Review on Flexural Performance of Reinforced Concrete Beams with Hybrid Fiber Reinforced - Concrete using Coconut Coir and Glass Fibers

M Rajath[1], Dr. Archana D P[2]
[1]PG Student(M.Tech), Department of Civil Engineering, Bangalore Institute of Technology, Bangalore, Karnataka, India
[2]Assistant Professor, Department of Civil Engineering, Bangalore Institute of Technology, Bangalore, Karnataka, India

Abstract — **Hybrid Fiber-Reinforced Concrete (HFRC) has emerged as an effective construction material because it offers higher strength, better durability, improved ductility, and greater crack resistance than conventional concrete. This review examines the performance of concrete reinforced with both natural fibers, such as coconut coir and bamboo, and synthetic fibers, including glass, polypropylene, steel, carbon, and Kevlar fibers. Previous studies show that hybrid fibers significantly improve compressive strength, tensile strength, flexural strength, toughness, impact resistance, and energy absorption capacity. Different fibers work together to control both microcracks and macrocracks, which reduces brittleness and improves post-cracking behavior. Natural fibers support sustainable construction due to their renewable and biodegradable properties, while synthetic fibers enhance strength, stiffness, and long-term durability. The literature also shows that fiber content, aspect ratio, fiber length, and fiber combinations strongly affect the overall performance of HFRC. Optimizing the fiber content in hybrid fiber-reinforced concrete enhances structural performance while ensuring adequate workability and uniform dispersion of fibers within the concrete matrix. HFRC demonstrates significant potential for use in reinforced concrete beams, pavements, repair and rehabilitation projects, precast concrete units, and other high-performance structural applications. This review summarizes key findings from prior studies, presents recent advances in HFRC technology, and emphasizes the need for further research on long-term durability, economic feasibility, and practical large-scale implementation in structural engineering applications.**

Index Terms — **Hybrid fiber reinforced concrete (HFRC), Coconut coir fiber, Glass fiber, Flexural behavior, Crack resistance, Ductility, Sustainable construction.**

I. INTRODUCTION

Concrete is widely used in construction for its excellent compressive strength, durability, and ability to be molded into various shapes. Despite these advantages, ordinary concrete has relatively low tensile strength and is brittle, making it susceptible to cracking under tensile and bending stresses. The formation of such cracks can adversely affect the structural strength, durability, and overall lifespan of concrete elements. To overcome these limitations, fibers are incorporated into concrete to improve its tensile strength, ductility, impact resistance, and crack control behavior [1]. Fiber Reinforced Concrete (FRC) has gained significant attention in recent years due to its ability to enhance both mechanical and durability properties of concrete structures. Different types of fibers such as steel [8], glass [2-3], polypropylene [14], carbon [17], Kevlar [15], and natural fibers like coconut coir [1-11], bamboo [19], sisal [10], and jute [10] have been used in concrete to improve its performance. Among these, hybrid fiber reinforced concrete (HFRC), which combines two or more types of fibers, has shown remarkable improvement in structural behavior compared to single-fiber reinforced concrete. The combination of natural and synthetic fibers helps in controlling cracks at different stages, improving energy absorption capacity, and enhancing flexural and tensile strength. Synthetic fibers mainly contribute to strength and durability, while natural fibers provide sustainability, economic benefits, and eco-friendly characteristics.

II. COCONUT COIR FIBER COMPOSITES

Coir is a natural lightweight fiber having the highest toughness among all-natural fibers. It is one of the most widely investigated natural fibers in cementitious materials compared to other natural fibers (i.e., jute fiber, sisal fiber, and banana fiber). In this review article, the findings of different research articles have been collected and analyzed to observe the possible benefits and drawbacks of using coir as fiber reinforcement in cementitious materials. The effect of coir was studied for the different properties of concrete, including workability, fresh density, hardened density, water absorption, compressive strength, modulus of elasticity, splitting tensile strength, flexural behavior, impact toughness, and ultrasonic pulse velocity [1]. The mechanical properties of Normal Concrete (NC), Glass Fiber Reinforced Concrete (GFRC), and Hybrid Fiber Reinforced Concrete (HFRC) were evaluated through standard laboratory tests, including compressive strength and splitting tensile strength tests. A total of 36 specimens were cast and tested using M30 grade concrete. The fiber content was maintained at 0.5% of the total concrete volume for all fiber-reinforced mixes. Six different concrete mixtures were prepared, consisting of a control mix without fibers, a mix containing 0.5% glass fibers, and four hybrid combinations of glass and coconut fibers with the same total fiber volume fraction. The test results indicated that the incorporation of fibers generally enhanced the mechanical performance of the concrete. However the increase was found to be nominal in case of compressive strength (29.74%), significant in the case of splitting tensile strength (70%), at 0.35% glass fibers and 0.15% coconut fibers [2].

Fig 1: Coconut Coir Fiber

Fiber reinforced concrete composites are a group of high-performance materials with considerably enhanced stress-strain properties. Similar effects can also be achieved using polymeric binders whereby the inclusion of the polymers as binder can significantly enhance the physical-mechanical properties of the resulting concretes. In this regard, the following study investigates the impact of utilizing natural (e.g., coconut) versus artificially manufactured fibers (e.g., glass fiber) in polymer-cementitious composites. In doing so, 14 mixes were produced using various ratios of the two fibers. To evaluate the properties of the produced samples a series of tests including flow diameters, unit weights, water absorption values, compressive strengths, flexural strengths and ultrasound transmission rates were determined. Also, to evaluate the micro structural cohesion of polymer-cement and polymer-coconut samples, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) has also been used. The results show that the surface texture of fibers can play a key role in major engineering properties of the fiber reinforced concretes and that the natural fibers have great potential to be used as high-performance materials in cementitious composites. Also, it is found that the use of polymer as the main binder can provide higher adhesion with fibers containing smoother surface (e.g., glass fiber) at the interfacial transition zone (ITZ) [3]. The present study investigated the mechanical properties and impact resistance of concrete reinforced with coconut fibers (CF) and polypropylene fibers (PPF). Accordingly, experimental evaluations of CFRC and PPFRC were conducted employing various fiber lengths and volume fractions to determine the optimal configuration. Results indicated that a combination of

12 mm polypropylene fibers and 50 mm coconut fibers is the most effective for Hybrid Fiber Reinforced Concrete (HFRC). Subsequently, hybrid concrete mixtures were designed by adjusting the proportions of both fibers while maintaining total fiber contents at 0.2% and 0.3% by concrete volume. The improvement in strength was observed to be maximum when the total fiber content in the hybrid fiber reinforced concrete was 0.3%. The increase in impact resistance of HFRC was almost double that of individual FRC and three times that of plain concrete [4]. Generally, plain concrete has a very low tensile strength and limited resistance to cracking prior to the ultimate load. Fibre hybridization with different types of fibres helps in resisting these cracks in the concrete structures. This study focuses on evaluating the rheological and mechanical characteristics of hybrid fiber-reinforced concrete (HFRC) containing steel fibers and coconut (coir) fibers, and comparing its performance with that of conventional concrete. Experimental investigations were conducted on cylinder and prism specimens prepared using control concrete and HFRC mixes containing 2%, 4%, and 6% fiber content by weight of cement. The proportion of waste steel fibers was maintained at a constant 1% in all HFRC mixtures throughout the study. The fresh concrete properties were assessed using slump, compacting factor, ball penetration, and density tests, and the results were compared with those of normal concrete. Additionally, the mechanical performance of HFRC was evaluated through compressive strength, splitting tensile strength, and flexural strength tests. The test results indicate that the incorporation of hybrid fibres in the concrete decreases the concrete workability compared to the control concrete. The experimental results showed that the compressive strength is improved compared to the control mix whether the splitting and flexural strength shows an 18.36% and 24.87% improvement over the control mix. Finally, the inclusion of optimum content of hybrid fibers that is 2% by weight of cement showed enhancement in the mechanical properties of HFRC in terms of compressive, tensile and flexural strength with compared to control concrete [5]. The use of untreated coconut coir fibers as a sustainable reinforcement in cement mortars, with emphasis on the combined effects of fiber content (0.5–2.0% by volume) and length (10–25 mm) on mechanical performance and water absorption. Sixteen mortar mixes were tested for water absorption, flexural and compressive strength, and micro structural characteristics. Results showed that moderate fiber addition significantly improved both strength and durability. The optimal mix (1.0% fiber, 15 mm length) achieved 8.36 MPa in flexural and 29.28 MPa in compressive strength, representing 61% and 131% improvements over the control, respectively. It also recorded the lowest water absorption (8.38%), attributed to improved fiber–matrix bonding and densification of the interfacial transition zone, as confirmed by Scanning Electron Microscopy. In contrast, excessive fiber dosages led to agglomeration, reduced workability, and diminished performance. A third-degree polynomial regression model was developed to predict mechanical properties based on fiber parameters. The findings demonstrate the feasibility of using untreated coconut waste fibers to enhance mortar performance while contributing to sustainable construction practices aligned with circular economy principles and SDGs. This work provides practical insights into fiber optimization and supports broader adoption of bio-based materials in cementitious systems [6].

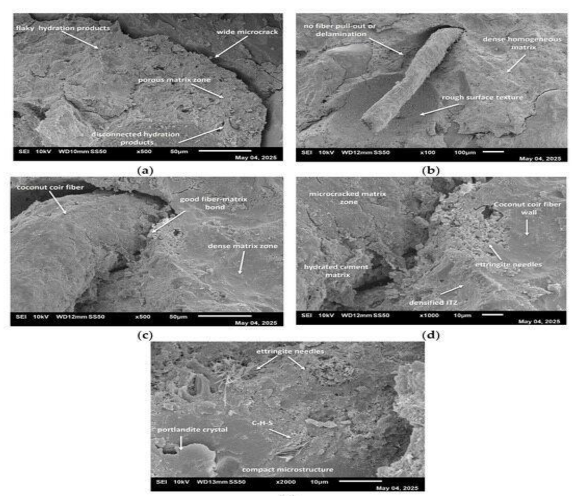

Fig 2: SEM and microstructural image showing fiber matrix interaction and crack bridging mechanism. Source: Danah Alenezi, Dema Mohammad. Strenth & water absorption behaviour of untreated coconut fiber reinforced motors. 2025, 5(3), 69. [6]

To evaluate the suitability of short coconut and PP fiber as a reinforcing agent in cement concrete.

Mixing and casting of untreated coconut and PP fiber in RCC check the mechanical properties of HFRC. The experimental background is cited in the literature. Methods/Statistical Analysis: From the basic tested data a mix design for M20 grade concrete at a weight of cement fraction is 1%.For this work 12nos of cube (150 mm * 150 mm * 150 mm) and 12nos of beam (700mm *150 mm*150 mm) were casted by using different fiber proportion of polypropylene fiber & coconut fiber in the laboratory; along with one set of control sample were examined and compared with the HFRC. Findings: All the cube specimens were tested by UTM and beam specimens were tested in UTM by using two points loading as per IS 516-1959. The test result shows that the weight fraction of 1% with Polypropylene 0.75 – coconut coir 0.25 combination specimens improves compressive strength and flexural strength as compared with control specimen. Applications/Improvements: The use of hybrid fiber reinforced concrete in non-structural components like Walls & Surfaces of Septic Tank, Water Storage Tanks and Dams, Sports Grounds, Industrial, Residential Floors & Warehouses etc. The major contribution of fibers in crack resistance and crack control, improve ductility of concrete [7]. This study examined the performance of high-performance concrete (HPC) reinforced with hybrid coconut and steel fibers. Different proportions of coconut fiber (0.1–0.3%) and steel fiber (0.5–1%) were used to evaluate compressive strength, tensile strength, flexural behavior, and durability. The results showed that the combined use of both fibers significantly improved the mechanical and flexural properties of HPC, with optimum performance observed at 0.1–0.3% coconut fiber and 0.5% steel fiber. The study also suggested that adding 0.1–0.2% coconut fiber provides better strength and durability while maintaining acceptable permeability resistance. This study provides insight into the development of eco-friendly and cheap hybrid fibre-reinforced HPC using CF [8]. Increasing concern about global warming and depleting petroleum reserves have made scientists to focus more on the use of natural fibres such as bagasse, coir, sisal, jute etc. The growing emphasis on sustainable construction has encouraged the adoption of natural fibers in composites as eco-friendly alternatives to petroleum-based materials. In India, the abundant availability of natural fibers makes them attractive for engineering and construction applications, owing to their low cost, light weight, biodegradability, recyclability, and good strength-to-weight ratio. Furthermore, agricultural waste can be efficiently repurposed for manufacturing fiber-reinforced composites. While synthetic fiber composites like glass fiber-reinforced plastics provide excellent mechanical properties, their widespread use is restricted by higher production costs. In this connection, an investigation has been carried out to make use of coir; a natural fibre abundantly available in India [9]. To address environmental concerns, studies have explored both natural (jute, coir, sisal) and artificial (steel, carbon, glass) fibres in M40 concrete at varying dosages (0–2.5% by volume). Results showed notable gains in compressive strength, with steel, carbon, glass, coir, jute, and sisal fibres enhancing strength by up to ~16% compared to plain concrete. Durability assessments, including chloride permeability, water absorption, porosity, sorptivity, and chemical attack tests, revealed that while natural fibre FRC exhibited higher water absorption and greater vulnerability to acid and chloride attacks, artificial fibre FRC performed better in resisting deterioration. Fibre addition overall improved ductility, anchorage, and crack resistance. Microstructural studies further confirmed the positive influence of fibres on concrete behaviour, particularly for artificial fibre composites [10].

Fiber	**Density (Kg/m^3)**	**Tensile Strength (MPA)**	**Elastic Modulus (GPA)**	**Elongation (%)**	**Main Characteristics**
Coconut Coir	1150	106 - 175	4-6	15-40	High toughness and ductility
Sisal Fiber	1450	468-640	9-22	3-7	Good tensile strength
Banana Fiber	1350	543-754	7-20	10-35	Good flexibility
Bamboo Fiber	900	140-800	11-17	2-6	High strength and eco friendly

Table 1: Physical and Mechanical Properties of Natural Fibres

Fiber-reinforced concrete composites are regarded as high-performance materials because of their improved mechanical properties and stress–strain behavior. In this study, the influence of natural coconut fibers and synthetic glass fibers on polymer–cementitious composites was investigated using 14 concrete mixes with varying fiber proportions. The composites were evaluated through flow diameter, unit weight, water absorption, compressive strength, flexural strength, and ultrasonic pulse velocity tests. Furthermore, SEM and spectroscopic elemental analysis were conducted to examine the microstructural bonding and cohesion within the polymer–cement and fiber-reinforced composites. The results show that the surface texture of fibers can play a key role in major engineering properties of the fiber reinforced concretes and that the natural fibers have great potential to be used as high-performance materials in cementitious composites. Also, it is found that the use of polymer as the main binder can provide higher adhesion with fibers containing smoother surface (e.g., glass fiber) at the interfacial transition zone (ITZ) [11].

III. GLASS FIBER COMPOSITES

The glass fiber reinforced concretes (GFRC) can meet the requirements of Smart City better than ordinary concretes. Glass fiber reinforced concrete (GFRC) improves the mechanical and durability properties of concrete by controlling crack propagation through the crack-bridging action of fibers. It enhances tensile, flexural, and splitting tensile strength, while also improving resistance to impact, abrasion, fire, freeze–thaw action, and corrosion. GFRC further increases ductility, toughness, and energy efficiency due to its lower thermal conductivity. Although it is more expensive than conventional concrete, its improved durability and reduced maintenance make it economical in the long term. However, these benefits depend on maintaining adequate workability and uniform fiber distribution within the concrete matrix. From the environmental point of view, GFRC are eco-friendlier materials than ordinary concretes since their application can decrease the emission of CO2 by 17%. The article also describes the GFRC application fields and emphasizes the possibility of the creation of not only structural elements mainly intended for load transferring but also elements accompanying the building process, as well as elements of small architecture that make public spaces more attractive, durable, and safer. Owing to greater design and shaping freedom, GFRC can also better fulfill the needs of habitants of Smart City [12]. Conventional concrete in its existing form possesses characteristics like better compressive strength, density, resistance against moisture and enhanced performance under various exposure conditions like elevated temperature and long-term durability etc. However, some of the shortcomings such as reduced ductility, brittleness can be improved by using additives like fibers to improve its properties. The present study highlights the performance evaluation of engineering properties and life cycle assessment (LCA) of hybrid fiber reinforced concrete (HFRC) incorporating with glass and polypropylene fibers in equal proportions (0%, 0.5%, 1.0%, 1.5%, and 2.0%). The impact resistance and durability of hybrid fiber - reinforced concrete (HFRC) containing glass and polypropylene fibers were evaluated and compared with conventional concrete. The results showed that increasing fiber content reduced workability; however, the mix with 1% hybrid fibers exhibited superior strength and durability performance. In addition, Life Cycle Assessment (LCA) analysis using SimaPro software and the EcoInvent database demonstrated that HFRC provides favorable environmental sustainability and satisfactory economic performance compared to conventional concrete. Finally, this research will address the need for HFRC mixes to achieve their adaptability in construction sector to make concrete economic and environmentally friendly [13].

Fig 2: Glass Fiber

the mechanical behaviour of high-strength fibre-reinforced concrete (HSFRC) using glass and polypropylene fibres at volume fractions between 0.25% and 1.5%. Both single-fibre and hybrid-fibre mixes were tested. Results showed that hybrid fibre concrete (HSHFRC) exhibited superior performance, with ductility and toughness increasing by 67% and 20% respectively compared to single-fibre mixes. Regression analysis was employed to predict strength, toughness, and ductility, and the predictions closely matched experimental outcomes [14]. Reinforced concrete structures such as bridges, buildings, retaining walls, and pavements often develop cracks due to seismic effects, creating a need for effective rehabilitation methods. This study aimed to develop High-Performance Hybrid Fiber Reinforced Concrete (HPHFRC) with superior properties compared to conventional HPC and HPFRC for structural strengthening applications. Hybrid mixes containing 35 mm Kevlar fibers and 25 mm glass fibers at a total fiber dosage of 1.5% by cement weight were prepared and tested. The results indicated that HPHFRC significantly enhanced compressive strength, flexural strength, splitting tensile strength, energy absorption, and toughness compared to the control and HPFRC mixes. It was found that the concrete hybridized with 0.75% KF and 0.75% GF (HF-G 0.75 K 0.75) had the most enhanced overall mechanical properties, illustrating its potential to be utilized in the rehabilitation of bridges and structures [15]. Hybrid Fiber-Reinforced Concrete (HFRC) has emerged as a new material that addresses the limits of traditional and single-fiber-reinforced concrete. By using a mix of fibers with different properties, such as steel, synthetic glass, and natural fibers, HFRC improves strength, ductility, crack resistance, and durability. This review summarizes recent advancements in HFRC. It highlights the combined effects of multiple fibers under various loading conditions and their role in improving mechanical performance and durability. The review also discusses challenges like fiber distribution, optimizing mix design, and cost issues. The paper ends by emphasizing the potential of HFRC for sustainable building and its promise for broad structural use [16]. This study evaluated the effect of short coir, glass, and carbon fibers on the compressive and flexural strength of fly ash–based geopolymer composites. Fiber contents of 1%, 2%, and 5% were incorporated along with a control mix, and strength tests were performed after 7, 14, and 28 days of curing. The results showed that fiber reinforcement enhanced the mechanical properties of the composites, with carbon fibers producing the greatest improvement in flexural strength, while glass and coir fibers provided moderate enhancement. Microstructural analysis further confirmed improved bonding within the composite matrix. However, the mixes containing 5% glass fiber and 1% and 5% coir fibers showed a reduction in flexural strength [17]. Concrete is strong in compression and comparatively weaker in tension, therefore, to enhance the tensile strength of concrete certain fibers are added into the concrete. Fiber reinforced concrete (FRC) contains fibrous material, which increases the structural stability and integrity. Fiber reinforcement in concrete, mortar, and cement paste can enhance many engineering properties of the basic materials, such as fracture toughness, deflection under lateral loading and resistance to fatigue, impact, thermal shock spalling, and durability. Hybrid fiber reinforced concrete, which is the combination of various fibers into the conventional concrete makes it subtle and enhances the mechanical behavior of the concrete. In the present study, experimental procedures were carried out to decode the compressive strength, tensile strength, and the durability of M40 grade hybrid Alkali Resistant (AR) glass and Coir fiber reinforced concrete. The addition of a combination of fibers into conventional concrete had proportional effects in increasing the ductility and impact resistance [18]. This study investigated the use of treated hybrid natural fibers—specifically wheat straw and bamboo fibers—as reinforcement in concrete for pavement construction. This study investigated the use of wheat straw and bamboo fibers to improve the mechanical and durability properties of concrete while promoting sustainable and cost-effective construction. Wheat straw fibers helped control micro-cracks and enhance tensile strength, whereas treated bamboo fibers improved toughness and reduced macro-crack propagation. Concrete mixes containing 0.1% wheat straw fiber and varying bamboo fiber contents (0.5–1.5%) were tested. The experimental results showed notable improvements in compressive strength, split tensile strength, flexural behavior, durability, ductility, and energy absorption compared to conventional concrete. The optimized hybrid fiber combination also improved post-cracking performance and enabled a reduction in pavement thickness according to AASHTO 1993 guidelines. This hybrid natural fiber-reinforced concrete presents a promising, sustainable, and eco-friendly alternative for rigid pavement construction [19]. the alkali treatment in improving the quality of coir fiber. Study coir fiber done by specifying the physical characteristics and methods of making specimen, mechanical treatment and testing the tensile strength of single fiber. Determine the characteristics physical of the fiber is done by observing and measuring the diameter of the fiber directly, testing the density and moisture content testing. Chemical treatment is done by the method of alkali. Single coir fibers for the treatment carried out using NaOH 5%. Alkali solution set with a variation of the submersion of 0, 1, 2, 3, and 4 hours. Single fiber tensile strength testing is done according to standard ASTM C1557-2003. Tensile tests showed that an alkali treatment can increase the tensile strength of single fiber of 27.9% in immersion lye for 2 hours compared without soaking and increase the elongation of over 20% compared without soaking [20].

Table 2: Physical and Mechanical Properties of Artificial Fibres

Fiber	Density (Kg/ m^3)	Tensile Strength (MPA)	Elastic Modulus (GPA)	Elongation (%)	Main Characteristics
Glass Fiber	2500	2000-3500	70-76	2-4	High stiffness and crack resistance
Polypropylene Fiber	910	300-600	3-5	15-25	Good impact resistance
Steel Fiber	7850	1000-2500	200	0.5-3	High tensile and flexural strength
Carbon Fiber	1750	3000-5000	230-600	1-2	Excellent stiffness and durability

The effect of treatment Alklali (NaOH) on the surface of coconut fiber covering the surface roughness, tensile strength, and the ability of bonding between coconut fiber with polyester matrix. Coconut fiber soaked in a solution of alkali with a concentration of 5%, 10%, 15%, 20%, and then dried in an oven at a temperature of 90 oC for 5 hours. Fiber surface roughness testing is done in two ways namely SEM and surface roughness measuring instrument. Single fiber tensile strength and fiber pull out test was performed with a tensile test. Based on these test results, it was concluded that concentration solution of alkali to give effect to the surface roughness of coconut fiber, increasing the tensile strength, and improve bonding with the fiber and polyester matrix. The alkali treatment increase of the surface roughness of coconut fiber until 3.96 m. In the 20% alkali treatment obtained tensile and shear strength is highest, respectively 280, 94 N/mm2 and 3, 09 N/mm2 [21]

IV. CONCLUSION

This review study examined the performance of hybrid fiber reinforced concrete (HFRC) containing coconut coir and glass fibers, with particular focus on mechanical properties, flexural behavior, durability, and sustainability. The reviewed studies showed that the incorporation of hybrid fibers improves the compressive strength, tensile strength, flexural capacity, ductility, toughness, and crack resistance of reinforced concrete members. Glass fibers mainly enhance stiffness, load-carrying capacity, and crack control, whereas coconut coir fibers improve ductility, energy absorption, and post-cracking behavior. The combined use of natural and synthetic fibers provides balanced structural performance and helps reduce the brittle nature of concrete. Most researchers reported that HFRC performs better than conventional concrete and single-fiber reinforced concrete in terms of strength, durability, and serviceability. In addition, the use of coconut coir fibers supports sustainable construction by utilizing renewable and biodegradable materials. Although the inclusion of coconut coir and glass fibers significantly improves the overall performance of concrete, further research is required to determine the optimum fiber proportions, evaluate long-term durability, and study the behavior of full-scale structural elements under different environmental and loading conditions. Overall, HFRC containing coconut coir and glass fibers has strong potential as a sustainable, cost-effective, and efficient material for improving the performance and service life of reinforced concrete structures.

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