP bars increases load carrying capacity than conventional steel bars.

Future Scope

Furthermore,

- The usage of external bonding of GFRPin number of layers in a traditionalreinforced concrete slab will be a newattempt to examine the strength of theslab.
- Proper delamination designs shouldbe considered.
- Research on experimental studies on debonding failures in FRP strengthened members should be developed.

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