Review on flexural performance of reinforced concrete beams designed with hybrid bars

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Abstract.. Reinforced steel bars, commonly used in concrete construction, are prone to corrosion due to their insufficient corrosion resistance, which ultimately leads to reduced durability and long-term performance. Moisture interaction is the leading cause of corrosion, which results in rust, cracks, and spalling, leading to durability and long-term performance issues. To address this problem, FRP bars are now being introduced to the market, which offer numerous benefits over steel bars, such as strong corrosion resistance, higher tensile strength, and reduced weight, leading to lower shipping and labor costs. Concrete gains mechanical stability, stiffness, durability when polypropylene fibres are used, improving the material's effectiveness. The purpose of this study is to examine the flexural behavior, load-deflection characteristics, and ductility of hybrid reinforced concrete beams. that use both GFRP bars and steel bars, as well as compare them with reinforced concrete beams that use only GFRP bars or steel bars with and without using polypropylene fibres as a supplement. In order to enhance the beams flexural strength as well as ductility, it has been identified that 0.25% of their volume should be made up of polypropylene fibres. After the experimental investigation is finished, analytical studies using ANSYS simulation will be carried out to determine the load-deflection behaviours.

Keywords. Glass Fiber Reinforced Polymer bar, Polypropylene fiber.

1 Introduction

Concrete is renowned for its versatility, durability, and reliability as a building material. Despite its high compressive strength, it has lower rigidity and is therefore sensitive. In many countries, the use of waste materials is challenging due to rising raw material costs and the depletion of natural resources. Throughout history, fibers have been used for reinforcement, such as horsehair and straw for mortar and mud.

In the 1950s, fiber-reinforced concrete became more important, and by the 1960s, steel, glass, and synthetic fibers, such as polypropylene and polyolefin, gained significance. Fibers prevent plastic and drying shrinkage, which cause cracks. The addition of polypropylene fibers decreases compressive strength but increases split tensile and flexural strength. Compared to traditional concrete, fiber-reinforced concrete has more pores, leading to improved tensile and flexural strength through fiber bridging. The fibers also enhance resistance to ion penetration, reducing the risk of reinforcing bar corrosion.When fibers are added, concrete becomes ductile, homogeneous, and isotropic, providing additional support and preventing fractures. The production of fiber-built-up concrete consolidates discrete, scattered, and irregular strands, forming a composite material. Hybrid fiber-reinforced concrete, which uses a combination of fibers, enhances ductility, controls fracture growth with strong fibers, and limits crack initiation and spread with thick and soft fibers. Steel fibers fill cracks in concrete mixtures, increasing joint shear strength.

1.1 Polypropylene Fiber

Polypropylene fiber (PPF) is a type of synthetic fiber made from the polymerization of propylene. Due to their beneficial characteristics, such as their low weight, excellent strength, superior toughness, and resistance to corrosion, PPFs are advantageous due to these characteristics in a number of industries, including the chemicals sector, energy, apparel, protection of the environment, and construction. Within the construction sector , PPFs are often used as a reinforcement material due to their versatility, low specific weight, mechanical properties, chemical properties, dimensional stability, and vapour barrier. Furthermore, PPFs are an affordable and practical replacement for mesh as a reinforcing technique. They expedite the building process by reducing the occurrence of retraction and contraction fractures,lower labour costs, provide a secondary, uniform reinforcement, non-magnetic and impervious to corrosion and give greater toughness, improved impact resistance, safety during construction, 3D strengthening, and excellent traction resistance. One of the benefits of PPFs is that they can be added to concrete mixtures in small quantities and still provide significant improvements to the material's properties. For example, adding a small amount of PPFs to concrete can improve its ductility and toughness, making it more resistant to cracking and damage. Additionally, PPFs can be added to other materials such as asphalt and plastics to improve their strength and durability. Overall, PPFs are a versatile and cost-effective reinforcement material that can improve the properties of a wide range of materials. Their use in construction is increasing due to their advantageous properties.

Fig 1 PPF

1.2 Glass Fiber Reinforced Polymer

The use of Glass Fiber Reinforced Polymer (GFRP) materials has become increasingly popular in recent years, particularly in the restoration and strengthening of older structures such as bridges and homes. However, the strength and stiffness of externally reinforced RC beams that are reinforced with GFRP plates and textiles can be significantly affected by the connection between the GFRP plate and the floor of the RC beam, particularly in harsh environmental conditions. Therefore, it is important to thoroughly examine the overall performance of these externally reinforced RC beams under various environmental elements. GFRP structures have gained significant attention in various technological sectors over the past few decades due to their high specific stiffness and strength. However, they are also prone to cycle stress or fatigue, particularly in aerospace and other structural applications. In the laboratory, fatigue is defined as a varying load or stress that is not sinusoidal, and its defining traits are the load ratio, frequency, and maximum stress. The phenomenon of fatigue impact (IF) is critical to the structural integrity of additives and structures due to its negative impact on overall performance. Even a modest number of low amplitude cycles can result in impact fatigue, making it crucial to the structural integrity of additives and structures. Therefore, it is essential to thoroughly investigate the effect of fatigue on GFRP materials, especially when they are used in critical applications. Furthermore, the use of GFRP materials in construction has several advantages, such as their high strength, low weight, and resistance to corrosion. They are also easy to handle and install, making them an attractive option for use in various structural applications. However, the properties of GFRP materials can vary depending on their manufacturing process and composition, and it is important to choose the appropriate material for each application to ensure maximum effectiveness. Overall, the use of GFRP materials in construction is a promising area that requires further research to fully understand their capabilities and limitations.

Table 1.1 Physical Properties of GFRP bars

Strength in Tensile(MPa)	950
Modulus of Elasticity(GPa)	Greater than 60
Ultimate Strain (%)	1.5-2%
Density (Kg/m^3)	2100
Bond Strength to Concrete(Mpa)	>20
Transverse Shear Strength	220
Yield Strain	>58%
Yield Tensile Strength	>13
Crack tolerations in aqueous condition	0.7mm
Length (m)	2m
Diameter(mm)	12mm

1.3 Micro Silica

Microsilica, commonly referred to as silica fume, is an outcome of the manufacture of ferrosilicon alloys and silicon metal. It is an additional cementitious material added to concrete to boost its characteristics. It is an extremely reactive, amorphous silica powder.. In civil engineering, microsilica has been widely used for over three decades to improve the durability, strength, and sustainability of concrete. One of the main advantages of microsilica is its high pozzolanic reactivity. During the hydration of cement, it reacts with the calcium hydroxide in order to produce more calcium silicate hydrate (C-S-H) gel. This gel fills pores in the concrete, making it denser and more impermeable. As a result, microsilica increases the compressive strength, flexural strength, and abrasion resistance of concrete. Another advantage of microsilica is its ability to reduce the permeability of concrete. The addition of microsilica decreases the size of the capillary pores in the concrete, making it less permeable to water and other substances. This reduction in permeability leads to increased durability and resistance to chemical attacks, as well as improved resistance to freeze-thaw cycles. Microsilica also has positive effect on the workability of concrete. It acts as a lubricant, improving the flowability of concrete during placement and reducing the amount of water needed. This results in a more cohesive and uniform mixture, which reduces the risk of segregation and bleeding. However, the use of microsilica in concrete does have some challenges. The high specific surface area of microsilica can cause it to clump together, making it difficult to disperse uniformly in concrete. This can result in lower workability and lower strength if not managed properly. Additionally, the high reactivity of microsilica can lead to a rapid increase in the temperature of the concrete during hydration, which can cause thermal cracking.

2 Literature review

Ramesh gopal (2020) said that In hostile conditions, hybrid GFRP-reinforced sections can replace traditional RC beams while retaining the same flexural capacity and enhancing reserve strength. In spite of having less stiffness, the hybrid sections exhibit superior post-cracking behaviour due to superior fracture distribution, consistent crack width, and higher post-yield stiffness. In accordance with deformability and energy criteria, ribbed bars are assessed to be more malleable than routine RC sections. The use of GFRP bars in place of bigger cover concrete in RC structures for flexural response is successful when paired with traditional steel reinforcement. As a way to prevent cracks from propagating to the primary reinforcement, GFRP bars should be placed in close proximity to the soffit of the beam. This element of durability, however, needs more research.
Phan Duy Nguyen (2020) The work extends the prior literature, which only provided three stages of performance and four failure modes, by identifying four stages of performance and six failure modes for hybrid GFRP/steel RC beams. The stiffness, ductility, and toughness of hybrid GFRP/steel RC beams are significantly influenced by the amount of longitudinal reinforcements (s, g), the ratio of longitudinal reinforcements, and the longitudinal reinforcements themselves. For evaluating the ductility of these beams, the energy ductility index was proposed. The inclusion of GFRP reinforcement protects steel from yielding, and enhancing the reinforcement ratio boosts the hybrid RC beams' capability to withstand greater loads. For determining the ductility of these beams, the energy ductility index has been suggested. The inclusion of GFRP reinforcement prohibits steel against yielding, and enhancing the reinforcement ratio boosts the hybrid RC beams' potential to withstand more weight. The load capacity of GFRP RC beams can possibly be calculated using the

recommended analytical model, which employs non-linear deformation models to calculate the steel yielding moment and ultimate flexural capacity.

Qiang Sun et al.(2020) On seven reinforced concrete beams with various PVA contents and GFRP diameters, the study examined the bending performance. The experiment highlighted that GFRP concrete beams lacking fibres failed brittlely, yet those with PVA fibres failed plastically due to the restriction of growth of cracks. The experimental findings indicated that the FRP suggestions for design were conservative, and the bending analysis agreed with the assumption of a plane section. The ultimate bearing capacity of beams risen with GFRP diameter, and PVA fibre content increased by GFRP reinforced concrete beams to boost crack formation resistance. The study provides suggestions for the design and construction of beams made of concrete by claiming that GFRP bars and PVA fibres can improve their ability to bend and avoid cracks from developing.

Filipe R.G.de Sa et al. (2020) The study looked at how Polypropylene (PP) fibre additions affected the tensile and flexural behaviour of concrete. Pullout tests, direct testing for tensile strength, and four-point bending tests were performed to evaluate the mechanical attributes of the material. The strategic placement of PP fibres improved the structural elements' ductility and stiffness as well as minimising the space between fractures and gaps. However, it turned out that there was little effect on the connection performance among GFRP and concrete. The study also discovered that the shear persistence effect may have had an impact on its findings and that stress must be taken seriously while examining fractures in tensile aspects. Overall, it showed that adding PP macro-fibers to concrete beams made of GFRP RC and GFRP/PP RC was advantageous, improving ductility by up to 162%.

Zein Saleh et al. (2019) In this study, two standards of design for FRP bar concrete beams made of reinforcement are investigated and their results are compared with those of GFRP bar reinforced concrete beams in test results. According to the study, the load taking capabilities, peak deflections, and absorption of energy capacities of under-reinforced as well as balanced GFRP-RC beams were over-predicted by the relevant code guidelines, whereas over-predicted readings have been identified for over-reinforced GFRP-RC beams. For GFRP-RC beams that had high concrete compressive strength and a reinforcement ratio of 1.0%, ACI and CSA was predicted nearer results to the actual data with respect to of maximum loads, midspan deflections at maximum loads, and EAC.

Xiangjie Ruan et al. (2019) This study analyses the bending behavior of beams made of concrete reinforced using GFRP-steel combination reinforcement, and it also summarizes the outcomes of that research. To lower the danger of steel corrosion in concrete, two hybrid reinforcing systems that substitute GFRP bars for steel bars have been developed. The failure in flexure for all tested hybrid-reinforced beams turned out to be compatible with the expected failure system when findings from experiments were contrasted with the results derived from present theoretical models. GFRP bars' strain throughout the failure phase was lower than their breaking strain. For these hybrid-reinforced beams, the requisite nominal reinforcement ratios held true. The cited steel-reinforced concrete beam's maximum bending capability was around 5% higher than that of the combination-reinforced beam with the identical area of GFRP bars substituting steel bars.

Seongeun Kim and Seunghun Kim (2019) The stiffness and strength of concrete specimens reinforced with FRP and steel bars were compared in the study. The samples made with FRP reinforcement could withstand further pressures even after the steel reinforcement started to give, despite producing more fractures and having less stiffness after cracks developed. For samples with FRP reinforcement, the displacement at their strongest point was more than threefold greater than the displacement at yield strength for specimens with steel reinforcement. Further investigations will employ the use of an analysis of the finite element model, which was utilised to assure the precision of the load-deflection curves. contrary to the study, FRP reinforcement in concrete constructions can be an effective replacement for steel reinforcement.

Wenchang He et al. (2020) This study looked at how steel and polypropylene fibres affected the mechanical characteristics of concrete made from recycled aggregate (RAC). While polypropylene fibres had little influence, steel fibres significantly raised the compressive strength of RAC. As when compared to plain RAC mixtures, the hybrid fibres enhanced their compressive strength by up to 16.7%. Beyond certain amounts of hybrid fibres, the effect was, however, diminished. The splitting tensile and flexural strengths of RAC were similarly seen to rise initially with the addition of polypropylene fibres, but afterwards to decrease with increasing content. The strongest influence in raising the flexural toughness of RAC came from steel and polypropylene hybrid fibres. The study advances to the conclusion that adding steel or polypropylene fibres can enhance RAC's post-cracking performance.

Wenjie Ge et al. (2019) The load carrying capacity, deflections, and fracture widths of hybrid reinforced beams utilising both steel and FRP bars were looked into in the study. In accordance with the findings, when compared with FRP reinforced control beams, the hybrid reinforced beams had a load capacity, deflection, and crack width of 1.19-1.37, 0.19-0.55, and 0.230.81, respectively. ECC implementation. additionally improved the concrete regulating beams' load capacity, deflection, and rupture breadth. The yield, final moment, material deformation, and fracture width of the hybrid reinforced ECC samples all improved. In contrast to GRP reinforced concrete samples, which ranged in fracture width and deflection from 23% to 81% and 19% to 55%, respectively.

Cong zang et al. (2018) In this work, the bending strength of self-compacting concrete (SCC) beams using various longitudinal reinforcement ratios was looked at in connection with the consequences of steel fibre, micro PP fibre, and macro PP fibre, separately and in combination. The ultimate flexural bearing capability of reinforced SCC beams may be substantially enhanced by steel fibre, and the load capacity can be further increased by combining steel fibre with macro PP fibre. However, as the proportion of longitudinal reinforcement advances, the impacts of fibres on the bearing capacity becomes less apparent. The bearing capacity of reinforced beams is considerably more influenced by steel fibre than PP fibre. The addition of fibers can also reduce the localized deformation-induced deflection and strain on longitudinal reinforcement.

3 Objectives

The purpose of this study is to:-

1. To investigate the flexural capacity and ductility of various FRP bar types.
2. To investigate the various fibres that optimise flexural qualities and determine the ideal volume proportions for fibres.

4 Conclusions

1. The addition of steel fibers results in a 16.9% increase in compressive strength for SFRC and a 21.7% increase for PPRC. The maximum split tensile strength of HFRC increases by 51.1% and 39.8% respectively.
2. The introduction of PP macro-fibers increases the strength in tensile portion of the reinforcement elements and decreases fracture intervals and apertures in the cracked stage but has no effect on the connection effectiveness among GFRP and concrete throughout the attachment stage.

3. The combination of conventional steel and pp fibers can enhance the post-fracturing behavior of cement-based matrices, resulting in higher post-fracturing bending strengths and tougher behavior.
4. High temperatures can significantly reduce the ultimate load of hybrid concrete GFRP reinforced beams.
5. High fiber content can cause mixing and compaction issues, non-uniform fiber distribution, and more voids. Combination(Hybrid) systems can address PFRG weaknesses, but careful selection and fiber content are crucial.

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