

Experimental Investigation Of Flexural Behaviour On GFRP Reinforced Concrete Beams Using Polypropylene Fiber And Partial Replacement Of Waste Granite Aggregate

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Abstract- *In this study, an experimental investigation was carried out on the flexural behaviour of Glass Fibre Reinforced Polymer (GFRP) reinforced concrete beams incorporating polypropylene fibres and waste granite aggregate. The primary objective of the research was to evaluate the structural performance, strength characteristics, and crack behaviour of sustainable concrete beams reinforced with GFRP bars.*

Waste granite aggregate was used as a partial replacement for conventional coarse aggregate to promote sustainable waste management and reduce environmental impact. Polypropylene fibres were added to improve the ductility, crack resistance, and overall performance of concrete. GFRP bars were adopted as reinforcement due to their high corrosion resistance, lightweight nature, and superior tensile strength compared to conventional steel reinforcement.

Concrete specimens such as cubes and prisms were cast added at varying percentages (0%, 0.5%, 0.75%) to improve ductility and minimize shrinkage cracks. Waste granite aggregate, obtained as a byproduct of stone cutting industries, was partially replaced with natural coarse aggregates at 0%, 10% & 20% by volume to improve sustainability and reduce natural resource consumption. Tested to determine compressive strength and flexural strength. This study presents an experimental investigation on the flexural behaviour of reinforced concrete beams incorporating Glass Fiber Reinforced Polymer (GFRP) bars, polypropylene (PP) Fiber, and partial replacement of natural coarse aggregate with waste granite aggregate. The primary objective is to evaluate the improvement in structural performance, particularly in terms of load-carrying capacity, crack resistance, ductility, and energy absorption characteristics under flexural loading.

A series of beam specimens were cast and tested, including control beams and modified beams with varying percentages of polypropylene Fiber and waste granite aggregate replacement. All specimens were subjected to two-point loading to simulate flexural conditions, and their structural responses were recorded in terms of load-deflection behaviour, crack development, and ultimate failure patterns.

The experimental results indicate that the inclusion of GFRP reinforcement significantly enhances corrosion resistance and increases tensile performance, while polypropylene Fiber contribute to improved crack control and post-cracking behaviour. Furthermore, the partial replacement of natural aggregates with waste granite improves sustainability without severely compromising mechanical strength. The combined effect of these materials leads to enhanced flexural strength, delayed crack propagation, and improved overall ductility of the beam specimens.

The study concludes that the synergistic use of GFRP bars, polypropylene Fiber, and waste granite aggregate can be effectively adopted in concrete structures to achieve sustainable and high-performance construction materials with improved structural efficiency under flexural loading.

I. INTRODUCTION

Concrete is one of the most widely used construction materials in modern civil engineering due to its versatility, ease of construction, and availability of constituent materials. However, conventional reinforced concrete beams often exhibit limitations such as brittle failure, low tensile strength, and susceptibility to cracking under flexural loading. These shortcomings have led to continuous research on improving the mechanical and durability performance of concrete structural members through innovative materials and sustainable practices.

In recent years, Glass Fiber Reinforced Polymer (GFRP) bars have emerged as a promising alternative to conventional steel reinforcement owing to their high tensile strength, corrosion resistance, and lightweight properties. The use of GFRP reinforcement in concrete beams significantly enhances durability, especially in aggressive environmental conditions where steel reinforcement is prone to corrosion. However, the linear elastic behaviour of GFRP and its lower modulus of elasticity compared to steel influence the flexural response of beams, necessitating detailed experimental investigations.

To further improve the performance of concrete, the incorporation of polypropylene Fiber has gained attention due to their ability to control micro-cracking, enhance toughness, and improve post-cracking behaviour. These Fiber contribute to improved energy absorption capacity and ductility of concrete under flexural loading conditions.

Additionally, the utilization of industrial waste materials such as waste granite aggregate as a partial replacement of natural coarse aggregates supports sustainable construction practices. It helps in reducing environmental impact caused by excessive quarrying while maintaining or enhancing certain mechanical properties of concrete.

In this context, the present experimental investigation focuses on evaluating the flexural behaviour of GFRP reinforced concrete beams incorporating polypropylene Fiber and partially replacing natural aggregates with waste granite aggregates. The study aims to assess improvements in load-carrying capacity, crack resistance, and overall structural performance, contributing to the development of durable and sustainable concrete systems for modern infrastructure.

1.1 Glass fiber Reinforced Polymer bar (GFRP):

Glass Fiber Reinforced Polymer (GFRP) bars are advanced composite reinforcement materials developed as an alternative to conventional steel reinforcement in concrete structures, particularly in aggressive environments where corrosion is a major concern. These bars are manufactured using high-strength glass Fiber embedded in a polymer resin matrix, typically vinyl ester, polyester, or epoxy.

Mechanical Properties:

1. High tensile strength (often higher than steel of equivalent diameter)
2. Linear elastic behavior up to failure (no yielding phase)
3. Low modulus of elasticity compared to steel (typically 40–60 GPa)

4. Lightweight (about 1/4th the weight of steel)
5. Anisotropic behavior (strength primarily along fiber direction)

Structural Behavior in Concrete

1. Improves ultimate load carrying capacity
2. Enhances crack control behavior when combined with fibers like polypropylene
3. Exhibits larger deflections due to lower stiffness compared to steel reinforcement
4. Failure is typically brittle, governed by rupture of fibers or concrete crushing

1.2 Polypropylene fiber:

Polypropylene (PP) Fiber is a synthetic organic Fiber derived from the polymerization of propylene monomers. It is widely used in cementitious composites due to its excellent chemical resistance, low density, and ability to enhance the post-cracking behaviour of concrete. In the context of experimental investigations on GFRP-reinforced concrete beams, polypropylene Fiber plays a crucial role in improving the overall toughness, crack control, and energy absorption capacity of the concrete matrix.

Polypropylene Fiber are generally produced in two main forms: monofilament Fiber and fibrillated Fibers. Monofilament Fiber are single continuous filaments, while fibrillated Fiber are mesh-like structures that improve mechanical interlocking within the concrete matrix. These Fiber are typically added in small volume fractions (commonly 0.1% to 1.5% by volume of cement or concrete), depending on the desired performance characteristics.

One of the most important properties of polypropylene Fiber is its high resistance to chemical attack, including acids, alkalis, and salts, which makes it suitable for aggressive environmental conditions. It is hydrophobic in nature, meaning it does not absorb water, thereby preventing any adverse effect on the water-cement ratio of concrete. Additionally, PP Fiber possess a relatively low melting point (approximately 160–170°C), but this property can be advantageous in high-temperature conditions such as fire exposure, where Fiber melt and create micro-channels that help relieve internal vapor pressure, thereby reducing explosive spalling.

From a structural performance perspective, polypropylene Fiber significantly improve the crack-bridging mechanism in concrete. They control plastic shrinkage cracks

at early stages and reduce micro-crack propagation under loading. This results in enhanced ductility, post-cracking strength, and flexural toughness, which are critical in flexural members such as beams. Although PP Fibers do not significantly increase compressive strength, they contribute to improved strain capacity and energy dissipation under flexural loading conditions.

In experimental studies involving GFRP-reinforced concrete beams, polypropylene Fibers act synergistically with GFRP bars by improving the concrete matrix surrounding the reinforcement. This leads to better stress distribution, delayed crack initiation, and improved load-deflection behaviour. When combined with partial replacement of natural aggregates (such as waste granite aggregates), PP Fiber help maintain matrix cohesion and reduce brittleness introduced by weaker recycled materials.

Overall, polypropylene Fiber is considered a cost-effective and sustainable reinforcement material that enhances the durability and flexural performance of concrete, making it highly suitable for advanced structural applications and experimental research in modern concrete technology.

1.3 Waste Granite aggregates (WGA):

refers to the crushed and processed by-product generated from granite quarrying, cutting, and polishing industries. During the production of granite slabs, tiles, and dimensional stones, a significant amount of waste is produced in the form of irregular fragments, slurry residues, and fine particles. This waste is further processed (crushed and sieved) to be used as a partial or full replacement of conventional natural coarse aggregates in concrete.

Mechanical Properties

1. High compressive strength due to the inherent strength of granite rock
2. Good resistance to abrasion and impact
3. Suitable for high-strength concrete applications
4. Improves bonding with cement paste due to rough texture

Role in Concrete as Partial Replacement

1. Enhances interfacial bonding between aggregate and cement matrix
2. Improves load transfer capacity under flexural and compressive loading
3. Contributes to higher stiffness and improved cracking resistance
4. Can improve durability characteristics depending on replacement level.

II. RELATED WORK

Naganna et al (2024): *completed an experimental investigation on steel and GFRP RC beams using polypropylene fiber.* In this study 11 beams of size 100×150 mm and a 1500-mm casted with M20 grade of concrete. The beams are casted by changing the percentage and type of reinforcement at tension-compression side. In this research the beam specimens varied with use of different combinations and proportions of steel reinforcement, GFRP bars, polypropylene fiber. B1-CB beams casted with 4 steel rebars of 10mm diameter at top and bottom. B2-SP beams casted same as per B1 but replacing one percent of concrete's fine aggregate volume which is composed of polypropylene fibers. B3-GP casted as per B1 just by changing steel rebars by GFRP rebars. B4-GP-T casted with 2 steel bars at top while 2 GFRP rebars at bottom of 10mm diameter in addition of one percent of concrete's fine aggregate volume which is composed of polypropylene fibers. B5-GP-C casted as per the same phenomenon used while casting B4 just by reversing both steel and GFRP rebars both at top and bottom. PFRC beams considered as polypropylene fiber reinforced concrete beams which involves beams B1, B2, B3. At the end it is concluded that when using GFRP in the compression zone, PFRC's ultimate load carrying capacity and first fracture load are both raised by 0.11% and reduced by 7.5%, respectively, in comparison to conventional beams, while there is a 125.5% increase in deflection at the initial crack.

Performance of doubly reinforced concrete beams with GFRP bars examined by Musa AbdulMuttalib Issa et al (2024): to assess their performance in relation to their deflection, load-bearing capability, and other mechanical attributes. A total of six beams with a rectangular form measuring 300 mm in width by 250 mm in depth, 2,400 mm in total length, and 2,100 mm in clear span were cast in this study. The testing of beams is done under static actuator having capacity of 150 metric-tons. Four long bars, each with a diameter of 15 mm, were used to singly strengthen the reference beam (R-1) in the tension zone with GFRP tension reinforcement ratio $\rho_f = 1.885$, ρ_{fb} (FRP reinforcement ratio producing balanced strain conditions). There were 2 \emptyset 8 mm longitudinal steel bars installed in the compression zone. Out of two groups the first group with 3 beams- G1GS1, G1GS2, and G1GS3 reinforced with GFRP bars. Here, constant reinforcement ratio for tension zone was 1.885 ρ_{fb} , where for compression zone reinforcement ratios varied by 0.5, 0.75, and 1.0. Two beams (G1 GS4 and G1 GS5) strengthened with GFRP bars make up the second group. Here, constant reinforcement ratio for tension zone was 2.357 ρ_{fb} , where for compression zone reinforcement ratios varied by 0.4 and 0.6. Because the fibers of GFRP bars will break if it is clamped

straight onto their ends, testing them in direct uniaxial tension is challenging. So, the ends of steel couplers were epoxy-bonded to GFRP bars. Applying a test for load control, the beams were subjected to a 5 kN loading step that increased monotonically until failure. In comparison to beam (G1GS1) with 2Ø15mm, specimens (G1GS2) and (G1GS3) have respective diameter specifications of 3Ø15mm and 4Ø15mm, achieved 9.29 and 6.29% increases in load capacity. It is clear that the entire service load that corresponded to an 8.75mm midspan deflection varied from 32.9 to 40.6% of the failure load. It has been confirmed that expanding the compression GFRP bar's area boosts the beam's stiffness and resistance to displacement when the load is at its highest. The examined beams had an average crack spacing of 100.7 to 150.7 mm. Ultimately, it is determined that when the compression GFRP-reinforcement ratio rises, the crack width falls under service stress. For sections intended to fail in concrete crushing, the service load that meets serviceability norms at the cross-section level is between 27 and 50% higher than the ultimate load.

Pham Thi Loan et al (2021):studied flexural behavior of beams made of GFRP reinforced concrete under 3-point bending test. 3 beams with different GFRP ratios are designed by ACI-440 1R provisions. The beams of size 1600mmx100mmx180mm are casted with B20 grade of concrete. The beams are designed in such manner to fail either by rupture of GFRP rebars at tension zone or pulverizing. All the beams are having 2#8mm diameter of GFRP rebars as top reinforcement. Beams B1, B2, B3 are with 2, 3 and 4 number of GFRP rebars at bottom having 8mm diameter. Mn is the nominal flexural strength after finding pf FRP reinforcement ratio. The design ultimate load calculated for the beams B1, B2 and B3 is (11.4, 14 and 14.4) KN respectively. The values obtained after testing the beams are (11.46, 14.38 and 14.4) KN with the difference of 0.5, 2.7,0 w.r.t design load respectively. FRP reinforcement ratio producing balanced strain conditions- ρ_{fb} was 0.46 for all the beams. For beams B1, B2, and B3 FRP reinforcement ratio- ρ_f was 0.43, 0.64 and 0.90 respectively. The beams' cracks were visually examined throughout the test, from the initial crack to failure, and the loads that accompanied them were noted. The first cracking appeared with the load values of cracking curves being 1.6 KN, 1.8 KN, and 3.8 KN in the sequence of beam B1, B2, and B3, respectively. Vertical flexural cracks are concentrated near the load point, whereas fractures spreading to the sides of the PAGE NO: 29 Journal Of Technology || Issn No:1012-3407 || Vol 15 Issue 4 supports tend to incline and it is observed that concrete in the compression zone of GFRP reinforced beams was severely crushed. For concrete crushing failure, the strength reduction factor ϕ was set at 0.65, while for FRP rupture failure; it was set at 0.55 as per ACI-440 1R

provisions. A linear branch and two major linear segments comprise the load-deflection curves of the RC beams with GFRP bars that represents the beam's cracked response and linear segments with a lower slope that indicate the stiffness degradation and cracked response of the beam. To guarantee beam resistance and prevent FRP rupture and concrete crushing failure during the service stage, it is essential that the strength reduction factor for flexural strength fall between 0.55 and 0.65. For GFRP reinforced concrete beams, the plane section assumption has remained valid.

Sayan Sirimontree, et al (2021):conducted a conduct an inquiry of flexural behavior of concrete beam. It involves casting and testing six full-scale beams measuring 150x250x2500 mm and strengthened with steel or GFRP bars using a four-point loading test. For Grades SD30 and SD40, the steel reinforcements' nominal yield strengths were 300 and 400 MPa, respectively. All the rebars used are of diameter 12mm. Beams B-30(A) & B-30(B), B-40(A) and B-40(B), B-FRP(A) and B-FRP(B) are casted by steel SD30, steel SD40 and GFRP rebars respectively. Shear failure is avoided by using 9 mm (RB9) stirrups spaced 100 mm apart. Testing of beams is conducted under simply supported boundary conditions by two steel rollers. LVDTs were used to measure deflections at two loading locations at the mid-span position. For all beams, the initial cracking load of 10kN was identical. Because GFRP bars have a lower elastic modulus than steel rebars, when concrete was reinforced with GFRP bars, it was less rigid than when steel bars were used. The test results are mentioned in the table below. When concrete beams were reinforced with GFRP bars, their maximum load was 98% greater than that of concrete beams reinforced with steel bars (grades SD30 and SD40), respectively. With maximum and average loads of about 35.6 KN and an average deflection of 55 mm, beams bearing the B30 mark have lower load capabilities. Better performance is demonstrated bybeams designated as B-40, which can support loads up to 62.2 KN and have an average deflection of 51 mm. With an average deflection of 52.3 mm, the best-performing beams, designated B GFRP, can support maximum loads surpassing 70.5 KN. These findings show an improvement in deflection control and load-bearing capability, most likely due to improvements in structural and material design.

The flexural behavior of deep beams made of high concrete reinforced with locally made GFRP rebars is examined by Mona K. Nassif et al (2021). Eight beams (1800 mm in length, 500 mm in depth, and 150 mm in width) with shear reinforcement of 7Ø8/m were cast and subjected via a two-point loading test until it failed. 50 and 60 MPa concrete compressive strengths were employed. Furthermore, various steel reinforcement ratios of 0.0033 and balanced condition

ratios of 0.8, 1.0, and 1.2 were employed. To cut costs, GFRP rebars with diameters of 8 mm, 10 mm, and 12 mm are made locally for this study. Following tensile testing, the resulting tensile strengths were 650 MPa, 740 MPa, and 1075 MPa, respectively. The a/d ratio of the beams was 1.33, where d is depth and a is distance from the applied load. The 8 beams were categorized in 2 groups. In group 1 - beams naming SP1, SP3, SP4, and SP5 with 50Mpa compressive strength having reinforcement ratios of 0.83 μ_b s, 0.80 μ_b , 1.00 μ_b , 1.20 μ_b respectively. In group 2- Beams naming SP2, SP6, SP7, SP8 with 60Mpa compressive strength having reinforcement ratios of 0.83 μ_b s, 0.80 μ_b , 1.00 μ_b , 1.20 μ_b respectively. Beams SP1 and SP2 are reference beams casted with steel rebars where other beams are reinforced with GFRP PAGE NO: 27 Journal of Technology || Issn No:1012-3407 || Vol 15 Issue 4 rebars. In group 1 SP1 reached failure load of 658.69kN where failure load was lower for other beams than for the control specimen. SP5 reached the failure load of 675.3 KN surpassing control specimen SP1 by 2.5%. In group 2 SP8 reached failure load of 720.4 KN surpassing control specimen SP2 by 4%. In accordance with the crack patterns, about group 1 the initial flexural fracture was caused by a force of 110kN, 117kN, 120kN for SP3, SP4 and SP5 respectively. The initial flexural crack for group 2 developed at a load of 115kN, 118kN, 130kN for SP6, SP7 and SP8 respectively. Higher deflection was the result of lowering the beams' stiffness more quickly, especially the GFRP RC beams. This might be as a result of GFRP bars' lower elastic modulus when contrasted with reinforcing steel bars. Non-linear finite element analysis (NLFEA) of deep beams carried out with the ANSYS-2019-R1 software. All models have a maximum meshing dimension of 25×25 mm. The deflection ratios are calculated from the results obtained from NLFEA and experimental work. With an average of 88.0%, the load-deflection curves for every specimen under examination and the numerical results showed good agreement.

GFRP rebars can be the perfect alternative for the traditional steel rebars for this the research has been made by the Shahad AbdulAdheem Jabbar and Saad B.H. Farid (2018): where the research work focuses on substitution of GFRP rebars for steel rebars in concrete buildings. In this study, researcher's main aim was to manufacture the GFRP rebar made of unsaturated polyester resin and glass fibers, cast the cube samples and beams and then test under three-point loading test. The test results highlight the tensile strength of GFRP rebar, bond behavior, bending strength and flexural strength of beam specimens. The manufactured GFRP rebar contains 86 fibers with resin to create a 1.25 cm diameter rebar. Unsaturated polyester resin made by Iran Company, Methyl ethyl ketone peroxide by a Turkey company. Iraqi specifications were met by the necessary fibers, fine

aggregates, and qualities such as density, specific gravity, sulfate content, and sieve analysis. Ultimately, a 12.5 mm diameter bar, typical for construction applications, was produced, with an 80% fiber volume fraction and a 20% polyester volume fraction. Ultimately, a 12.5 mm diameter bar, typical for construction applications, was produced, with an 80% fiber volume fraction and a 20% polyester volume fraction. The test results showed that the tensile strength of GFRP rebars (593 MPa) was approximately 13% higher than that of steel rebars, and the flexural strength of sand-coated GFRP reinforced concrete reached 13.5 MPa at 28 days, which was close to steel-reinforced concrete (17.5 MPa). Moreover, GFRP RC exhibited higher strain and more ductile behavior before failure, providing a better failure warning compared to traditional steel RC. While GFRP bars had lower flexural modulus, the bond performance was significantly enhanced through sand coating, leading to reduced crack widths and improved energy absorption. The study concluded that GFRP rebars particularly with surface modification can serve as a highly effective and durable replacement for steel in reinforced concrete, especially in aggressive environments where corrosion resistance and ductility are critical.

Flexural Behavior of Beams was examined by Omar Gouda et al. (2022): where, Eleven GFRP-reinforced concrete beams measuring 4,350 x 400 x 200 mm (length x height x breadth) casted and tested under 4-point loading. The distance between the centers of beam supports was 3,750 mm, while the gap between the centers of the loading points on the beams was 1,000 mm. In order to measure the load values, a 500kN load cell was used with an accuracy of ± 0.05 kN. The beams were having the unique nomenclature Beams 3#5-c50-s317, 3#5-c50-s200, and 3#5-c50-s100 here, B is the size of the reinforcement, c is the transparent concrete cover, and a is the total number of tensile reinforcements made of GFRP. Each GFRP reinforcement had at least two strain gauges are installed, each measuring 2 mm in gauge length. During the experiment, the widths of the initial 3 flexural cracks were recorded up to the point of failure. The initial widths of these cracks were first measured using a portable microscope and subsequently with the LVDT. In this study researchers achieved the cracking Moment M_{cr} by experimental investigation which is validated with previously calculated cracking moment by CSA-S806-12 (Canadian Standard Association-2012), ACI440.1R-15 (American Concrete PAGE NO: 24 Journal of Technology || Issn No:1012-3407 || Vol 15 Issue 4 Institute-2015) and by CSAS6-14 (Canadian Standard Association-2014). The highest cracking moment capacity was theoretically calculated for beam 2#5-c30, c38, c50 which means beam with 2 GFRP bars and 15mm diameter of bars at tension side with clear concrete cover (30, 38, and 50) mm respectively. The calculated moment was 20. 2kN.m, 20.

9kN.m, and 13. 5kN.m by the CSAS806-12, ACI440.1R-15, and CSAS6-14 design provisions respectively. But experimentally the highest critical moment was achieved by 2#8-c50 which means 2 GFRP rebars 25mm diameter of bars with 50mm clear concrete cover which is 19kN.m. While talking about the failure modes that all beams failed due to the crushing of top concrete fibers which were already expected by the researchers. As the reinforcing ratio rose, so did the depth of crushed compression concrete blocks. As per the researcher this happened because of the extensive separation between the stirrups particularly in the intermediate bending zone, the lateral support for compression reinforcements is insufficient. Ultimately, it is determined that the concrete crushing at the intense compression fibers caused the tested beams to collapse. Beams with a lower reinforcement ratio ($\leq 0.85\%$) showed bilinear load-deflection behavior, whereas trilinear behavior was displayed by individuals with a greater reinforcement ratio. Moment capacity predictions from the CSAS806-12 (CSA 2012) and ACI440.1R-15 (ACI 2015) were in close agreement with the experimental findings.

Steel rebar has a higher stiffness than Glass fiber reinforced polymer (GFRP) rebar, which should be accounted for its ultimate conditions and serviceability including the impact on crack widths and member deflection. Omar I. Abdelkarim et al. (2019) concluded that the increase in the GFRP rebar ratio has a better effect on the service moment than the resistance moment and the effects on the spacing of bar formed on the wide beams behaviour were examined and it is revealed that when the moment of service increases while the spacing of bar decreases, when the moment of resistance rises then the strength of concrete also rises. Moreover, the concept of the deformability formed has higher ductility. Fergani et al. (2018) had concluded that the stressed specimens of concrete which is hardened in the wet environment which experienced a decrease in the tension stiffening response. It also indicates that the accelerated aging conditions affect the flexural behavior of the element and it leads to larger crack widths and also higher deflections.

Goldston et al. (2017) found that the over-reinforced high strength concrete and ultra-high strength concrete in which the GFRP bar is reinforced have an amount of ductility which is compared to under-reinforced high strength concrete and ultra-high strength concrete reinforced with GFRP rebar. The energy absorption capacity was detected at the lower for GFRP reinforced high strength concrete and for the same amount of reinforcement collated to GFRP reinforced ultra-high strength concrete.

Edgaras Atutis et al. (2015) had investigated experimentally the concrete beams reinforced with GFRP

rebar based on flexural strength. Both the prestressed concrete and the reinforced concrete beams had tested. The effect of prestressing on the cracking and deflection was analysed and it is possible to predict the mode of failure of concrete members with GFRP reinforcement taken into account of flexural strength design methodology which is grounded on reinforcement ratio. Experimental and predicted mode of failure of concrete beams is coincided.

Long-term behaviour of composite materials is still a very provocative affair among the engineering circle though the fibre reinforced polymer (FRP) rebar is steadily used in infrastructure applications. Tarek H. Jikai Zhou et al. (2011) had experimentally investigated the durability of the bond between conventional steel rebar to the concrete and GFRP rebar to the concrete under acidic environment for comparison. These samples were forced to corrode by immersing it in the acid solutions with different concentration. For this test pullout samples were used just to expose the effect on the rebar in different environment on bond strength. The result shows that the maximum bond strength loss is higher in steel rebar compared to the GFRP rebar. It had evaluated that the durability of three different glass fibre reinforced polymer rebar types is based on the exposure to the aggressive environments such as that those are experienced in coastal areas. The samples were submerged in seawater at 60 °C which counterfeits the alkalinity of the concrete at various time periods. The long-term performance of these GFRP rebar was assessed by testing the four different mechanical properties such as elastic modulus, tensile strength, and horizontal and transverse shear strength. It is found that the tensile strength was the most affected mechanical properties of GFRP rebar.

(Alvaro Ruiz Emparanza et al. 2020). Jianwei Tua et al. (2020) had carried out durability tests on a GFRP rebar with the seawater and the concrete environment at various temperatures. The durability of the GFRP rebar was examined by analysing its tensile properties. The durability of GFRP rebar was exposed to concrete under various temperature levels and used by the method of Arrhenius theory. The GFRP rebar have a good durability property by comparing the design limits, literature results, test results. Bond characteristic of GFRP bars in concrete is the most critical parameter for implementation of the material to the corrosion-free concrete structures. Unlike steel reinforcement, GFRP materials behave anisotropic, non-homogeneous and linear elastic properties, which may result in different force transfer mechanism between reinforcement and concrete.

Giulia Fava et al. (2016) they have presented a larger exploration on the bond behaviour of GFRP rebar and

concrete and concluded that when the steel bar is deboned, the concrete crushed around the ribs of the steel due to the concrete splitting and in the case of GFRP rebar the failure is ascribed because of the striping of the rebar. When the bond length of the bar shortens then the bond strength of the bar increased and when the stress in concrete rises then the problem of crushing, spalling and splitting of concrete are ascribed. It is concluded that the glass Fiber reinforced polymer (GFRP) rebar tested showed a lower bond capacity than steel. The two beams reinforced with GFRP rebar failed at a higher peak load than the steel reinforced beam, since all of them were designed to be tension-controlled. At service loads, GFRP reinforced beams showed higher crack-width and mid-span deflection compared to the steel reinforced beams because of the lower stiffness of GFRP rebar in comparison to steel is concluded by Tassinari,

A. et al. (2019). Eswanth and Dhinakaran (2017) found out that the assessment of bond properties of the GFRP rebar embedded in the normal concrete and the GFRP rebar embedded in the high strength concrete has disclosed that the pull out test loaded on the GFRP rebar is within the scale and also established that due to the bar surface and the length of embedment the bond failure was caused and due to the longer length of embedment and the increase in diameter the splitting failure occurs which curtail the average bond strength. It is also inaugurated that the Pullout load in high strength concrete was higher than that of the normal strength concrete. Moreover, the bond strength of the steel rebar is higher than that of the glass fibre reinforced polymer bars. When the splice length increases and the cover thickness decreases, then the average bond strength of GFRP rebar was decreased.

Jose Sena-Cruz et al. (2018) they intend to study the RC structures where the concrete is mixed with sea water and also the change of conventional steel rebar is replaced with GFRP rebar. They concluded in the result that there is no effect on the bond behaviour even when the concrete is mixed with sea water and there was also no severe problem with the properties of both concrete and the GFRP rebar. These results are concluded by two phases, such as the manufacturing of concrete using seawater and the other phase is to assessing the bond behaviour between concrete and GFRP rebar using pullout test, in these both phases the effect caused because of the usage of seawater instead of tap water was studied. By doing the pullout test the factors such as anchorage length and rebar diameter were also evaluated.

Mehmet Mustafa Onal (2014) experimentally investigated about concrete beams were strengthened by wrapping the shear edges of the beams twice at 45° in opposite directions by either CFRP or GFRP, the study includes CFRP

wrapped beams, 3 GFRP wrapped beams and control beams, all of which were 150x250x2200 mm and manufactured with C20 concrete. Data were evaluated in terms of load displacement, bearing strength, ductility and energy consumption. In the CFRP and GFRP reinforced beams, compared to controls 38% and 42% respectively. Strength increase was observed. In all beams, failure flexural stress occurred in the centre as expected. No cracking was observed in the flexural region. A comparison of CFRP and GFRP materials reveals that GFRP reinforced parts absorb more energy. Both materials yielded successful results. Thicker epoxy application in both CFRP and GFRP beams was considered to be effective in preventing backups.

Deepak Kumar and Govind Ravish (2015) investigated about the use of Fiber reinforced polymer (FRP) reinforcements in concrete structures has increased rapidly in the last 10 years due to their excellent corrosion resistance, high tensile strength, and good non-magnetization properties. Fiber-reinforced polymer (FRP) application is a very advanced method for the purpose of repair and strengthens structures which are weak during their life span. FRP repair systems provide an economical and effective method for repairing repair systems and as a material.

Christopher Bright et al (2016) present about a reinforcement system that utilizes unique geometries in order to improve reinforced concrete beam stiffness, shear strength and reinforcement bond properties, as compared with conventional glass Fiber reinforced polymer bar style reinforcement is introduced. These specimens were tested and compared to similar specimens with conventional strength GFRP bars in order to document their behaviour and assess the effect on beam performance of the new geometry under typical loading. Both failures that occurred in the control specimens were not present in the prototype specimens. Ultimate shear capacity in one of the prototype variations was increased by 26% over the bar reinforced control specimens.

Keru Suzan AA Mustafa and Hilal A Hassan (2017) paper presents about a nonlinear finite element model to investigate the behaviour of hybrid Fiber reinforced polymers and steel reinforcement. Different types of Fiber reinforced polymers. CFRP and GFRP were used along with steel rebars in the studied concrete beams. The study was conducted using nonlinear finite element program "ANSYS". Nonlinear material models for the components of the concrete beam were used in the three-dimensional finite element models.

Alizadeh S.M. Hasanur Rahman et al (2017) in this paper, test results of six large scale glass Fiber reinforced

polymer RC continuous. T-Beams are presented. The test specimens include one steel RC beam to serve as reference, one GFRP RC beam designed to meet the serviceability criteria at the service load level calculated for the reference beam, and four GFRP RC beams designed to achieve the same theoretical ultimate load of the reference beam. The test variables included the assumed percentage of moment redistribution, the spacing of lateral reinforcement in flange, and the arrangement of shear reinforcement. The test results showed that moment redistribution from the hogging to the sagging moment region occurred in GFRP RC beams with T-section and that a small spacing of lateral reinforcement in the flange improved the moment redistribution through enhancing the stiffness of the sagging moment region.

A. Deifalla et al (2015) presents in international committee on shear and torsion reported that giving physical significance for the torsion design is an upcoming challenge. The purpose of this paper is to propose a reasonably accurate and relatively simply model capable of predicting the torsional strength of concrete beams reinforced with glass Fiber reinforced polymer stirrups. In this paper, a database for concrete beams reinforced with GFRP stirrups, tested under torsion is compiled. The implementation of the torsion design provisions of the conventional steel reinforced concrete design codes is discussed. A few deflected strength models were used to predict the ultimate torsional strength to be tested beams. The predicted strength was compared with that measured during testing. The comparison showed that more improvement is required in calculating the inclination of the diagonal concrete strut and the effective strain in the GFRP stirrups. Two strength models were modified and proposed. The proposed models showed better compliance and consistency with the experimental results compared to the available models and design codes. However, further experimental testing will help refine the proposed models.

Trupti Amit Kinjawadekar, Shantharam Patil, Gopinatha Nayak et.al(2023):- “A Critical Review on Glass Fiber-Reinforced Polymer Bars as Reinforcement in Flexural Members.” The literature review focuses on the application of Glass Fiber-Reinforced Polymer (GFRP) bars in reinforced concrete structures. Through experimental testing and numerical analyses, the review assesses the behaviour of GFRP-reinforced flexural members, including their performance under shear and bending, bond strength, crack patterns, and load-deflection characteristics. In this study, the effort is made to appreciate response of concrete structural members reinforced with GFRP under flexure. Various properties of glass FRP reinforced flexural members are studied. A brief review of various properties of GFRP-

reinforced flexural members will help to understand the response of these rebars

Conclusion The behaviour of the beam in flexure can be enhanced using steel rebar in combination with GFRP reinforcement in terms of increased capacity for carrying the load, higher deflection compared to GFRP reinforced beam. In the post-cracking stage, GFRP bar, along with the steel bar, is taking more load, and the beam fails in shear. Therefore, shear reinforcement needs to be taken care of.

Mohamed S. Moawad and Ahmed Fawzi (2021):- “Performance of concrete beams partially/ fully reinforced with glass Fiber polymer bars.” This research focuses on the performance of concrete beams partially/fully reinforced with glass Fiber-reinforced polymer bars with 50% of GFRP bars were used to reinforce partially concrete beams at flexural zone. While 100% of GFRP bars were used to reinforce fully concrete beams at flexural and compression zones with different concrete compressive strength. This study reported the test results of 6 reinforced concrete beams with dimensions 150×200 mm and a 1700-mm clear span length subjected to a four-point loading system. The tested beams were divided into three groups; the first one refers to the glass Fiber-reinforced polymer bar effect. The second group is referring to the effect of concrete compressive strength, while the third group is referring to the effect of the GFRP bar volume ratio.

Conclusion Using longitudinal GFRP bars as a full or partial replacement of longitudinal steel bar reinforcement led to an increase in the failure load capacity and the average crack width, while a decrease in ductility was reported with a lower number of cracks. Increasing the concrete compressive strength is more compatible with GFRP bar reinforcement and enhanced the failure IJERTV13IS070067 ISSN: 2278-0181 Vol. 13 Issue 07, July-2024 performance of beams compared with normal compressive strength concrete

Jianwei Tu , Quan Zhao , and Kui Gao et.al (2021) :-“The Design of Concrete Beams Reinforced with GFRP Bars Based on Crack Width.” in this paper for GFRP-RC beams based on the flexure crack width. The state when the maximum flexure crack width in the tensile zone reaches the limit of 0.5 mm specified by ACI 440.1R-15 was used as the design limit state. The concrete compressive strain at the extreme compression Fiber of concrete under the design limit state was obtained by four-point bending tests of eight full-scale GFRP-RC beams and finite element analysis. Based on the concrete compressive strain under the design limit state and cross-sectional analysis, a design method for calculating the longitudinal reinforcement ratio of GFRP-RC beams under the design limit state is proposed. This design method is

proven to be feasible by the experimental and the finite element results.

Conclusion GFRP-RC beams based on the design method proposed in this paper have the flexural capacity coefficient of about 2.5, which means the beams have a very high factor of safety and reserve strength. Generally, the stress of the tensile bar material is no more than 30% of the ultimate strength, which makes it safe against creep failure too, thereby ensuring its long-term performance

Piotr Dybel, Milena Kucharska, Izabela Rzadzka et.al (2020):- “Analysis of flexural strength of beam elements reinforced with GFRP bars.” a composite reinforcement made with fibre-reinforced polymer (FRP) can be a suitable alternative to the traditional reinforcing steel due to its mechanical and physical properties. the purposes of this paper, an analysis of the flexural strength of concrete elements reinforced with FRP bars with varying reinforcement ratios was conducted. The tests were performed on six beam elements reinforced with glass fibre-reinforced polymer (GFRP) bars. The beams with dimensions of 0.15x0.2x2.5 m were subjected to 4-point bending. This study aimed to assess the influence of the reinforcement ratio on the flexural strength of concrete beams reinforced with composite bars and to verify the failure mechanisms against the guidelines presented in the standard ACI 440.1R-06.

Conclusion The reinforcement ratio has a significant impact on the failure mechanism and the flexural strength of beam elements reinforced with GFRP bars. An increase in the reinforcement ratio results in an improvement in the flexural strength of the specimen and is likely to change the failure mechanism - from rebar rupture to concrete crushing. The guidelines of ACI 440.1R-06 correctly estimate the flexural strength of the beam elements reinforced with GFRP bars.

Divya S Dharan, Aswathy Lal et.al (2016):- “Study The Effect Of Polypropylene Fiber In Concrete.” India leading developing country in world. In future high strength high performance concrete required for construction work. Fiber-reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. The character of Fiber-reinforced concrete changes with varying concretes Fiber materials, geometries, distribution, orientation, and densities. Polypropylene Fiber is a lightweight synthetic Fiber. It prevents crack formation and provides reinforcement to the concrete structure. In this project work polypropylene Fiber(Blended type) of different percentage (0.5%, 1%, 1.5%, and 2%) added in concrete. Tests on workability, compressive strength, flexural resistance, split tensile strength

Conclusion Compressive strength of 1.5% of blended length polypropylene Fiber reinforced concrete has found to be 17% increase in strength, when compared to that of Conventional concrete. Strength enhancement in split tensile strength is 22%, flexural strength is 24% and modulus of elasticity is 11% compared to that of Conventional concrete. The experimental studies proved to be the best method or way in providing strong and durable concrete. It is observed 1.5% Fiber in concrete yields max. strength

A.Mohamed Firdows, R.Mohamed Zakkaria: Corrosion has necessitated repairing or replacing steel reinforcing in many concrete structures. Non-corrosive reinforcing bars made of polymers with Fiber reinforcement (Fiber-reinforced polymer (FRP)) have seen a significant uptick in utilization over the last decade due to their improved characteristics and cost-effectiveness in concrete construction. It is recommended that Fiber-reinforced concrete (FRC) be used instead of plain concrete in FRP-reinforced beams to mitigate the issue of excessive crack width caused by using FRP bars as flexural reinforcement. Adding Fiber to concrete has been found to increase its durability and resilience against cracking. Flexural capacities and the cracking response of beams reinforced with FRP bars are examined to see whether FRC may improve them. Failure loads and cracking response in the constant-momentum zone were determined after beams were immersed/exposed to saline and alkaline solutions under accelerated conditions for 180 days (6 months). The beams used either plain or FRC reinforcing bars (glass Fiber-reinforced plastic (GFRP)-twisted and GFRPsand-coated). FRC and glass-reinforced polymer rebar (GFRP) are defined in terms of the bending behaviour of a hybrid system with discontinuous parts. Maximum fracture widths and flexural strength of beams reinforced with GFRP reinforcing bars may be improved using FRC.

Nooshin G. Amirabad, Farshid J: Fiber reinforced polymers (FRPs) have received considerable research attention because of their high strength, corrosion resistance, and low weight. However, owing to the lack of ductility in this material and the quasi-brittle behaviour of concrete, FRP-reinforced concrete (FRP-RC) beams, even with flexural failure, do not fail in aPCCBs were cast and tested under four-point bending conditions. The control beam failed due to shear, and the PCCBs exhibited different confinements and perforations. The goal was to find an appropriate PCCB for use in the compression zone of the beams, which not only improved the ductility but also changed the failure mode of the beams from shear to flexural. Among the employed blocks, a ductile PCCB with low equivalent compressive strength increased the ductility ratio of the beam to twice that of the control beam.

D. H. Tavares conducted experiments on six beams with steel and GFRP bar reinforcement. The cross-section of the beam specimen was 150×300 mm for a 2.9 m span length. The study of the beams was carried out using a four-point bending experiment. Observations showed comparatively high strain and lower elastic modulus at rupture. These critical parameters impact the flexural response of beams with GFRP reinforcement. When the behaviour of beams reinforced using hybrid reinforcement (GFRP and steel) was evaluated against concrete beams reinforced only with steel, it was observed that regulation of maximum internal tension force and reinforcement stiffness could result in appropriate flexural characteristics of beams reinforced with hybrid reinforcement.

Biswarup Saikia studied the performance and serviceability of GFRP-reinforced flexural members. In GFRP-reinforced concrete beams, bars mainly yielded due to slip along concrete and the bar, as well as a reduction in post-crack stiffness value. Supplementing the polypropylene Fibers did not significantly affect the post-cracking characteristics of beams reinforced with GFRP. An analytical equation was employed to predict the load–deflection response for the beams reinforced using GFRP, and predictions were close to the corresponding experimentally observed response. The response of hybrid-reinforced beams in flexure was studied by Wenjun Qu. Eight beams were cast, two using only steel rebars and GFRP, respectively, and the remaining six beams using hybrid reinforcement. The beam length was 1800 mm, and the cross-sectional area was 180×250 mm. Steel stirrups with 100 mm spacing and 10 mm diameter bars as shear reinforcement were used.

Bazli [67] investigated and tested RCC assemblies with hybrid-reinforced bars, discovering that the novel reinforcement technique exhibits bilinear stress–strain characteristics that can be implemented in new concrete structures. Furthermore, hybrid-reinforced [68] bars outperform traditional reinforcement in weight, corrosion resistance, and strength; additionally, tensile testing shows linear stress–strain characteristics. The beam can withstand more significant deformation than inelastic deformation during testing [69]. Studies were conducted regarding the shear stress of GFRP-reinforced members [70], and it was discovered that longitudinal reinforcement has little consequence on shear capability in GFRP-reinforced beams with various ratios. As a result, usual rational equations can be used to approximate shear strength.

In contrast, during the deformation in shear, the beams reinforced with GFRP were observed to be parallel

with RC beams having steel reinforcement. Additionally, shear strength was noticed to be less in beams of GFRP reinforcement than in beams of reinforcing bars of steel [66]. The main reason for the lower shear capability of GFRP-RC members compared to steel RC members is their lower modulus of elasticity leading to smaller compression block depth and weaker aggregate interlock. A shear stress equation was proposed in view of the data received from experimental analysis over the member reinforced with steel, found to be un-conservative in the beams using GFRP reinforcement [71]. Seven RC flexural rectangular members were tested, each with GFRP reinforcement and steel rebars (hybrid reinforcement). Two different types of rebars in two different layers were used near the tensile face of the beam. In addition, two concrete mixes are formed with strength values 30 MPa and 50 MPa, respectively [63]. Experiments with four-point flexure were performed on the flexural member, shown in Fig. 3, for the span of 2.1 m. It was witnessed that the beam failure was caused due to high deflection. The flexural member reinforced with only GFRP bars showed that at 7 kN load, beam stiffness is changing and increased in load–deflection behaviour till it failed at around 56 mm deflection. For steel and hybrid reinforced beams, a change in stiffness is observed at around 10 kN load and an increase in load–deflection behaviour till it fails at around 60 to 70 mm deflection. Also, due to distinct cracks along the middle part progressing in the direction of the beam top, the steel rebar employed for reinforcing had yielded crushing failure in concrete under compression. This failure is observed at the load value of around 40 kN (deflection: average 70 mm). Specimen of the concrete beam with lower strength was observed with increased cracks. The beam's failure also occurred due to a slip in the bond of internal rods made of GFRP, where the beams with composite reinforcement showed a mainly crushing failure of concrete. Bond-slip failure for GFRP-reinforced beam occurred at around 34 kN load (deflection at 56 mm). D. H. Tavares conducted experiments on six beams with steel and GFRP bar reinforcement [31]. The beam specimen's cross section was 150×300 mm for a 2.9 m span length. The study of the beams was carried out employing a four-point bending experiment.

Biswarup Saikia The observations showed comparatively high strain and lower elastic modulus under rupture. These critical parameters impact the flexure response of beams with GFRP reinforcement. When the beams' behaviour reinforced using hybrid reinforcement (GFRP and steel) was evaluated against concrete beams only with steel reinforced, it was observed that regulation of maximum internal tension force and reinforcement stiffness could result in appropriate flexural characteristics of beams reinforced with hybrid reinforcement [72]. studied the performance as well as serviceability of GFRP-reinforced flexural members [64]. In

the GFRP-reinforced concrete beams, bars yield mainly because of slip along concrete and bar as well as the post-crack stiffness value reduction. Supplementing the polypropylene Fibers did not significantly result in the post-cracking characteristic of beams reinforced using GFRP [73]. The analytical equation is employed to predict load–deflection response for the beams reinforced using GFRP, and predictions were close to the corresponding experimentally observed response [74].

The response of hybrid-reinforced beams in flexure was studied by Wenjun Qu. Eight beams were cast. Two beams used only steel rebars and GFRP, respectively, and the rest of six beams were cast using hybrid reinforcement. The beam length was taken as 1800 mm, whereas the cross-sectional area was 180×250 mm. Steel stirrups incorporating 100 mm spacing and 10 mm diameter bars as shear reinforcement were used [75]. Leung and Balendra studied the load vs deformation analysis of concrete beams internally reinforced using GFRP and steel bars. They observed that the presence of GFRP bars and the strength of concrete would significantly affect the maximum load bearing capability and failure pattern of the flexural member [63]. They also observed that flexural strength for the beam reinforced with mixed or hybrid reinforcement is higher. Saikia and P. Kumar experimented with the strength as well as service ability performance of beams with GFRP reinforcement. It is seen that the serviceability conditions for beams reinforced with GFRP are ruled by maximum crack width [76]. Researchers studied the influence of reinforcement ratio, surface characteristics, and concrete cover on the width and spacing of cracks in GFRP-reinforced elements [77]. It is observed that more concrete cover gives more crack spacing. For various load cases, the higher value of concrete cover will give scattered results. K. Subramanian and V. G. Kalpana assess the behaviour of beams with GFRP reinforcement in flexure. Experimental results were compared to numerical results. They observed that less stiffness of GFRP causes an increase in crack width. Concrete strength will not affect the crack width significantly. The load vs deformation response of numerical and test models was comparable [65]. Goldstone presented studies on the flexure behaviour of glass FRP-reinforced HS (high-strength) and UHSC (ultra-high-strength) concrete. Fang Yuan studied the behaviour of CFRP-reinforced concrete beams, and concrete was mixed using seawater and sea sand coral aggregates. Linear strain distribution is noted along the beam cross section. Due to the higher moment, the neutral axis shifted to the top of the beam, exhibiting the gradual formation of cracks in flexure [78]. Omar Gouda conducted experimental studies on the serviceability and performance of flexural GFRP-reinforced concrete beams [79]. It is seen that the beam fails due to

concrete crushing at the outermost compression layer. The beams with less ratio of reinforcement ($\leq 0.85\%$) showed bilinear behaviour in load–deflection, whereas those having high reinforcement ratio exhibited trilinear behaviour. An increment in the ratio of reinforcement led to a significant reduction in terms of deformity using deflection as well as energy influenced approaches. Furthermore, for a similar increment in the reinforcement ratio, the flexure capacity in serviceability increased more significantly than the highest moment capability. Omar Gouda also presented studies on “equations of development length” for GFRP bars in reinforced concrete beams. The “equations” proposed by authors showed required effectiveness and reliability in forecasting the development length based on initial stress intercept as per the regression analysis of the end splice test results. After reviewing the flexural behaviour of concrete beams with GFRP reinforcement, it can be concluded that the section with GFRP can be designed as over reinforced section and it is flexure critical. The strength of GFRP bars as well as grade of concrete significantly affects the load deflection behaviour of the member and load-carrying capacity of the member. The strong confinement in the flexure region by close spaced secondary reinforcement could result in a high index of ductility and maximum capacity with negligible influence on the “post-cracking” stiffness of the beams. Also, higher reinforcement ratio can increase ultimate capacity and can decrease deflection at service conditions as well as ultimate load conditions. The concrete covers considerably affect forecast of the “development length” which in turn depends on the bar size. For the development of full bonding stress of the GFRP bars, the cover of concrete to the midpoint of the bar is suggested as 2.5 of bar diameter for nearly all diameters of bar [80]

The failure loads in the tested beams show that the flexure capacity of the concrete beam with hybrid reinforced using hybrid steel/GFRP enhances with an elevated effective reinforcement ratio, ρ_{eff} . The observation implies that ρ_{eff} is one of the prime parameters in determining its flexural capacity for the hybrid reinforcement in the concrete beams using steel/GFRP. This hybrid structure enhances flexural behaviour in the concrete beams, whereas the reinforcement using steel improves the ductility in the beams with hybrid reinforcement. R. Mathieu, B. Brahim studied the outcome of aging this bond along with concrete and GFRP bar. Study shows that this mode of bond deformation mainly relies on the bar’s coating layer and surface profile [81]. The coating layer enhances bond performance. The bond strength along GFRP concrete will reduce with increasing immersion time. Under aggressive atmospheric conditions, the study shows that change in bond strength is minor and hence negligible at elevated temperatures.

V G Kalpana cast and studied nine beams for the two-point loading experimentation. For the given beam, a 200×250 mm cross-sectional dimension with an 1800 mm span length. They studied the characteristic behaviour of beams reinforced using GFRP bar in the concrete under a two-point loading system with a diameter of bar and grade of concrete as a variable parameter. In the first group, three beams were cast using an actual strength value of 20 N/mm². Also, GFRP bars of diameters 16 mm, 20 mm, and 24 mm were used for the reinforcement along the tension face. In the second phase, beams were cast using the same count of GFRP bar and diameter value with a concrete compressive strength value of 40 N/mm². The last group consists of three beams with the same GFRP bar count and a concrete compressive strength value of 60 N/mm². Two hanger bars (GFRP) with 10 mm diameter were employed for all beams. High-strength concrete embedded with GFRP bar exhibits better performance when compared with regular strength concrete embedded with GFRP bar regarding the load-carrying and deflection capacity because of the high-tension capacity. GFRP bars with depressed stiffness led to enhanced crack width. Mohamed S. Issa experimented with the behaviour of beams using Fibers to assess mechanical properties like flexure and ductility. Further, it was noted that adding steel Fibers enhances the ductility in FRP-reinforced flexural members by around 300%. The accuracy in the deflection equation varies with varying load levels. More substantial deviations were observed nearer to the ultimate load. The span to experimental load deviation ratio was comparatively more remarkable than the regularly recognized ratio for the span/250. M.W. Goldston experimented and studied the flexural behaviour in the concrete beam with the GFRP-reinforced high and ultra-high strength. Observations were made that using UHSC with 117 MPa is more advisable for enhancing load-carrying capacity in over-reinforced (GFRP-RC) beams compared with the HSC with 95 MPa [5]. Also, as the strength of concrete is enhanced to 117 MPa, UHSC from 95 MPa, HSC load carrying capacity is elevated by 13% and 27% for the reinforcement ratio of $p_f = 2.0\%$ and $p_f = 1.0\%$, respectively [56]. Deviation in the middle of the span was noticed to have increased with increasing the concrete strength to 117 MPa, UHSC from 95 MPa, and HSC with the same reinforcement for GFRP-RC beams over reinforced. It is observed that over the period, many studies have been carried out to understand the flexural behaviour of GFRP-reinforced concrete members. This discussion highlights the various parameters affecting flexural strength. Hybrid reinforcement for cement, high-strength concrete enhances the flexural behaviour of FRP-reinforced concrete structures. Concrete cover, reinforcement ratio, bar spacing, and confinement due to the transverse reinforcement

in the bending zone are the parameters required to study the flexural strength of such structures.

III. RESEARCH GAP

- 1) Limited studies have investigated the combined effect of GFRP bars, polypropylene Fibers, and waste granite aggregate on the flexural performance of reinforced concrete beams.
- 2) The synergistic influence of polypropylene Fibers and waste granite aggregate on crack propagation and serviceability behaviour of GFRP-reinforced beams remains insufficiently explored.
- 3) Existing research predominantly focuses on individual material performance, while integrated sustainable concrete systems incorporating GFRP, PP Fibers, and WGA are rarely evaluated.
- 4) There is a lack of comprehensive experimental data on the optimum proportions of polypropylene Fibers and waste granite aggregate for maximizing the structural efficiency of GFRP-reinforced concrete beams.

IV. OBJECTIVE

- [1] To investigate the flexural behaviour of GFRP-reinforced concrete beams incorporating polypropylene Fibers and waste granite aggregate.
- [2] To evaluate the influence of polypropylene Fibers on crack resistance, ductility, and post-cracking performance of concrete beams.
- [3] To assess the effect of partial replacement of natural coarse aggregate with waste granite aggregate on the structural performance of beams.
- [4] To develop a sustainable and high-performance concrete system with enhanced load-carrying capacity, durability, and flexural strength.

V. CONCLUSION

1. The literature review confirms that GFRP bars are an effective alternative to conventional steel reinforcement due to their high tensile strength, corrosion resistance, and lightweight characteristics.
2. GFRP-reinforced concrete beams exhibit superior durability, particularly in aggressive environments where steel reinforcement is vulnerable to corrosion.
3. The flexural performance of concrete beams can be significantly enhanced through the incorporation of GFRP reinforcement.
4. Most studies reported an increase in ultimate load-carrying capacity with the use of GFRP bars compared to conventional steel-reinforced beams.

5. The lower modulus of elasticity of GFRP bars results in higher deflections under service loads when compared with steel reinforcement.
6. Polypropylene Fibers effectively control micro-crack formation and delay crack propagation in concrete members subjected to flexural loading.
7. The addition of polypropylene Fibers improves post-cracking behaviour, toughness, and energy absorption capacity of concrete.
8. The combined use of GFRP bars and polypropylene Fibers provides a synergistic improvement in crack resistance and structural performance.
9. Partial replacement of natural coarse aggregate with waste granite aggregate contributes to sustainable construction practices by reducing environmental waste.
10. Waste granite aggregate can be utilized in concrete without significantly affecting its mechanical properties when used within optimum replacement levels.
11. Several researchers observed improved bond characteristics and load transfer mechanisms when GFRP reinforcement was properly integrated into concrete.
12. Increasing the GFRP reinforcement ratio generally enhances flexural strength and changes the failure mode from reinforcement rupture to concrete crushing.
13. GFRP-reinforced beams commonly exhibit a linear elastic response up to failure, unlike steel-reinforced beams which possess yielding behaviour.
14. The use of GFRP reinforcement improves the service life of reinforced concrete structures by eliminating corrosion-related deterioration.
15. Experimental investigations demonstrated that crack widths and deflections remain the primary serviceability concerns in GFRP-reinforced members.
16. The incorporation of polypropylene Fibers helps mitigate these serviceability issues by improving crack control and matrix integrity.
17. Sustainable concrete containing waste granite aggregate and polypropylene Fibers show promising potential for structural applications.
18. The reviewed studies consistently indicate that GFRP-reinforced concrete beams possess excellent load-bearing capability and enhanced durability characteristics.
19. The combined utilization of GFRP bars, polypropylene Fibers, and waste granite aggregate offers an innovative approach for developing high-performance and eco-friendly concrete structures.
20. Overall, the review establishes that GFRP-reinforced concrete beams incorporating polypropylene Fibers and waste granite aggregate represent a viable and sustainable solution for modern infrastructure requiring improved flexural performance, durability, and long-term structural reliability.
21. The present review study examined the flexural behaviour of concrete beams reinforced with Glass Fiber Reinforced Polymer (GFRP) bars and enhanced with polypropylene Fibers and waste granite aggregate. Based on the comprehensive review of previous experimental investigations, it is evident that GFRP reinforcement offers significant advantages over conventional steel reinforcement in terms of corrosion resistance, high tensile strength, lightweight characteristics, and long-term durability.
22. The literature indicates that GFRP-reinforced concrete beams exhibit superior load-carrying capacity and improved resistance to aggressive environmental conditions. However, due to the relatively lower modulus of elasticity of GFRP bars, higher deflections and wider crack widths may occur when compared to steel-reinforced concrete members. The incorporation of polypropylene Fibers effectively improves crack control, post-cracking behaviour, toughness, and energy absorption capacity, thereby enhancing the overall ductility of the concrete matrix.
23. Furthermore, the partial replacement of natural coarse aggregates with waste granite aggregate has been found to promote sustainable construction practices by reducing environmental impacts associated with quarrying activities while maintaining satisfactory mechanical performance. Several studies have reported that an optimum percentage of waste granite aggregate can improve the interfacial bond characteristics and contribute to enhanced strength properties of concrete.
24. The review also highlights that the combined utilization of GFRP bars, polypropylene Fibers, and waste granite aggregate creates a synergistic effect, leading to improved flexural performance, delayed crack initiation, enhanced durability, and sustainable structural behaviour. Therefore, this integrated approach represents a promising solution for the development of high-performance and environmentally sustainable reinforced concrete structures.
25. Finally, the findings from the literature provide a strong foundation for conducting further experimental investigations on GFRP-reinforced concrete beams incorporating polypropylene Fibers and waste granite aggregate, with the objective of optimizing material proportions and improving structural efficiency under flexural loading conditions.

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