An Analytical Study on Flexural Behavior of Concrete using Glass Fiber Reinforced Polymer Bars

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Abstract - *Glass fiber reinforced polymer (GFRP) bars are now attracting as an alternative reinforcement in concrete beam because of their high resistance to corrosion that is a major problem for steel bars. A concrete beam is a structural element which carries load primarily in bending. Bending phenomenon causes a beam to undergo in tension and in compression. Beams carry vertical gravitational forces and can also be used to carry horizontal loads. These loads carried by beam are transferred to foundation. The beam compression section is designed to resist buckling and crushing, and tension section is designed to resist tension or flexure. Understanding the behaviour of concrete beam during loading is crucial for the development of an overall efficient and safe structure. This study presents the results of the comparison made between the predicted and the measured load – deflection relationship for finding flexure strength by modeling of 12 concrete beam reinforced either by steel or GFRP bars. ANSYS 14.0 is used for modeling and analyzed the results obtained from the ANSYS 14.0 were compared with the theoretical.*

Key Words: GFRP, ANSYS, fibre-reinforced polymer, flexural capacity, crack width, deflection, failure, one point loading, two points loading, IS 456:2000

1.0 INTRODUCTION

Reinforced Concrete has become one of the most important building materials and it is widely used in many types of engineering structure. The economy, the strength, the efficiency and the stiffness of reinforced concrete make it attractive material. Glass Fibre Reinforcement Polymer (GFRP) bars are becoming the wave of the future due to their resistance to corrosion, high strength to weight ratios and the ability to handle the material with such simplicity. Glass Fibre - reinforced polymers (GFRP) are non - metallic reinforcement utilizing high performance hybrid, the surfaces of the rods are treated with undulations to provide mechanical interlock with concrete. Their application is seen primarily as a means to avoid corrosion problems encountered in concrete structures when using conventional steel as reinforcements. Keeping this in mind, the present research was planned to study the flexure behaviour of concrete using GFRP bars.

2.0 LITERATURE REVIEW

After study various research papers which has been related to flexural strength of concrete and GFRP bars. Also methodology and conclusions are discussed.

2.1 Saleh Hamed Alsayed (1997) – In this paper, analyzed Flexural Behaviour of Concrete Beams Reinforced with GFRP Bars. GFRP-RC beams designed to fail by crushing of concrete, the beam capacity in flexure can be reasonably estimated using the ultimate design method for over-reinforced sections. However, the deflection at service load for such beams may control the design of many types of FRP-RC structures. The average ratio of the measured service load deflection of GFRP-RC beams to that of steel-RC beams of the same ultimate flexural capacity and the same dimensions is about 2. The load-deflection relationship for steel- RC beams underestimates the actual deflection of GFRP-RC beams. The error in predicting the actual service load deflection of the GFRP-RC beam is about 70%. Therefore, until more data become available it should not be used for FRP-RC beams. Considerding a factor of safety of 1.5 against the possibility of tensile failure of GFRP bars Concrete beams reinforced with GFRP bars assures a relatively gradual type failure of FRP-RC beams due to concrete compression failure rather than a catastrophic failure due to rupturing of the FRP bars.

2.2 VG Kalpana and K Subramanian (2011) – They analyzed Behavior of concrete beams reinforced with GFRP BARS. The GFRP bars embedded in the high strength concrete show a better performance compared to bars within the normal strength concrete, in terms of deflection and load-carrying capacity due to its high tensile strength. The reduction in stiffness of the GFRP bars results in an increased crack width. As the concrete strength increases, the changes in ultimate crack widths are relatively small. The general behavior of the FE models represented by the load-deflection plots at mid span shows a good agreement with the test data. The effects of bond slip (between the concrete and reinforcing bar) and micro-cracks occurring in the actual beams were excluded in the FE models, contributing to the higher stiffness of the FE models.

2.3 G B. Maranan ,A C. Manalo ,W Karunasena ,B Benmokrane and D Lutze (2014)- In this paper, Flexural behaviour of glass fibre reinforced polymer(GFRP) bars subjected to elevated temperature. The temperature increases, the flexural strength and stiffness of the GFRP bars decreases. The bars with a larger nominal diameter showed better flexural strength decay resistance than those with a smaller nominal diameter at elevated temperatures.

2.4 Joshi A. A.,Dr. Rangari S. M., and Shitole (2014)- In this paper, basically focus on flexural strength they used Basalt Fibers to improve the Flexural Strength of Concrete Beam. They finding the workability of concrete significantly reduced as the fiber dosage rate increases. The flexural test showed that as the basalt percentage increases up to 0.07% flexural strength of Beams goes on increasing and after that from 0.07% again it goes on decreasing. The usages of fibers were fully utilized when it comes to post-cracking stage, as it increase on ductility and toughness of concrete.

2.5 Sudhir P. Patil , Keshav K. Sangle (2015)- They analyzed the Shear and flexural behaviour of pre-stressed and non-pre-stressed plain and SFRC concrete beams. Concluded that the load carrying capacity of steel fibre reinforced concrete beam specimens were more than the plain concrete beam specimens by approximately 30–50%. The use of steel fibres in a concrete mix was found to increase the crack resistance of the beams.

2.6 Thong M. Pham and Hong Hao (2015)- Review of Concrete Structures Strengthened with FRP Against Impact Loading. They concluded that the FRP materials can be used to improve the impact resistance of RC structures including beams, slabs, columns and masonry walls. They lead to an increase in the load carrying capacities, ductility and energy absorption. The tensile strength of FRP materials increases as the strain rate increases while a conclusion on the failure strain and stress–strain relation could not be made.

2.7 Abdelmonem Masmoudi , Mongi Ben Ouezdou And Mohammed Haddar (2016)- In this paper, analyzing Mode of failure for reinforced concrete beams with GFRP bars. Find the concrete beam reinforced with GFRP sections experienced a lower load carrying capacity and stiffness compared with the conventional reinforced concrete beam. The number of cracks for the beam reinforced with GFRP section was higher than in the conventional beam. The GFRP reinforced concrete beams fail either by concrete crushing at the compression zone or rupture of the GFRP reinforcement. Failure due to rupture of GFRP reinforcement is not recommended since it may result in catastrophic failure of the structure.

2.8 Yehia A. Zaher Ali (2017) - In this paper, mainly analyzed the composite beam and find their stiffness and load capacity. They analyzed the Flexural behaviour of FRP strengthened concrete-wood composite beams. This study shows that timber web can be successfully used for the manufacture of concrete-timber composite beams since it contributes in providing higher stiffness and load carrying capacity.

2.9 Mayur A.Patil, Prof.P.M.Kulkarni (2017) - Experimental Investigation of Mechanical Properties of Partially Pre-stressed Fiber Reinforced Concrete. Results indicate that addition of steel, glass and polypropylene fibers to the concrete beams greatly increase the Flexural strength of beam for both types of loading, i.e, single point loading and double point loading. Testing indicate that among the three fibers, i.e., steel, glass and polypropylene, polypropylene reinforced concrete beams gives the lowest deflection for a particular value of load. The use of polypropylene fiber in prestressed concrete enhances the mechanical properties like early compressive strength, flexural strength and improves the durability properties.

2.10 T.P. Meikandaan and Dr. A. Ramachandra Murthy Senior Scientist CSIR (2 Feb, 2017)- Flexural behaviour of reinforced concrete beam wrapped with Glass fibre reinforced polymer sheets. In this paper, analyzing the ultimate load carrying capacity of the strengthened beam is 14 % more than the controlled beam. 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. 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 t o invisibility of the initial cracks, it gives less warning compared to the beams strengthen only at the soffit of the beam. Use of FRP laminate improves load carrying capacity; delays crack formation and energy absorption capability of beam reinforced with FRP laminates. The 70% damage degree beams increases load carrying capacity 14% when strengthened with 100 mm width and 1.2mm thick of GFRP sheet in single layer for bottom full as compared with control beam.

2.11 Yuvasankar. R, Dr. Nandini Devi. G (2 April, 2017)- Experimental Study on GFRC Beam Reinforced With GFRP Rebar Under Flexure . In this paper, concluded that The maximum compressive strength of GFRC is 6.3% greater than conventional concrete. The maximum split tensile strength of GFRC is 19.8% greater than the value of conventional concrete. The maximum flexural strength of GFRC is 11.43% greater than the value of conventional concrete. The load carrying capacity of GFRC with GFRP beam was found to be 35.09% greater than the value of conventional concrete beam. The value of GFRC with GFRP beam for load Vs deflection is about 27.33mm greater than conventional concrete beam which is 16.36mm.Ultimate moment of GFRC with GFRP beam is 85.64 KN-m greater. when compared to the conventional concrete beam which is 63.36 KNm. Replacement of steel rebar with GFRP rebar beam has shown better result in flexural load carrying capacities. Ductility of GFRC with GFRP beam is 0.118 smaller than the value of conventional concrete beam which is 0.166.

2.12 Koothan Baskar, G. Elangovan, K. Mohan Das (2018) - Flexural Behaviour of Fibre Reinforced Concrete Beams with Different Aspect Ratios . The average compressive strength (28 days) of the control cubes is 32.44 N/mm2, compared to a strength increase of 4.3 N/mm2, a percentage rise of 11.8%, for wrapped specimens. The average split tensile strength (28 days) of the control cubes is 4.60 N/mm2, as compared to the strength increase of 0.43 N/mm2, a rise of 8.7%, for wrapped specimens. Flexural strength (modulus of rupture) is increased by 25.85% for 1% (0.75% of steel and 0.25% of polypropylene) of the total volume of concrete.

2.13 Shivapooja Vivek, T.Dhilip, B.Vijaya Prasad, Dr. L. Sudheer Reddy(2018) - Study on the effect of using Glass Fiber Reinforced Polymer bars as main Reinforcement in Beams. The experimental value of moment of resistance of the beams reinforced with steel bars is 53.29% higher than that of the theoretical value. The experimental value of moment of resistance of the beams reinforced with steel bars is 12.2% higher than that of the theoretical value. The load carrying capacity, Moment of Resistance, and flexural strength of the GFRP bars reinforced beams is 31.5 % lesser than that of the Steel bars Reinforced beam. The Deflection of GFRP bars reinforced beams is 14.9% lesser than that of the Steel bars Reinforced beam.

2.14 A. Sagaya Bastina , M. Renganathan Student (2018) - Flexural Behaviour of Concrete Beams with Glass Fiber Reinforced Polymer Rods . GFRP bars tensile strength was calculated by UTM machine. GFRP bars tensile strength more than the HYSD bars. Poisson's ratio and tensile modulus values are within the permissible limits. Deflection values are low for Glass Fiber reinforced polymer bars compared to normal High Yield strength bars of Grade 500 depends upon the Load by using loading frame machine. 7 days and 28 days strength were calculated and compared the strengthened beams. GFRP reinforced beams have more strength than HYSD reinforced beams.

2.15 Cene KRASNIQI, Naser KABASHI, Enes KRASNIQI and Vlorian KAQI (7 May, 2018) - Comparison of the behavior of GFRP reinforced concrete beams with conventional steel bars . They concluded that the effect of the low modulus of elasticity of the GFRP bars was evident in an early crack initiation in the beams reinforced with the GFRP compared with conventional reinforcement. The crack width is related to the ratio: load-bearing of 36% starts from value of deformations 0.015 mm - 0.804 mm and then linearly increases to reach the maximum value of 0.473 mm - 1.581 mm at the ratio of 72%. The average deflection increases as a function of the ratio: load-bearing starting to deflection from the 0.758 mm steel bars to 6.333 mm GFRPs for a ratio 72%. This is a result of the modulus of elasticity and bonding parameters in concrete; A non-linear finite element analysis with software ATENA yields results for the ratio similar to the experimental examinations in comparison with other methods. The failure of the GFRP reinforced concrete beams is mainly due to its reduced post cracking stiffness and the slip between the rebar and concrete matrix.

2.16 Nawal kishor Banjara , K. Ramanjaneyula (2019) - Investigations on Behavior of Flexural Deficient and CFRP strengthened reinforced concrete beams under static and fatigue loading. It is found that load carrying capacities of 20% and 30% flexural deficient RC beams are around 8% and 20% respectively less than that of control beam. The fatigue lives of flexural deficient RC beams strengthened with one layer of CFRP fabric (SFD1 and SFD2) are increased beyond that of control beam. One layer of CFRP fabric has improved the load carrying capacities of flexural deficient RC beams FD1 and FD2 by 17.27% and 31.77% respectively.

2.17 P.M. Stylianidis and M.F. Petrou (2019) - Study of the flexural behavior of FRP-strengthened steel-concrete composite beams. They concluded that the FRP-strengthening effects should be restricted to some specified limits. The decrease in the beam maximum curvature should not exceed 50% of the original value.

2.18 Yaqiang Yanga,Mohamed F.M. Fahmyb, Jing Cuid, Zhihong Pana , Jianzhe Shie (2019)- Nonlinear behavior analysis of flexural strengthening of RC beams with NSM FRP laminates. The load-deflection response of RC beams strengthened with the CFRP laminates was predicted. The full range load-deflection responses comparison of the prediction result and test result shows that the average comparative error was less than 20%.

2.19 Huazhe Jiao, Yachuang Wu , Xinming Chen, and Yixuan Yang (2019) - Flexural Toughness of Basalt Fibre-Reinforced Shotcrete and Industrial-Scale Testing. The flexural strength at day 7 and 28 increased 2.5%–9.8% and 1.6%–6.8%, respectively, at a fibre dosage of 1.5–7.5kg/m3. The BF can significantly increase the residual stress under the same deformation. There is a clear trend in the flexural toughness, increasing to a peak followed by a declining curve with the BF dosage. The dosage range of 3–4.5kg/m3 demonstrates acceptable beneficial effects regarding the BFRS performance. The total porosity ranges from 1.92% to 3.02%, increasing with the BF dosage.

2.20 Cristina Barris , Pau Sala, Javier Gómez and Lluís Torres (2019) - Flexural behaviour of FRP reinforced concrete beams strengthened with NSM CFRP strips. The load-deflection behaviour of NSM strengthened beams internally reinforced with GFRP bars presents a practically linear curve, only becoming slightly non-linear at high loads owing to the non elastic behaviour of concrete at different strain levels.

2.21 Geosciences, Delft (2019) - Experimental and analytical studies on shear behaviors of FRP-concrete composite sections. The shear failure mode of FRP-concrete composite sections is brittle and characterized by the fracture along the horizontal direction at FRP webs or the upper web-flange joint.

2.22 Achudhan ,Deepavarsa ,Vandhana and Shalini (2019) - Strengthening and Retrofitting of RC Beams Using Fiber Reinforced Polymers. FRP'S were able to take more loads. Therefore, the strength of retrofitted beams are more than that of control beams. The stiffness of the GFRP-retrofitted beam is increased 59% compared to that of the control beam.

2.23 Hesham A. Haggag and Mostafa M. Abd Elsalam (2020) - Flexural Behavior of Two-way Solid Slabs Reinforced with GFRP Bars . Slabs reinforced with GFRP bars with thickness of 70 mm achieved the ultimate load of the control specimen (steel bar reinforcement) by increasing the reinforcement ratio by 77%.Slabs reinforced with GFRP bars with thickness of 70 mm achieved the displacement at the service loads of the control specimen (steel bar reinforcement) by increasing the reinforcement ratio by 22%.Crack pattern for slabs reinforced with GFRP bars has better distribution with increasing the reinforcement ratios. · GFRP bars in the tested reinforced slabs did not fail in rupture so crushing of concrete forms the mode of failure.In GFRP slabs increasing slab thickness by 1cm, the ultimate capacity is increased by about 10% with the same reinforcement ratio of about (0.53%).

2.24 Syed Basharat Pasha, Dr. R. B. Khadiranaikar (2020) - A Study on Flexural Behavior of High Performance Concrete Beams using ANSYS . Reinforced concrete beam can be modeled and analyzed using ANSYS software and obtain correct results and can be best alternative for laboratory tests. When steel plates at loading points and support conditions is removed, results are not accurate. The beam without steel plates shows inaccurate results. Hence for accurate analysis in modeling steel plates are to be included. When single point loading is applied, induced compressive stresses are increased in by 46.42%. Tensile stresses and deflections are increased by 20%. In case of uniformly distributed loads stresses and deflections are reduced by 75% compared to two point loading. Steel reinforcement and grade of concrete effects the deflection as the amount of steel reinforcement and grade of concrete increases, deflection decreases slightly.

2.25 Cristina Barris, Pau Sala, Javier Gómez, Lluís Torres (2020) - Flexural behaviour of FRP reinforced concrete beams strengthened with NSM CFRP strips. For the case of beams internally reinforced with steel bars, the flexural capacity of the beam increases almost linearly with the internal reinforcement ratio and the concrete strength. For beams internally reinforced with steel bars with the highest concrete strength (fc = 50 MPa) and strengthened with NSM CFRP with a modulus of elasticity of 180GPa and a tensile strength of 1800 MPa, the failure mode changes from concrete crushing to CFRP failure. Due to failure of concrete an increase of the concrete strength, the GFRP modulus of elasticity or the NSM CFRP reinforcement ratio implies an increase of the flexural capacity.

2.26 R. Abirami, S.P. Sangeetha (2020) - Study on fiber reinforced concrete beam-column connection . Results shows the physical and Mechanical Properties of Natural and Synthetic fibers varies from fiber to fiber. The presence of fiber in concrete helps to reduce the crack width and lesser damages to the fibrous specimen. The natural and synthetic fiber reinforced concrete beam column joints increases the ultimate load carrying capacity, stiffness, ductility and energy absorption capacity than that of conventional RC specimen.

2.27 Rabee Shamassa, K.A. Cashellba (2020) - Experimental investigation into the flexural behaviour of basalt FRP reinforced concrete members. The tests have generally shown that the members with BFRP bars perform very well, and provide a valid and durable alternative to traditional CSRC. In the analysis of the test results presented herein, particular attention was given to the overall load–deflection relationship as well as the cracking moment, bending moment capacity, deflections and the crack opening width at service loading.

2.28 Ali Raza , Umer Rafique (2020) - Efficiency of GFRP bars and hoops in recycled aggregate concrete columns: Experimental and numerical study. The axial compressive strength of GRAC columns was less than that of SRAC columns by an average difference of 7.79%. The failure modes were the same for both GRAC as well as SRAC columns. The area of failure was mostly the top or bottom half region of concentrically loaded columns while the eccentrically loaded columns failed in the middle portion. The average ductility index 4% greater than the ductility index of SRAC columns. The axial strength increased with a percentage of 3.80% and 7.15% for GRAC and SRAC concentric columns, respectively when the stirrup spacing was reduced from 150 mm to 75 mm, respectively.

2.29 Rizwan Karim, Behrouz Shafei (2020) - Performance of fiber-reinforced concrete link slabs with embedded steel and GFRP rebars . The FRC link slab reinforced with steel rebars provided an ultimate capacity of 991.1 kN . The link slab remained elastic up to 444.8 kN . The recorded load–deflection and the load–strain curves showed a smooth trend during loading and unloading. The GFRP-reinforced FRC link slab showed an ultimate capacity of 1033.8 kN. The load–deflection and the load–strain curves showed a trend similar to that observed in the steel-reinforced FRC link slab during both loading and unloading.

2.30 M.Vadivel, Dr.J.Brema (2020) - Flexural Behaviour of Hybrid fiber Reinforced Concrete Beams Under Cyclic Loading. While applying the load on the beams, the deflection in each beam for varying mixes increases with increase in the ultimate load. The hybridized beam specimen with combination of 0.5% steel fibre and 0.5% polypropylene fiber has maximum deflection compared to other mixes. The analytical deflection of M6 mix is 8.63% higher than the experimental deflection of the beam specimen. On analyzing the load deflection results, it was found that the analytical results is higher than the experimental results obtained. On analyzing the cracking load, it was concluded that the fiber bridging inside the specimen increases the load carrying capacity.The load carrying capacity of M6 mix is 14% higher than the conventional mix. The ductility factor of mix M6 is maximum which 56% higher than conventional mix.

2.31 Mahdi Nematzadeh , Saber Fallah-Valukolaee (2020) - Experimental and analytical investigation on structural behavior of two-layer fiber-reinforced concrete beams reinforced with steel and GFRP rebars. The flexural loading capacity of the beams increased with the increasing volume fraction of fibers, and the ductility and post-peak response also saw a significant improvement. Moreover, the flexural load-carrying capacity of the two-layer concrete beams increased with increasing reinforcement ratio, while it experienced a reduction by replacing the steel rebar with GFRP rebar. The ductility index of the beam specimens increased as a result of introducing steel fibers in the concrete mix, due to enhanced post-peak behavior, with an increase of 118 and 94% in the ductility index of the specimens.

2.32 Muayad M . Abdullah, Hassan F. Hassan (2021) - Flexural behavior of Normal and High strength continuous beams reinforced by GFRP bars. Increasing the reinforcement ratio from ($\rho fmin$) to (ρfb), leads to increase the ultimate capacity by (13, 32 and 42) %, for beams with $f'c$ (30, 50 and 70 Mpa), respectively. Increasing (ρf) shows a major decrease in deflection at all loading stages.GFRP bars reinforced continuous beams with collapsed by crushing of concrete, meanwhile they were over-reinforced designed, whereas the under-reinforced beam failed by rupture of GFRP bars. The cracks size was significantly decreased with increasing in reinforcement ratio, at the same load level.

2.33 Michał Barcikowski , Grzegorz Lesiuk , Karol Czechowski and Szymon Duda (2021) - Static and Flexural Fatigue Behavior of GFRP Pultruded Rebars. The elastic modulus of GFRP rebars is significantly lower than for steel rebars. It is worth underlining the higher static flexural properties of GFRP materials than high-quality fe500 steel. In comparison with steel rebars the obtained results for GFRP are comparable in the HCF regime. It is worth noting that in near fatigue endurance regime (2–5 × 106 cycles) both rebars exhibit similar behavior. Further studies considering the environmental influence on fatigue endurance both GFRP and steel rods are necessary regarding the possible anti-fatigue design of the geometry of the rebars using pultrusion process in order to redistribute damage stress in the outer part of the composite rods.

2.34 Tae- Kyun Kim ,Jong-Sup Park, Sang-Hyun Kim and Woo-Tai Jung (2021) - Structural Behavior Evaluation of Reinforced Concrete Using the Fiber-Reinforced Polymer Strengthening Method . The strain of the steel bar was 0.002, whereas the compressive failure strain of concrete for the prevention of brittle failure was 0.003. Thus, with respect to the strain of the steel bar, the one specimen demonstrated the highest yield strength of 270 KN, while other exhibited the lowest yield strength of 154.2 KN. The ductility index based on the deflection and the ductility based on the energy ratio have similar trends. The EP (External pre-stressing) and EB (External boding) methods failed the structure immediately after yielding, whereas the NSM method showed sufficient ductility after yielding.

3.0 CONCLUSIONS

After reviewing a lot of research papers that are based on the using GFRP bars in concrete structure component many papers found that concrete failure , comparison of results, compare with experimental results and describes its properties and crack pattern.

After that we concluded for further work on the basis flexure strength of concrete using GFRP bars following are conclusion:-

1. The load carrying capacity, Moment of Resistance, and flexural strength of the GFRP bars reinforced beams is 31.5 % lesser than that of the Steel bars Reinforced beam.
2. The Deflection of GFRP bars reinforced beams is 14.9% lesser than that of the Steel bars Reinforced beam.

3. Deflection obtained using ANSYS 14.0 are in good agreement for lower and higher range of load values.
4. Beam strengthened with GFRP strip exhibited relatively good ductile behaviour. All beam exhibited ductile failure modes.
5. Strengthening and retrofitting of reinforced concrete beams by GFRP strips is effective technique.
6. For analysis ANSYS 14.0 software can be used.
7. Fibrous material can reduced cracks width and control crack width tightly which develop due to environment effect or any other. Improve in flexural behavior.

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