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State of The Art Review On The Evaluation Of Fiber-Reinforced Concrete

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Abstract. *In many cold countries, concrete buildings frequently experience early deterioration that is primarily brought on by steel corrosion. Chloride seeps into the concrete's fissures and starts the corrosion process. Due to its increased durability and resistance to crack development, fiber-reinforced concrete (FRC) is recognized as a suitable substitute for traditional concrete in cold climates. FRC is a brand-new structural substance that is becoming more and more significant. Numerous engineering characteristics of concrete are enhanced by the discrete addition of fiber reinforcement. Fiber-reinforced concrete (FRC) is gaining popularity in various applications such as thin un-bonded overlay tunneling, bridge decks, pavements, concrete pads, and concrete slabs, loading docks, and exhibiting excellent performance. However, there is limited research on FRC. This paper aims to conduct a literature review of FRC research, which reveals a significant increase in research on the theory and practice of FRC. The study identifies the main topics, key articles, and major author groups in FRC research, which can help expand the scope of research in FRC to various subfields in the future.*

Keywords*: Building Material, Concrete, Fiber Reinforcement Concrete, sustainable development*

1. INTRODUCTION

Concrete is a composite material comprising fine and coarse aggregate combined with a fluid cement paste during mixing, and is a highly prevalent and widely used construction material in civil engineering. From straightforward beams, slabs, and columns to complex structures like silos, bunkers, water tanks, launch pads, and much more, it can be cast into almost any structural configuration. Although concrete is very brittle and has a low strain capacity in tension, which results in low toughness, it is powerful in compression [1]. Two significant things are upsetting in the construction business. The development of construction techniques, such as the use of automated tools in construction, is one method. The development of high-performance building components is the other, leading to high-strength concrete. Fiber-reinforced concrete (FRC) is one of the high-performance materials. Recently, creative fabrication processes using fibers and their matrix materials have quickly taken off in the construction business. Their advantages over other building materials include the ability to assume a variety of shapes, resistance to environmental factors, and a high tensile strength-to-weight ratio which may result in a potentially low upkeep cost. FRC composite is a respectable choice for inventive building because of these interesting features [2]. Demand for lightweight, environmentally friendly building materials with excellent mechanical properties and low energy usage is rising as environmental awareness grows. It is recognized that the construction industry's use of synthetic and natural fibers will help achieve a sustainable consumption pattern for building materials. Natural fibers like flax, coir, areca nut, and jute as well as synthetic fibers like plastic (obtained from windmill sectors) are both affordable, low-density, renewable, non-abrasive, and widely accessible. Utilizing both natural and synthetic fibers as building and construction materials will lower costs and improve energy efficiency, which will help address urgent infrastructure requirements while advancing the idea of sustainability [3]. It is common knowledge that traditional concrete built on the basis of compressive strength does not effectively satisfy numerous functional requirements, including impermeability, resistance to frost, acceptable resistance to thermal cracking, and energy absorption. These functional requirements can be reduced by utilizing or incorporating fibers, a material that solves all of these problems. When these fibers are put into concrete, Fiber Reinforced Concrete is created (FRC). Natural fibers made from flax, coir, areca nuts, jute, etc. are readily accessible and are obtained as byproducts of many materials. Artificial fibers are also leftovers or by-products from other industries, including plastic fibers. (wastes from the Windmill industry). This research facilitates to review offiber-reinforced concrete with different fibers about mechanical, flexural behavior, durability and sustained elevated temperature variation properties [4].

Bibliometric Analysis

This article presents a comprehensive review of numerous articles published in the last decade, which have been analyzed using bibliometric methods from databases such as IEEE Xplore, Science Direct, MDPI, ASCE Library, Copernicus, AAS, Springer, and Scopus, etc employing state-of-the-art models. The search was conducted using the keywords "Fiber Reinforced Concrete" to extract relevant data, which may have a direct or indirect impact. A total of 8,000 documents from these ten databases were classified into distinct categories spanning the past decade. By analyzing each database, the clusters obtained are “Articles (70%), Book Chapters (10%), Conference Papers (8%), Encyclopedia (3%), Short communication (2%), Editorial (6%), Abstract (2%), Mini review (2%), Case report (4%), News (4%)”. It is evident that each section collected from databases carries a particular weightage when compared to Science Direct, which has the highest volume of publications.

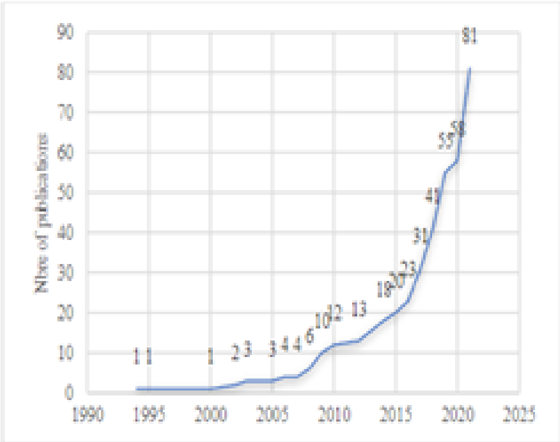

FIGURE 1.

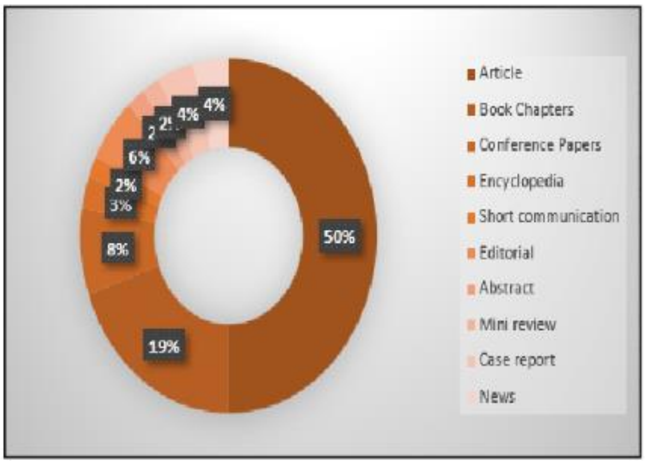

FIGURE 2. The amount of publications/year through the period of analysis

Key Objectives

This paper provides a review of FRC, which has been under consideration for a decade, highlighting the following points:

- To define the Fundamentals of FRC.
- To discuss the advantages, application, and various factors that affect the FRC properties.
- Review fiber-reinforced concrete with different fibers about mechanical, flexural behavior, durability, and sustained elevated temperature variation properties.

Organization of the paper:

The article begins with an introduction in Section 1, followed by the rest of the content in the subsequent sections. Section 2 offers a comprehensive summary of the -FRC and the difficulties associated with it. In Section 3, different approaches are reviewed. Section 4 covers experimental results and observations. Finally, Section 5 presents the conclusion.

2. FIBER-REINFORCED CONCRETE

Fibers are used as a means of reinforcement in ancient times. In the past, straw and horsehair were both used to make mud bricks. When the health dangers associated with asbestos were recognized in the early 1900s, By the 1960s, the use of asbestos in building materials such as concrete had to be replaced, leading to the adoption of alternatives such as steel, glass, and synthetic fibers like polypropylene fibers. This practice remains prevalent today [5]. Fiber Reinforced Concrete (FRC) is a type of concrete that contains synthetic or natural fibers to strengthen the structure. Concrete contains a consistent distribution of short, distinct threads known as fibrous materials. The qualities of FRC with a single type of fiber system can only be slightly improved. Therefore, integrating two different fibers in concrete at a reasonable ratio can result in more desirable engineering features of concrete than using just one type of fiber. Hybrid fibers, which contain many fibers, allow for more effective use of the potential qualities of other fibers [6]. fiber reinforcement (FRC) concrete containing Steel, glass, synthetic, and natural fibers are all types of fibers. To increase the mechanical qualities of concrete, the weakness in tension can be mitigated by using a volume percentage of particular fibers in adequate amounts. Mixing cement with fibers that have a high tensile strength is a good idea. Concrete's toughness is significantly increased by the addition of fibers. adding fibers also changes how the fiber matrix composite behaves after it has broken, increasing its toughness. If two or more types of fibers are logically integrated into one matrix to create a composite that drives benefits from each of the separate fibers and exhibits a synergetic response, that composite is referred to as Hybrid Fiber Reinforced Concrete (HFRC). Short discontinuous fiber addition has a significant impact on the mechanical characteristics of concrete. Short-cut fibers' primary role as a secondary reinforcement in concrete is to raise elastic modulus, reduce brittleness, and limit crack initiation as well as growth and spread. Deboning and pulling out of the fiber need additional energy absorption, increasing the materials' toughness and fracture resistance to cyclic and dynamic stresses significantly. This study focuses on the differences between Fiber Reinforced Concrete (Mono and Hybrid) and Conventional Concrete in terms of Mechanical Properties, Flexural Strength of the Slab, Durability, and Temperature Variation [7]. Factors Affecting Fiber Reinforced Concrete's Properties are Relative Fiber Matrix Stiffness, Mixing, Workability, Volume, Orientation of fibers, Aspect Ratio of the Fiber, Compaction of Concrete, and Size of Coarse Aggregate.

Applications of FRC are

- ✓ Hydraulic Structures: The primary benefit of employing FRC in hydraulic projects is that it has a strong resistance to erosion caused by high-velocity water cavitations.
- ✓ Highways and Airfield Pavements**:** FRC is used in highway and airport pavements because it increases flexural strength, which reduces pavement thickness and improves resistance to impact and repetitive loads.
- ✓ Structural Applications**:** Due to its significant crack resistance, FRC is employed in many structural components of buildings, boosting flexural strength. Blast-resistant structures are designed with the requisite strength to withstand blast-induced pressure waves inside the furnace. These structures are composed of FRC.

3. LITERATURE REVIEW

One of the aims of this literature review is to give an extensive survey of the work carried out by different researchers in the field of FRC. The research work concerning FRC made by the various natural and synthetic fibersis discussed.

Review based on Mechanical Properties of FRC: Studies on the Comparative Strength Study of Coir Fiber Reinforced Concreteagainst Plain Cement Concrete were carried out by Anoopsingh Chandel et al. in 2016 [8]. (PCC) Coir fibers that were used for the study are 2mm in diameter and contain three different amounts of cement, ranging from 1% to 5% by weight. The strongest findings were achieved for 1% fiber content at 2 mm average fiber length, and it was determined that CFRC has a compressive strength that is over 13% higher than plain cement concrete (PCC). In 2017, Sasha Arumuga Pandi [9] conducted a study on Coir FRC, evaluating mechanical properties including compressive strength, modulus of rupture of M30Grade concrete, and split tensile strength. The study involved the addition of coir fibers ranging from 0% to 8% to conventional concrete. In the end, concluded that the Coir fiber reinforced concrete has high compressive strength related to Conventional concrete. Flexural Behavior of High Strength Coir FRC Blended with Silica Fume was studied by

Chandar and Prakash in 2022 [10]. Their studies aim to investigate the flexural behavior of concrete reinforced with high-strength coir fiber and silica fume. Research on the effectiveness of concrete using metakaolin with natural fibers was carried out by Karthikeyan et. al. (2018) [11]. The purpose of the current work is to investigate the applicability of metakaolin as a mineral addition and its impact on the characteristics of concrete. Ordinary Portland Cement alone was used as the control, and cement was additionally replaced with metakaolin in amounts of 5%, 10%, 15%, 20%, 25%, and 30%. This experimental inquiry examined the workability, strength, and durability of concrete mixes with and without coir fibers and metakaolin replacing some of the cement. According to the data, metakaolin has a greater compressive strength at 15% replacement of OPC than at the other replacement levels.

Review based on the Flexural Behavior of FRC: A study on the effectiveness of concrete using metakaolin with natural fibers was carried out by Karthikeyan A trial investigation using pineapple leaf fiber-reinforced RCC beams was undertaken by Raji et al. in 2022 [12]. In this study, pineapple leaf fiber coated with a polymer and treated with diluted alkali is provided as additional support for concrete beams. The specific people were considered hesitantly. The normal RCC beams and a defined Load transporting limit of beams were compared. The PALF-reinforced beam's maximum permissible load is increased by 24%. The exploratory behavior of a natural hybrid fiber-reinforced slab made of nano concrete was explored by R. Sakthivel et al. (2020) [13]. This trial addressed the behavior of reinforced solid slab structures made of natural hybrid common fiber (coir and hair) and nano silica (NHFRC). According to Indian standards, the design mix for M25-grade concrete was completed. The examinations use various fiber rates ranging from 0.5% to 2.5% by weight of cement and varied nano silica rates ranging from 0.2% to 4.5% by weight of cement.

Similar research on the use of artificial and natural FRC for ground floor slab applications was done by Chin et al. in 2018 [14]. The introduction and description of a study of the mechanical characteristics of concrete reinforced with polypropylene, steel, and rice fibers. The experiments are conducted on blends that contain 0.25% of each fiber type by volume, and their effects on ground floor slab conduct are taken into consideration. Table 1 summarizes the previous review papers in the field of FRC

TABLE I. Authors Contributions In FRC

Authors	Contributions
(2020) [15]	Studies the impact of a quick, acid-catalyzed sol-gel silica nano-coating on the draw-wire Polypropylene fibers used as dispersion reinforcement in FRC mechanical performance. Investigating the mechanism of failure.
(2021) [16]	To achieve a high-density calcium silicate hydrate in ultra-high-performance concrete with minimal chances of ettringite production and alkali-silica reactions, finer-grained mineral admixtures and lower water/binder ratios ranging from 0.16 to 0.24 are added. However, the inclusion of fibers in UHPC can pose a challenge in maintaining its rheology, requiring technically proficient concrete professionals for field applications.
(2022) [17]	First, describe the jute fiber's structure, chemical makeup, and potential applications. Then, we give a summary of different surface treatments applied to jute FRC to enhance its mechanical properties. We analyze and contrast several jute fiber surface changes based on graphene derivatives and their effects on FRC performance. They developed next-generation strong and sustainable FRC for high-performance engineering applications without causing environmental issues.
(2023) [18]	The multiple blast resistance of G-HPC slabs reinforced with steel wire mesh (SWM) and covered in ultra-high molecular weight polyethylene,FRC was investigated through experimental and numerical methods. A parametric analysis was conducted to examine the impact of UHMWPE FRC thickness and placement on the multiple blast behavior of the SWM-reinforced G-HPC slab. The failure mechanisms of the slabs and their blast-resistant design were elucidated through this study.

Review based on Numerical Analysis of Fiber Reinforced Concrete for Static Loading by Finite Element Analysis Using ANSYS: Finite Element Modelling of a Hybrid FRC Beam with Elastomeric Bearing Pads was carried out by Anjali P V et. al. in 2022 [19]. This work employs steel and polyolefin fibersin a hybrid form. In order to investigate the overall behavior of a composite beam with and without elastomeric bearing pads, a three-dimensional nonlinear finite component analysis is conducted using the ANSYS software program. A novel type of composite waffle slab made up of an orthogonal steel girder and a flat RC slab was proposed by

Rinsha C et al. (2018) [20]. The steel girders and RC slab are joined together using shear studs. Finite element analysis is used in ANSYS Workbench 16.1 to study the behavior of composite waffle slabs with varied steel section sizes, rib angular arrangements, percentages of steel fibers, and grades of steel sections with varying percentages of steel fibers. Also, by converting an I beam into a castellated beam with and without a stiffener, analyze the performance of the composite waffle slab. According to the results of ANSYS, ISMB250 is the most affordable steel section.

Review based on Durability Studies of Fiber Reinforced Concrete: The effects of acid attack on high-strength concrete with hybrid fiber reinforcement, artificial sand, and coconut shell were studied by Lee et al. in 2017 [21]. M50 is the concrete grade that was employed in the investigation. The weight of cement replaces 10% of the silica fume, and the weight of sand replaces 40% of the produced sand. 20% of the coarse aggregate is replaced by coconut shells. Three different types of fibers—steel, sisal, and coir fiber—are employed. Adewumi John Babafemi, et al. (2019) [22] carried out an experiment to look at the mechanical and durability characteristics of coir FRC. This study examined the impact of coir fiber content at 0.5 and 1% on the workability, density, splitting tensile and compressive strength, and concrete durability. After curing in water for the first 28 days, hardened cube specimens were placed in 1, 3, and 5% magnesium sulphate solutions for 28 and 56 days to test the durability of the coir FRC.

4. FINDINGS

The review of the literature reveals that numerous studies on concrete have been conducted utilizing various fibers, such as steel, glass, and polypropylene, to enhance the hardened qualities of concrete. On the use of coir, areca (a natural fiber), plastic fiber (industrial waste fiber), and their combination in concrete, very little information is accessible. Various cutting-edge materials have been included to extend the service life while being exposed to acids, chlorides, and sulphates.

For repair and strengthening of concrete structures in early seismic damage stage, it is necessary to evaluate sesmic damage of concrete. When a beam is subjected to cyclic loading, a certain amount of energy is absorbed in each cycle. The relative energy absorbed in each cycle is calculated by the area under the load deflection curves for each cycle in load deflection graph. It is also found that with addition of steel fiber, energy dissipation was increased by 76 % in case of beam B4 compared to the plain RCC beam. Figure shows that energy dissipation of beams in each cycle and cumulative energy dissipation in beams.

TABLE 2. Energy dissipation of beams in each cycle and cumulative energy dissipation in beams.

Cycle No	B1	B2	B3	B4	B5	B6	B7
1	7.4310	12.290	21.720	19.017	18.500	17.870	15.277
2	9.4562	15.450	16.890	15.270	15.290	19.200	18.500
3		16.000	16.890	15.270	15.290	19.200	18.500
4		13.500	14.280	13.500	12.110	15.100	18.560
5		13.500	14.280	14.880	13.133	10.611	0.000
Cumulative Energy Dissipation	16.8872	70.84	74.4037	75.317	70.437	73.9574	72.057

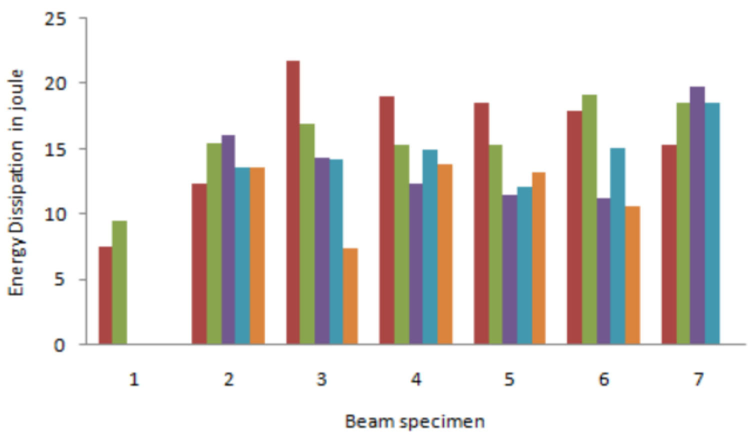

FIGURE 3. Energy dissipation in each cycle plot

There is relatively less information available on the durability of concrete made with waste plastic, coir, and areca fibers. Studies have been done on how typical concrete performs when exposed to high temperatures and FRC and hybrid fibers. The following suggestions are offered for engineers and designers to take into account:

- Glass fibers can be employed to enhance the flexural strength of concrete structures, particularly in cases where large slabs or thin-shelled elements with smaller thicknesses are involved. In such situations, the inclusion of fibers can increase the strength of the structure and its resistance to bending.
- Polymer fibers are advantageous for locations susceptible to corrosive materials due to their high corrosion resistance. Furthermore, these fibers are particularly suitable for pillars submerged in water, such as those found in bridges and dams.
- The high yield strength of steel makes it a desirable material for use in concrete to enhance its strength. Steel fibers can be added to the concrete mix to achieve this, but care must be taken in fire-prone areas, as these fibers can cause the concrete to behave explosively under certain conditions.

TABLE 3. Estimated Coefficient Of Carbonation Of Fibre Reinforced Concr

Structural element	**Average coefficient of carbonation - K(mm/year0.5)**
Slab	4.420
Beam	3.510
Column	3.905
Others	3.475
Average	3.8275

With chemical test analysis, it is observed that except 4 out of 14 structures (28.57%), the quantity of chlorides in concrete was below limit to initiate corrosion (below chloride threshold) in 10 out of 14 (71.43%) structures inspected. The permissible limit of quantity of chloride in concrete is 0.6kg/m3 as per Indian Standard (I S 456 of 2000) limit for chloride content in concrete. The chloride threshold of conventional reinforcing steel ranges between 0.6 and 1.2kg/m3.

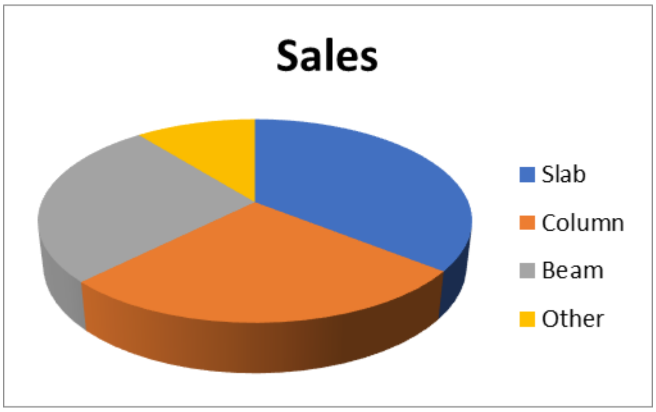

FIGURE 4. Show structural member samples tested for carbonation

It is advised that a standard be created for the mixing of fiber-reinforced concrete based on the challenges is discussed in this study. To create a uniform framework for doing research, this can be found in the ASTM or ACI Standards. All of the components should be at room temperature, even though it's crucial to make sure that the sand is completely dry. In order to confirm that the mix complies with the industry's standards, it is also advised to measure compressive strength on samples with longer curing ages. The volume of steel fibers utilized in the concrete mix would have been sufficient to cause repeated cracking and produce higher yield strength if the equations used to create ECCs had been employed. Following these recommendations, further research can be undertaken to investigate the use of fibers in concrete with the goal of improving its mechanical properties and expanding its applications in infrastructure.

5. CONCLUSION

The results of a thorough review that attempted to greatly advance our knowledge of FRC behavior have been provided. An attempt has been made to review the FRC literature in this study. We have provided a review of current publications published between 2016 and 2024 in the literature. The only requirement for research articles was that they be completed after 2016. Papers for review were chosen at random. Even if several of the reviewed studies belong to the same category, we did not consider papers that had exactly the same outcomes. Hence, although there are no articles with exactly the same results, the outcomes of certain papers may be relatively near. Our analysis of the papers involved the discussion method, and we did not conduct any quantitative analysis that could be used in future research. However, our literature review revealed a significant surge in research related to the theory and practice of fiber-reinforced concrete. We also observed that previous literature reviews have provided valuable insights, but they were based on randomly selected articles, book chapters, and conference proceedings.

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