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# A Review on Shear Behavior of RC Beams Reinforced with Steel and GFRP Bars

C.S.Janani[1], Dr.S.Sidhardhan[2]
[1]*Post Graduate Student, Department of Civil Engineering, Government College of Engineering, Tirunelveli, Tamilnadu, India.*
[2]*Professor, Department of Civil Engineering, Government College of Engineering, Tirunelveli, Tamilnadu, India.*
*Corresponding Author: C.S.Janani*

***ABSTRACT:***
*As glass fiber reinforced polymer (GFRP) bars do not corrode in the same way as conventional steel reinforcement, their physical and mechanical properties are prone to degradation following exposure to a variety of aggressive environments, such as in the case of marine structures, parking garages and barriers, which accelerates the need for costly repairs and may lead to catastrophic failures. Whereas several methods have been employed to protect the steel reinforcement and minimize the risk of corrosion, replacing the steel reinforcement with the non-corrodible Fiber Reinforced Polymer (FRP) reinforcement totally eliminates the problem. Concrete beams reinforced with glass fiber-reinforced polymer bars exhibit large deflections and crack widths compared with concrete members reinforced with conventional steel. Based on the research work presented in this paper and past studies, a theoretical correlation for predicting the crack width and deflection is proposed by testing concrete beams. The research objective is to analyze the behavior of the beams under loading and obtain the differences in their behavior in terms of the following parameters: deflections, cracking patterns, failure modes and an analysis of the influence of variable parameters on the shear behavior of elements.*
***KEYWORDS:*** *Glass fiber-reinforced polymer bars, Deflections, Crack widths, Reinforced concrete, Shear capacity*

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## I. INTRODUCTION

Fiber Reinforced Polymer (FRP), also Fiber reinforced plastic, is a composite material made of a polymer matrix reinforced with fibers. The use of FRP reinforcements in concrete structures has increased rapidly owing to their excellent corrosion resistance, high tensile strength, and good non-magnetization properties, make FRP bars a viable alternative to conventional steel reinforcement in concrete structures such as marine structures and seawalls, as well as pavements, superstructures and bridge decks that are subjected to de-icing salts. However, the low modulus of elasticity of the FRP materials and their non-yielding characteristics result in lesser deflections and wide cracks in FRP-reinforced concrete members. In various cases, the serviceability requirements may satisfy the design parameters of the members of a structure. GFRP bars have a low elastic modulus and behave elastically up to near failure; therefore, protection from corrosion in reinforced concrete structures actually leads to the development of more durable concrete, in which the risk of corrosion is high.

## II. LITERATURE REVIEW

### 2.1 SHEAR PERFORMANCE

Shear failure occurs when structural concrete constructions are subjected to very impulsive loads and results in a rapid and catastrophic failure. Higher reinforced concrete beams without transverse reinforcement are more likely to experience shear failure due to the formation of diagonal cracks. The progressive micro cracking appears in the tip of the inclined crack, but strain softening of tensile concrete is not the only mechanism of carrying shear stresses.

**Ashour (2006)** tested the flexural and shear capacities of GFRP-reinforced concrete beams. A simple approach for predicting shear capacity was devised and validated in this work. The results revealed that under-reinforced beams failed in flexural mode due to GFRP bar rupture, whereas over-reinforced beams failed in shear mode. When flexure-failure beams were compared to shear-failure beams of the same depth, the flexure-failure beams showed excessive deflection. A simplified approach for forecasting flexural capacity was devised and verified using experimental data published here and elsewhere. The proposed method had a high degree of agreement with test results.

**Thamrin et.al (2011)** presented the experimental study on diagonal shear cracks of concrete beams without stirrups longitudinally reinforced with GFRP bars. The beams were simply supported and two-point loads were applied. Two types of shear failure were identified. First one is, diagonal shear-tension failure indicated by sudden formation of diagonal crack in the shear span zone immediately before the beam collapsed. The second one is shear-compression failure dominated by diagonal shear crack developed gradually in the shear span zone before collapse. In this study, concrete compressive strength slightly influences the shear capacity of the beams. The crack patterns as well as the slope of diagonal crack in the shear span zone were significantly influenced by the ratio of longitudinal reinforcement. In general, when the longitudinal reinforcement ratio increases, the slope of diagonal cracks decreases.

**Hamid et.al (2013)** presented the experimental investigation on the shear behavior of concrete beams reinforced with GFRP reinforcement bars. In comparison to steel RC beams, GFRP RC beams had a large number of closely spaced cracks. The capacity of GFRP is slightly higher than steel due to the higher tensile strength of GFRP bars. The ultimate loads and shear capacity of stirrups in GFRP were lower than steel when beams collapsed under shear. Thus, the expected shear performance was achieved due to lower a/d and stirrups ratio provided in the beams.

**Kim et.al (2015)** investigated the shear behavior of concrete beams reinforced with GFRP shear reinforcement. Increasing the bonded area between the GFRP plate and the concrete improves the performance of the shear reinforcement, provided the basic parameters are met. Analysis of the GFRP strip-width-to-spacing ratio showed that as the ratio increased, the bonded area increased, which improved resistance to shear cracks.

**Goldston et.al (2016)** conducted the experimental investigation of the behavior of concrete beams reinforced with GFRP bars under static and impact loading. The load–deflection behavior, energy absorption capacity, crack pattern, and failure mode were the primary parameters studied. The failure mode of GFRP RC beams can be accurately predicted from sectional analysis used for traditional RC beams. Under impact loading, the over-reinforced beams have been observed to experience minor inclined shear cracking and crushing of concrete cover around the impact zone at approximately 45°, resulting in a "shear plug" type of failure, regardless of the shear capacity of the GFRP RC beams.

**Jabbar and Farid (2018)** studied the replacement of steel rebars by GFRP rebars in the concrete structures. This demonstrates that GFRP reinforcing bar has greater tensile strength and higher corrosion resistance than steel rebar. From the results the tensile strength of bare GFRP bar is high, since they are anisotropic composite materials, GFRP rebar achieved yield tensile strength about 13% higher than that the steel rebar, while yield strain of GFRP is higher than steel about 58%.

**Zakaria et.al (2021)** conducted the enhancement the shear behavior of concrete beams reinforced with hybrid-wires bars by using steel fibers. The modulus of elasticity of hybrid-wire bars is higher than that of GFRP bars but lower than that of steel bars. When the ratio is increased to 75%, the shear strength increases, and it can be utilised as main reinforcement instead of steel reinforcement.

According to the study, Beams with lesser a/d ratios shows higher ultimate capacity compared to beam with higher a/d ratios, Shear capacity of GFRP RC beams is lower compared to steel RC beams and tensile strength of bare GFRP is high, since GFRP is a anisotropic material.

### 2.2 FATIGUE PERFORMANCE

Fatigue is the major cause of crack formation on any surface. Fatigue performance is a major concern for mechanical components subject to cyclical stresses, particularly where safety is paramount. The fatigue performance of components relies closely on their surface integrity because the fatigue cracks generally initiate from free surfaces.

**Zhu et.al (2021)** experimented the fatigue shear performance of concrete beams reinforced with hybrid (glass-fiber-reinforced polymer + steel) rebars and stirrups. At the critical diagonal crack, all GFRP stirrups and some steel stirrups cracked, and the concrete in the top shear compression zone was not crushed at failure. The strain development in the longitudinal bars was significantly influenced by the initial phase of fatigue and the maximum limit of the fatigue load. The damage accumulation and fatigue life were closely related to the stress range in the steel and GFRP stirrup.

According to the observation, the strain development in the longitudinal bars was significantly influenced by the initial phase of fatigue and the maximum limit of the fatigue load. And it is found that the fatigue cycling had no significant influence on the shear capacity.

**2.3 CRACK BEHAVIOR**

Crack behavior is a branch of mechanics that studies the propagation of cracks in materials. Crack growth under cyclic loading is thought to occur in three stages such as crack initiation, crack propagation, and structural fracture.

**Tureyen and Frosch (2002)** investigated the shear tests of FRP-reinforced concrete beams without stirrups. In this paper the shear strength and behavior of concrete beams reinforced with fiber-reinforced polymer (FRP) bars and steel reinforcement were simply supported and loaded with one concentrated load at midspan. This shows diagonal tension crack in these specimens developed closer to the supports and had a longer horizontal projection than the other specimens within their respective series. They concluded that flexural concrete members reinforced with FRP bars in the longitudinal direction can fail in shear at loads considerably lower than those reinforced by an equivalent area of steel bars.

**Tariq and Newhook (2003)** experimented the shear testing of FRP reinforced concrete without transverse reinforcement. The specimens without transverse reinforcement were selected to make the clear comparison of shear strengths. Three different longitudinal reinforcement ratios (0.72%, 1.1%, 1.5%) were selected to examine its effect on shear strength. All the beams failed under diagonal-tension and the observed shear failure was similar in all samples. With increasing load, these cracks progressively become inclined and propagated towards the load. In general, it was the flexural-shear crack located closest to the end support that eventually led to the diagonal-tension failure.

**Guadagnini et.al (2003)** conducted the shear performance of FRP reinforced concrete beams. Instrumentation was designed to measure the applied load, displacements, end rotations and diagonal deformations of the web during the tests. Also observed in the first phase of testing, vertical deflections for the GFRP reinforced beams were much lesser than those measured for the equivalent steel reinforced beams due to its lower modulus of elasticity. For the second phase beams that failed in shear, strain values recorded at failure in the GFRP flexural reinforcement always exceeded 0.7% while maximum strain values ranging from 1.0 to 2.0% for GFRP were recorded in the shear reinforcement. Shear resisting mechanisms are mobilised in a similar way in both GFRP and steel reinforced concrete beams and failure modes are characterized by similar behavior. Hence, summing the contributions of the concrete and reinforcement shear resistance mechanisms appears to be valid.

**Thamrin et.al (2011)** presented the experimental study on diagonal shear cracks of concrete beams without stirrups longitudinally reinforced with GFRP bars. The beams were simply supported and loaded with two-point loads. Shear failure, which was consisted of two categories. The first one is, diagonal shear-tension failure indicated by sudden formation of diagonal crack in the shear span zone immediately before the beam collapsed. The second one is shear-compression failure dominated by diagonal shear crack developed gradually in the shear span zone before collapse. In this study, concrete compressive strength slightly influences the shear capacity of the beams. The crack patterns as well as the slope of diagonal crack in the shear span zone were significantly influenced by the ratio of longitudinal reinforcement. In general, the slope of diagonal crack decreases as the longitudinal reinforcement ratio increases.

**Krassowska and Kazberuk (2018)** experimented the failure mode in shear of steel fiber reinforced concrete beams. Steel fibers have a direct impact on the shear strength of concrete beams. Fibers can transform a brittle shear mechanism to a ductile flexural mechanism. The obtained results confirm the potential possibility of using fibers to partially replace the stirrups. The combination of stirrups and steel fibers can improve both the ultimate and shear cracking strength.

**Bywalski et.al (2020)** investigated the shear behavior of concrete beams reinforced with a new type of glass fiber reinforced polymer reinforcement: experimental study. All the support zones were damaged as a result of the failure of the transverse reinforcement cut through a diagonal crack (shear–tension failure). Experimental studies demonstrated that GFRP headed bars could be used as shear reinforcement in concrete beams. Unlike GFRP stirrups, these bars allow stress redistribution in bars cut by a diagonal crack.

**Szczech and Kotynia (2020)** experimented the shear tests on GFRP reinforced concrete beams. After reaching about 90% of the ultimate load, one of the diagonal shear cracks became a critical crack from the support to the loading point. The increased shear reinforcement ratio increased the shear strength of the beams and resulted in a larger shear cracking load, as seen by higher GFRP stirrup strain values. The shear capacity of the tested beams was increased when the longitudinal reinforcement ratio was increased. The increase in the transverse reinforcement ratio through the reduction of the stirrup spacing caused an increase in the stiffness of the beams.

**Menam et.al (2021)** investigated the flexural and shear behavior of beams reinforced with GFRP rebars. Due to the reduced Youngs modulus of GFRP rebars, the cracking loads were lower for beams reinforced with GFRP rebars than for beams reinforced with conventional bars. Steel reinforced beams had a larger number of flexural and shear cracks than GFRP RC beams at all reinforcement ratios. In comparison to reinforced steel beams, reinforced GFRP beams had slightly steeper cracks and less shear cracks.

According to the research, as stress increases, cracks become increasingly inclined and propagate towards the load. The cracking stresses for GFRP rebar reinforced beams were lower because GFRP rebars have a lower young's modulus than conventional bars.

**2.4 ANALYTICAL AND THEORETICAL STUDY**

An analytical study is one in which action will be taken on a cause to improve the future performance of the system of interest. The aim of an enumerative study is estimation, while an analytical study focuses on prediction.

**Weigan and Abdalla (2005)** investigated the shear capacity of concrete beams reinforced with fiber reinforced polymers. The beams were tested under four point loading to investigate their deflection, cracking and shear capacity Fiber reinforced polymer (FRP) reinforced concrete beams react linearly up to breaking and linearly after cracking with reduced stiffness. Strains and deflections are generally higher in concrete beams reinforced with FRP bars than in concrete beams reinforced with steel.

**Ahmed et.al (2010)** conducted the fiber-reinforced polymer composite shear reinforcement performance evaluation in concrete beams and code prediction. This research examines the performance of carbon and glass fiber-reinforced polymer stirrups, as well as the accuracy of the shear design provisions included in current design code regulations and guidelines. As a result, the stiffness of the shear reinforcement given in concrete members reinforced with FRP stirrups is directly proportional to the response of the concrete members reinforced with FRP stirrups. The capacity and average stirrup strain increase as the shear stiffness increases.

**Minh and Rovnak (2011)** investigated the shear resistance of GFRP-reinforced concrete beams. The deflection at midspan and at the supports of the beams was measured using three linear variable differential transformers (LVDTs). The beams were loaded by a 500 KN capacity hydraulic testing machine in increments of 5 KN up to failure. The beams failed in flexure-shear and diagonal tension. The shear capacity of GFRP-reinforced concrete beams was lower than that of conventional reinforced concrete beams, according to the testing data.

**Ali et.al (2014)** conducted the evaluation of shear strength of concrete beams with GFRP reinforcement. All tested beams were reinforced longitudinally only, with no shear reinforcement, in order to simulate the occurrence of shear failure. They came to the conclusion that GFRP-reinforced beams had similar shear behavior to steel reinforced beams. However, the shear strength of beams reinforced with GFRP bars is lower than that beams reinforced with steel bars. Beams reinforced with longitudinal GFRP reinforcement displayed substantially larger deflections than those strengthened with steel reinforcement due to the low modulus of elasticity of the reinforcement.

**Valivonis et.al (2015)** experimented the study on shear resistance of fiber reinforced polymer reinforced concrete beams. The load was applied in 10 kN increments throughout the test. Crack widths were measured after each increment. Crack widths were measured until the applied load reached around 60% of the specimen's estimated theoretical shear strength. When using non-metallic shear reinforcement, the results of experimental tests on concrete beams reinforced with straight FRP shear stirrups revealed that anchorage is the most important consideration. Straight FRP bars must be securely fixed to the longitudinal reinforcement if they are used.

**Juhasz and Schaul (2015)** presented the shear behavior of synthetic fiber reinforced concrete beams reinforced with FRP bars. Only corrosion-free synthetic reinforcements were used to make reinforced concrete beams: basalt fiber reinforced polymer (BFRP) or glass reinforced polymer (GFRP) bars in a synthetic fiber reinforced polymer. Shear capacity was increased with the use of synthetic fibers. Despite a 24%-34% increase in load bearing capability, shear was still the failure mode.

**Said et.al (2016)** investigated the experimental and analytical shear evaluation of concrete beams reinforced with glass fiber reinforced polymer bars. The cracks of the specimens were mapped and test observations were recorded during loading and at the time of failure. The majority of the specimens failed abruptly and without warning, resulting in a considerable reduction in load carrying capability. The inclined cracks in the specimens appeared at 50.1% of the peak load for beam without shear reinforcements and appeared at 29.6–43.6% of the peak load for beams with shear reinforcements. When compared to specimens without shear reinforcements, specimens with GFRP vertical stirrups had a higher reserve capacity after formation of the first inclined crack.

**Krasniqi et.al (2018)** investigated the comparison of the behavior of GFRP reinforced concrete beams with conventional steel bars. The influence of the GFRP bars' low modulus of elasticity was visible in the early beginning of cracks in the GFRP-reinforced beams as compared to conventional reinforcement. The failure of GFRP reinforced concrete beams is mainly due to reduced post cracking stiffness and rebar-to-concrete matrix sliding.

**Krall and Polak (2019)** presented the concrete beams with different arrangements of GFRP flexural and shear reinforcement. The primary conclusions are as follows, beams with the same stirrup arrangement, but different longitudinal reinforcement ratios, failed in shear at similar applied loads. In shear tension, beams without stirrups failed and showed an increasing longitudinal reinforcement ratio. Beams with stirrups failed in shear compression with arching / direct-strutting action as the primary shear resisting mechanism.

**Hosseini et.al (2020)** conducted the prediction of shear behavior of steel fiber-reinforced rubberized concrete beams reinforced with glass fiber-reinforced polymer (GFRP) bars. Since no stirrups were present, the failure of each beam was in the form of the shear-compression, shear-tension, or diagonal tension. Most beams experienced sudden failure occurring at one end on the right or left of the supports. When the ratio of shear span to depth declined from 2.5 to 1.5, an increase of around two folds occurred in the shear strength of all the beam specimens, with the highest such increase pertaining to the beam without fibers with an increase of up to 120%.

According to the study, the shear strength of beam reinforced with GFRP bars is lower than that beam reinforced with steel bars, the response of concrete members reinforced with FRP stirrups is directly proportional to the stiffness of the shear reinforcement provided and GFRP behave linearly upto cracking then linearly after cracking with reduced stiffness.

## III. CONCLUSION

- A decrease in modulus of the reinforcement resulted in a decrease in shear strength of the beam.
- The slope of diagonal crack decreases as the longitudinal reinforcement ratio increases.
- The tensile force of longitudinal reinforcement at the support considerably increased after the occurrence of diagonals cracks and with increasing of shear span length the tension force at the support decreases.
- Strains and deflections are generally higher in concrete beams reinforced with FRP bars than in concrete beams reinforced with steel.
- As the GFRP flexural reinforcement ratio increased, the ultimate shear capabilities increased.
- By using 1.2% steel fibers by volume incorporated with minimum steel stirrups, the mode of failure changes from catastrophic and brittle diagonal tension failure accompanied with reinforcement rupture to more ductile diagonal tension failure.
- Confirming that 1.2 % of steel fibers can replace a part of steel stirrups which reaches moderately higher shear stresses at failure and improves crack propagation resistance and shows higher ductility at failure in case of beams reinforced with hybrid wires bars.

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