International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 10 Issue 4 ǁ 2022 ǁ PP. 58-62

A Review on the Flexural Behaviour of RC Beams Reinforced with Steel and GFRP Bars

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Abstract
Nowadays, the construction industries around the world face a major problem due to corrosion of steel reinforcement. Glass Fibre Reinforced Polymer (GFRP) rebar emerged as a promising alternative to traditional steel reinforcement with excellent results in terms of corrosion resistance. The unique advantages of GFRP materials such as excellent resistance to corrosion, high strength to weight ratio, electromagnetic neutrality and ease of handling make these materials potentially suitable for the use in reinforced concrete under conditions where conventional steel reinforced concrete has resulted in unacceptable serviceable problem. This paper summarizes the most significant research work published on the flexural behaviour of Reinforced Concrete (RC) beams. A comprehensive review of the literature on the flexural behaviour of RC beams reinforced with steel and GFRP bars subjected to static and cyclic vertical loads.

Keywords: *Flexural strength, GFRP bars, RC beam, Flexural behaviour.*

Date of Submission: 06-04-2022 Date of acceptance: 22-04-2022

I. INTRODUCTION

Fibre-reinforced polymer (FRP) bars are being increasingly used in concrete structures due to their light weight (1/4th weight of steel rebar), high stiffness to weight ratio, ease of handling, lower maintenance cost, lower transportation fee, easy cutting, proper bonding to concrete. Tensile strength of FRP rebar is typically 1.5 to 2 times greater than steel. The FRP is made of continuous fibre filaments embedded in resin matrix to form various shapes such as bars, structural sections, plates and fabric. Now a days, FRP bars are available in glass, carbon, and aramid fibres and as hybrid rods with the combination of fibres. One of the most commonly used composite rebars are glass fibre reinforced polymers (GFRP) bars mainly due to their relatively low cost combined with good performance. The mechanical properties of the GFRP bars are better than those of steel bars in several ways. The benefits of GFRP rebar are high corrosion resistance, superior tensile strength, electric and magnetic neutrality.

II. LITERATURE REVIEW

2.1 FLEXURAL PERFORMANCE

This section focuses on past research performed on the flexural behaviour of GFRP reinforced concrete beams. The flexural behaviour including the load-deflection relationship, the flexural capacity, the stiffness, and mode of failure is discussed.

Leung and Balendran (2003) performed an experimental study on flexural behaviour of concrete beams internally reinforced with GFRP rods and steel rebars. It was found that GFRP bars showed improved flexural strength. The flexural strength also improved when used as hybrid reinforcement. For hybrid reinforcements, an increase in the amount of GFRP rods can provide enhancement in the load carrying capacity. Increase in concrete strength causes increase in both flexural and shear capacities, but the increase in flexural capacity is found to be larger than that in shear capacity.

Sam and Swamy (2005) experimentally investigated the flexural behaviour of concrete beams reinforced with Glass Reinforced Polymer bars. This paper presents the flexural behaviour of concrete beams reinforced with GFRP and stainless steel bars. Performance of the GFRP reinforced concrete beams improved when stainless steel mesh used as shear reinforcement. The use of stainless steel mesh as shear reinforcement proved to be beneficial in enhancing the stiffness, ultimate load, and cracking performance of the GFRP reinforced concrete beam.

Ashour (2006) presented the flexural and shear capacities of concrete beams reinforced with GFRP bars. All beams had no transverse shear reinforcement. Under-reinforced beams failed in flexural mode due to GFRP bar rupture whereas shear failure occurred for over-reinforced beams. A simplified method for predicting the flexural capacity has been developed and validated against experimental results presented. The proposed method provided good correlation with test results.

Devi (2015) investigated the flexural behaviour of concrete beams reinforced with Gfrp reinforcements. The ultimate load of GFRP beam is higher than steel beam. Load carrying capacity of GFRP bar reinforced beam is 1.5 times higher than steel beam. When compared to standard steel rebar, the initial cost of GFRP rebar is found generally higher and is roughly comparable to epoxy-coated steel rebar. But on life cycle cost (LCC) basis it can be quite economical and performs better than steel rebar.

Masmoudi et.al (2016) studied the mode of failure for reinforced concrete beams with GFRP bars. The modes of failure for beams reinforced with GFRP sections were slightly different compared with the control beam. The GFRP reinforced concrete beams fail either by concrete crushing at the compression one 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.

Goldston et.al (2016) made experimental investigation of the behaviour of concrete beams reinforced with GFRP bars under static and impact loading. The failure mode of GFRP RC beams can be accurately predicted from sectional analysis used for traditional RC beams. Effect of concrete strength was shown to be more prominent in reducing midspan deflection and increasing post-cracking bending stiffness. Resistance of GFRP RC beams under impact loading have been observed to be controlled by inertia forces at first contact before beam flexural behaviour starts contributing to resisting the impact load. Thus, the geometrical properties of the beam, as well as the total mass are major factors in resisting dynamic forces.

Nemr et.al (2018) Evaluated the flexural strength and serviceability of concrete beams reinforced with different types of GFRP bars. The beams showed typical bilinear behaviour for strain and deflection until failure. When the mechanical properties and surface profile of GFRP are maintained, using smaller diameters enhances the strain and cracking behaviour. Smaller GFRP bars exhibit smaller strains and narrow crack widths than larger bars due to limiting bar spacing, which controls crack propagation. The cracking behaviour of the tested beams tends to confirm that sand-coated GFRP bars provide better bond performance than helically-grooved GFRP bars because of the uniform surface and the absence of discontinuity points.

Dybel et.al (2020) made analysis of flexural strength of beam elements reinforced with GFRP bars. The reinforcement ratio had a significant impact on the failure mechanism and the flexural strength of bent concrete elements reinforced with GFRP bars. An increase in the reinforcement ratio in the studied scope resulted in a clear increase in the section's flexural strength. This increment was of a linear dependence character. The nominal flexural strength values determined according to ACI recommendations were, on average, 7% lower than those obtained experimentally. The ACI standard provides conservative flexural strength values which are further decreased by safety factors.

Sirimontree et.al (2021) conducted experimental study on the flexural behaviour of concrete beam reinforced with GFRP bars compared to concrete beam reinforced with conventional steel reinforcements. The maximum load of concrete reinforced with steel bars tended to increase as the steel strength increased. The maximum load of beams increased up to 69%. The maximum load of the concrete beams reinforced with GFRP bars was greater than that of the beams reinforced with steel bars with Grade SD30 and Grade SD40 about 98% and 17% respectively.

The results show that the GFRP reinforced beams exhibit increased flexural strength and it also improved when used as hybrid reinforcement. Increase in concrete strength causes increases in both flexure and shear capacities.

2.2 FATIGUE PERFORMANCE

Bridges, concrete pavements, marine structures and railways are exposed to at least several-million-times repeated load during their lifetime and are likely to affected by the fatigue failure caused by repeated loads rather than by static failure. Therefore, to secure safety and availability against fatigue during the lifetime of a structure, the fatigue characteristics must be applied to design and analysis of the FRP rebars.

Sim et.al (2009) made study on the flexural behaviour of concrete beams reinforced with GFRP rebars under fatigue. The fatigue performance of the concrete beam reinforced with FRP rebars was similar to that of the concrete beam reinforced with the existing reinforcing bars, which indicates that the FRP rebar has a reinforcing effect that is strong enough to merit its replacement of the reinforcing steel bar. As for the physical characteristics of the FRP rebar, however, the behaviour and failure type of the concrete structure differed, which indicates that studies on the appropriate reinforcing ratio are needed according to the type of FRP rebar used.

Xu et.al (2019) presented fatigue flexural analysis of concrete beams reinforced with hybrid GFRP and steel bars. The parametric study was performed with the proposed model. With the increase of load amplitude, reinforcement strains and concrete strains increase, and the fatigue life reduces significantly. With the increase of effective reinforcement ratio, reinforcement strains decrease, concrete strains increase, and the fatigue life increases. With the increase of area ratio of FRP to steel bars (A_f/A_g), reinforcement strains and concrete strains increase and the fatigue life decreases.

The fatigue performance of the concrete beam reinforced with FRP rebars were similar to that of the concrete beam reinforced with the existing reinforcing bars, which indicates that the FRP rebar has a reinforcing effect that is strong enough to merit its replacement of the reinforcing steel bar.

2.3 LOAD-DEFLECTION BEHAVIOUR

This section focuses on the effects of concrete strength and the reinforcement ratio on the bahaviour of concrete beams reinforced with GFRP rebars. The results of load-deflection and load-crack width characteristics are discussed.

Saikia et.al (2006) experimented the strength and serviceability performance of beams reinforced with GFRP bars in flexure. Addition of polypropylene fibers had marginal effect on the post cracking behaviour of the GFRP reinforced beams. An analytical model has been proposed for strength assessment. An empirical model has been proposed for predicting the maximum width of cracks. The load deflection response of the various GFRP reinforced beams have been predicted and seems to closely predict the corresponding experimentally observed response.

Barris et.al (2008) conducted experimental study of flexural behaviour of GFRP reinforced concrete beams. A good repeatability in deflection behaviour for each couple of identical beams is observed. The experimental moment-curvature relation fits reasonably well Eurocode 2 approach. The experimental crack width fits well with the minimum crack width predicted by ACI 440.IR-06, which proves good bond between concrete and the bars used in the experimental programme.

Shin et.al (2009) determined the performance of concrete beams reinforced with GFRP bars. The behaviour of beams reinforced with GFRP bars is bilinearly elastic until failure. To ensure adequate flexural stiffness for deflection, the flexural design of FRP reinforced concrete beams requires over-reinforcement. As the concrete strength and the reinforcement ratio increase, the flexural capacities of the tested beams increase, but the increase is limited by the concrete compressive failure strain of over-reinforced concrete beams.

Ascione et.al (2010) investigated the flexural behaviour of concrete beams reinforced with GFRP bars. The moment-curvature relation of FRP reinforced members is basically linear in both the pre-cracked and post-cracked phases, no relevant tension stiffening contributions appear. Neglecting effects of tension stiffening in calculating the deflection of flexural members leads to results in good accordance with experimental data.

Issa and Elzeiny (2011) investigated the flexural behaviour of cantilever concrete beams reinforced with glass fiber reinforced polymers (GFRP) bars. The area of the GFRP reinforcement has a small effect on the load-deflection relation up to close to the ultimate load. Utilizing the equation of Brown and Bartholomew for the effective moment of inertia gives the best deflection predictions for GFRP-reinforced cantilever beams.

Kalpana and Subramanian (2011) presented the behaviour 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 general behaviour of the FE models represented by the load-deflection plots at midspan shows a good agreement with the test data.

Roja et.al (2014) studied the flexural behaviour of concrete beams reinforced with GFRP bars. A reduction of 15.1 percent in ultimate load carrying capacity was found in beams with GFRP reinforcement when compared with the conventional beams with TMT reinforcement. Similarly, an increase in average deflection at the ultimate load to an extent of 54.2 percent was observed in beams with GFRP reinforcement when compared with the conventional beams with TMT reinforcement.

Murugan and Kumaran (2019) experimented on RC beams reinforced with glass fibre reinforced polymer reinforcements. The ultimate load carrying capacity of GFRP reinforced beams increases when increase in percentage of reinforcement when compared with steel reinforced beam. The number of cracks at ultimate load level is higher in sand coated GFRP beams when compared with grooved GFRP and steel reinforced beams. The grooved GFRP reinforced beams are found superior when compared to sand coated GFRP and conventional steel reinforced beams.

The GFRP bars embedded in the high-strength concrete showing better performance compared to bars within the normal strength concrete, in terms of deflection at each increment of the load. Increase in tension reinforcement leads to lesser deflection at ultimate in all the grades of the concrete.

2.4 EXPERIMENTAL AND ANALYTICAL STUDY

Experimental, numerical and analytical study of the flexural behaviour of concrete beams reinforced with glass fibre reinforced polymers (GFRP) bars are to be discussed.

Saraswathy and Dhanalakshmi (2014) proposed an analytical model to predict the flexural behaviour of GFRP reinforced RC beams. An experimental study was conducted to investigate the flexural behaviour of RCC beams using GFRP bars. The load deflection response of the various GFRP reinforced beams have been predicted and seems to closely predict the corresponding experimentally observed response.

Adam et.al (2015) made analytical and experimental flexural behaviour of concrete beams reinforced with glass fiber reinforced polymers bars. It can be considered a good agreement between the experimental results and the numerical analysis was achieved in terms of the predicted ultimate loads of the test specimens compared with experimental results. In addition, the numerical analysis reflected the significance of test parameters investigated on the load-carrying capacity.

Kabashi et.al (2017) presented the flexural behaviour of the concrete beams reinforced with the GFRP and crack analysis. This paper presents the methods for predicting deflections and crack widths in beams reinforced with GFRP. The moment-curvature relation of FRP reinforced members is basically linear in both the pre cracked and post-cracked phases during the analytical analyses and no relevant tension stiffening contributions appear. Experimental results substantially assess the reliability of the predicting formulae proposed in nonlinear analysis in software ATENA for both deflections and crack width.

Krasniqi et.al (2018) comparison of the behaviour of GFRP reinforced concrete beams with conventional steel bars. From the experimental and analytical work, it was found 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. A non-linear finite element analysis with software ATENA yields results for the ratio similar to the experimental examinations in comparison with other methods.

Shirmardi and Mohammadizadeh (2019) conducted numerical study on the flexural behaviour of concrete beams reinforced by GFRP bars. It was found that the numerical modelling approach presented in the current study is able to predict the flexural capacity FRP reinforced beams with a very high level of accuracy. The total load-deformation curve from the FE analysis is in good agreement with available experimental data.

Sethi et.al (2020) designed flexural members reinforced with GFRP bars. From the Analytical analysis, it is concluded that increase in reinforcement ratio in the flexural member increases the load carrying capacity of the member and it is recommended to design the GFRP RC structures as over-reinforced. The variation in theoretical and experimental results ranges between 18% to 25%. The GFRP reinforced concrete structure gives better performance with the high strength and ultra-high strength concrete. If the grade of concrete is increased then the ultimate load carrying capacity also increased.

From the Analytical analysis, it is concluded that increase in reinforcement ratio in the flexural member increases the load carrying capacity of the member and it is recommended to design the GFRP RC structure as over-reinforced. From the literature study, it is observed that hybrid reinforcement plays a significant role to enhance the bending strength in the concrete beams. It improves flexural strength.

III. CONCLUSION

Following are the major conclusions derived from the literature study,

- GFRP showed improved flexural strength and it also improved when used as hybrid reinforcement.
- Performance of the GFRP reinforced concrete beams improved when stainless steel mesh was used as shear reinforcement.
- Stainless steel mesh can be used to reduce the cracking of the GFRP reinforced concrete beam.
- The GFRP bars embedded in the high strength concrete show a better performance compared to bars within the normal strength concrete.
- Sand-coated GFRP bars provide better bond performance than helically-grooved bars.
- An increase in the reinforcement ratio resulted in a clear increase in the section’s flexural strength.

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