**REVIEW ON FIBRES IN CONCRETE**

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**ABSTRACT**

*For many decades, concrete has been the most important building material, and it has maintained its market supremacy over time. Due to its excellent mechanical performance, hybrid fiber reinforced concrete (HFRC) has recently become a very well-liked and appealing material in structural engineering. The three main benefits include preventing macro cracks from forming, delaying the spread of micro cracks to the macroscopic level, and improving ductility when micro cracks form. This study examines the features, characteristics, and methods used to improve the durability of concrete when metallic and natural fibers are applied.*

***Key words:*** *Fibre reinforced concrete , durability*

**1. INTRODUCTION**

**1.1 General**

After the discovery of Portland cement in 1824, concrete has become the most commonly used structural material in modern civilization. However, it is well known that concrete is a brittle material , which greatly limits its application domain in practice. For the sake of overcoming the shortage of high brittleness of and further satisfying the requirements of actual engineering structures a considerable amount of research work has been devoted over the last decade to make concrete more robust in resistance to cracking and toughness. Especially worldwide growth of automobile industry and increasing use of heavy machine in different industries , they need high resistant flooring.

Normally concrete has high compressive strength but least in tensile strength and ductility. Inorder to improve the tensile strength and ductility, fibres are introduced in to High Strength Concrete. Due to the addition of fibres in concrete, cracks (due to plastic shrinkage and drying shrinkage) also minimised.Fibres used in concrete should be cost effective, so I preferred hybrid combination. Metallic fibers contribute towards the energy absorbing mechanism( bridge action to arrest propagation of cracks). Natural fibers delayed the formation of micro cracks.

The characteristics of the concrete and the fibers affect how well fiber reinforced concrete (FRC) performs. Fiber concentration, fiber shape, fiber orientation, and fiber distribution are the characteristics of fibers that are typically of interest. Additionally, using just one kind of fiber may only marginally enhance the characteristics of FRC. The idea of hybridization, which is the practice of incorporating two or more types of fiber into concrete, can, nevertheless, provide more desirable engineering features since the presence of one fiber enables the more effective application of the potential properties of the other fiber. According to earlier research (Eether Thanon Dawood et al. 2012), the idea of hybridization—where two or three different fibers are incorporated into a single cement matrix—can provide more desirable engineering properties because the presence of one fiber makes it possible to use the potential properties of the other fiber more effectively. Compared to other fiber kinds, steel fiber has a noticeably longer length and a greater Young's modulus of elasticity. Despite the high volumetric density, this improves flexural rigidity and has excellent fracture control potential. It's also crucial to remember that steel conducts in both electric and magnetic fields, thus the amount of steel fibers must be decreased to a particular extent. Optimization of mechanical and conductivity properties can be achieved by combining different types of fibres, such as in the case of natural fibres ( coir, sisal, and palm fibre )and steel fibers. The appealing feature of a hybrid fiber system is that it offers a system in which one type of fiber, which is stiffer and stronger, enhances ultimate strength and first crack stress, and the second type of fiber, which is more flexible and ductile, results in increased toughness and strain capacity in the post-cracking zone. Additionally, it adds to a hybrid reinforcing system in which the smaller fibers minimize crack widths and bridge microcracks. As a result, the composite has a higher tensile strength. The second type of fiber is larger, which allows it to stop the spread of macro cracks and significantly increase the composite's durability. However, most of the research work and utilization of fibre reinforcement are about monotype fiber. Using hybrid fibres as reinforcement to improve the performance of concrete are not frequently reported. Therefore, this review facilitate the researchers to carry investigation on hybrid fibre reinforced concrete.

**2. REVIEW**

**2.1. METALLIC FIBRES**

Steel fibre reinforced concrete become a most attractive one in structural engineering due to its ductility nature and reducing the crack propogation. Experimental studies in [1] shows that steel fibre reinforced concrete has good toughness and high residual strength even after the first crack occurs. Based on available experimental data [1] appropriate fiber contents, fiber types and most efficient suitable combination of fibres are selected. Test conducted on [1] demonstrate that addition of silica fume, fly ash and super plasticizers in steel fibre reinforced concrete improves the mechanical properties of concrete.

Nowadays construction industry is in requirement of finding suitable materials to improve strength of concrete. Therefore in [2], an attempt has been to study the effect of addition of steel fibre at a dosage of 1.5% of total weight of concrete and 8% of cement replaced by metakaolin . Experimental work done on M40 mix concrete and tests are carried out as per relevant codes. From this experimental work [2] , it observed that compared to control concrete , steel fibre reinforced concrete compressive strength increased by 8.91% and tensile strength increased by

26.94%.

Addition of steel fibres in concrete improves the mechanical properties of concrete but suitable percentage need to be added in concrete. The following paper [3] reveals the optimum percentage, steel fibre is added on concrete from %, 0.5%, 1% and 1.5% by weight of cement. These specimens are tested at 28 days ,60 days and 90 days. Based on experimental results[3] it was found that optimal steel fibre is 1% for concrete with out any addition of cementitious material. If more than 1% of steel fibres added in concrete,it affects the Compressive strength, Split tensile strength and Flexural strength of the concrete.

In [3] it indicates that 1% steel fibre is optimum one for concrete with out any cementitious material.To find steel fibre percentage in concrete with cementitious material following paper [4] reviewed. In this , steel fibres are added in concrete of volume fractions 0, 0.5, 1.0, and 1.5 % and 10% of silica fume. Due to the incorporation of steel fibres, silica fume in concrete, it improves ductility and crack resistance. Addition of fibers gives better performance to the cement-based composites, while silica fume adjust the fiber dispersion and strength losses caused by fibers and improve the bond between fiber and matrix with dense calcium-silicate-hydrate gel. Based on the experimental result [4] optimum silica fume replacement level is 10% for a w/c ratios ranging from 0.25 to 0.45 with varying dosages of water-reducing admixture added to maintain a fluid consistency. Then the compressive strength of concrete higher at 1.5% volume fraction and split tensile and Flexural Strength improved at 2.0% volume fraction.

In [5] the impact resistance and mechanical properties of steel fiber-reinforced concrete with water cement ratios of 0.46 and 0.36, with and without the addition of silica fume have been investigated. It was observed remarkable increase in impact resistance of the fibrous concretes when compared to reference materials. Experimental results[5] shows that when steel fiber is introduced into the concrete including silica fume, the impact resistance and the ductility of the resulting concrete are considerably improved.

In[6] investigation made on the use of different percentages of steel fiber (0, 1.0, 1.25, 1.5, 1.75 & 2%).Specimens of different percentages of steel fibres are casted and tested as per relevant codes. Experimental results show that the use of 1.0% of steel fibers increases the compressive strength by 13% compared to other proportions.

To investigate the mechanical behaviour of steel fibre reinforced concrete[7], M-40 grade of concrete containing fibers of 0%, 1%, 2% and 3% volume fraction has been casted and tested as per relevant codes. Experiment results [7] obtained has been analyzed and compared with a control specimen (0% fiber). Results [7] clearly show that due to the addition of fibres compressive strength increases from 11 to 24%, flexural strength increases from 12 to 49% and split tensile strength increases from 3 to 41%.

Generallyfibres are used for resisting the propogation of cracks and improve the strength of concrete. In this paper [8], tests are carrying out to find the optimum quantity of steel fibres required for maximum flexural strength for M25 grade concrete. From this detailed experimental work [8], it was observed that with increase in steel fibre content in concrete, there was a remarkable increase in flexural strength. Flexural strength is 5.36 N/mm2 at 0% but due to the addition of 1 % steel fibre content flexural strength increased to 6.46 N/mm2.

**2.2. NON METALLIC FIBRES**

When two or more fiber kinds are utilized in an appropriate mix, concrete's overall characteristics and performance can be greatly enhanced. The process of combining these strands is known as hybridization. This study [9] investigates it. Different steel and polypropylene fiber quantities are used while casting M25 grade concrete. According to the applicable codes, tests including the compressive test and split tensile strength were carried out. Out of control and two fiber hybrid composites, a hybrid combination of steel and polypropylene in 0.8% and 0.2%, respectively, gives higher strength than conventional concrete; however, if the percentage of steel fiber in the hybrid combination is increased, the slump value is reduced, and we must increase the percentage of polypropylene fiber in order to maintain a constant slump.

This study's main goal [10] was to assess how well hybrid fiber combinations at low volume fractions could alter the post-peak behavior of highly durable concrete. According to the study's findings, hybrid fiber concretes containing steel and fibers made of glass, polyester, and polypropylene are more ductile than conventional concrete without fibers. These results have significant implications since they show that non-metallic fibers can partially replace steel fibers in concrete without sacrificing ductility. In terms of applications in high strength or high performance concrete, this, along with the enhanced early age crack resistance made available by the non-metallic fibers, makes hybrid fiber combinations highly competitive.

Studies on high strength concrete reinforced with hybrid fibers (hooked steel and a non-metallic fiber in various combinations) have been done in [11], and the volume fraction is up to 0.5%. Steel-polypropylene, steel-polyester, and steel-glass hybrid fiber combinations were used to create concrete. Then, tests were performed to determine the concrete's compressive strength, split tensile strength, flexural strength, and flexural toughness. In general, adding steel fibers aided in the energy absorption process (bridging action), but non-metallic fibers slowed the development of microcracks

In [12] investigation is done on three types of hybrid composites such as polypropylene (PP) and carbon, carbon and steel, and steel and PP fibers. From this experiment following results obtained (i.e) when fibres used in a hybrid form, it could result in superior composite performance compared to their individual fiber-reinforced concretes. Out of three types, carbon–steel combination gave concrete of the highest strength and flexural toughness.

In [13] the strength behavior of concrete by using hybrid fibre reinforced concrete (HFRC) is analyzed. The concrete beams are casted for a grade of M25 as per IS 10262:2009. The fibres added in concrete are glass and steel (crimped) fibres in various aspect ratios. Main reason for adding steel fibres in concrete matrix is to improve the post-cracking response of the concrete (i.e.) to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control. Compared to steel fibre, glass is highly resistant to the majority of aggressive agents and will never oxidize when exposed to the conditions which cause steel to rust. Hybrid fibres are in various aspect ratio 60,70,80,90 and 100 by adding 2% weight of cement were used in the concrete. By this investigation[13] following results obtained(i.e.) by using hybrid fibre in concrete, the compression, split tensile and flexural performance are increased corresponding to increase in aspect ratios.

Fiber Reinforced Concrete (FRC) is a composite material consisting of cement based matrix with an ordered or random distribution of fiber which can be steel, nylon, polythene etc. Addition of steel fibre increases the properties of concrete viz., flexural strength, impact strength and shrinkage properties. Hence, an attempt has been made in the present experiment [14] to study the influence of addition of polythene fibers (domestic waste plastics) at a dosage of 0.5% by weight of cement. Due to the addition of 0.5% of polythene (domestic waste polythene bags) fiber to concrete following results were obtained (i.e.) cube compressive strength of concrete in 7 days increased to an extent of 0.68% and in 28 days it reached to 5.12%. Similarly in cylinder compressive strength of concrete in 28 days also increased (i.e.) to 3.84%.The split tensile strength increased to an extent of 1.63% and the increase in the various mechanical properties of the concrete mixes with polythene fibers is not in same as that of the steel fibres.

The effects of adding waste items such lathe dust, soft drink bottle tops, empty waste tins, and workshop waste steel powder at a dose of 1% of the total weight of concrete as fibers were investigated in [15]. M25 mix was used in tests with lathe debris, empty tins, and soft drink bottle caps that were bent into rectangular strips measuring 3 mm broad by 10 mm long. The tests were then carried out in accordance with the recommended procedures of the applicable codes. It was discovered that adding steel powder to concrete increased its tensile strength and compressive strength by 40.81% and 41.25%, respectively

In this investigation[16] is done for a M40 grade concrete at a volume fraction of 0.5%. Control and three hybrid fiber composites were cast using different fiber proportions of steel and polypropylene. Compressive strength, split tensile strength and flexural strength test were conducted and results were analyzed to above fiber combinations.Maximum compressive strength reaches in the HFRC S0.75 P0.25, i.e., 75% steel fibres and 25% polypropylene fibres because of the high elastic modulus of steel fibre and the low elastic modulus of polypropylene fibre work in good combination and in spilt tensile strength of fibre percentage with S0.75P0.25 shows slight increase in strength. Tensile strength can be improved by increasing the percentage of steel fibres. (i.e.) while higher number of fibres bridging the diametric ‘splitting’ crack; the higher would be the spilt tensile strength. The increased fibre availability of PP fibre in combination with high stiffness of steel fibres, resulted in a significant enhancement of the split tensile strength for this combination. The flexural strength of HFRC containing the volume fraction of 75% steel fibres and 25% polypropylene fibres is higher than the other HFRC. It can be observed that, under axial loads,cracks occur in microstructure of concrete and fibres limit the formation and growth of cracks.

In general Fibre Reinforced Concrete (FRC) can improve the strength properties of hardened likewise this investigation [17] is to find the mechanical properties of Hybrid Fibre Reinforced Concrete with the combination of Recycled Polyethylene therephthalate and steel fibres. M25 grade of concrete was designed by using the codal provisions of IS 10262 Compressive strength, Tensile strength and Flexural Strength of specimens were found out for the various mix proportions of Hybrid Fibre Reinforced Concrete RPET.75ST0.25, RPET0.5ST0.5, for 1.5% volume fraction . Totally 36 number of specimens were casted, out of which nine numbers of control and twenty seven were hybrid fibre reinforced concrete specimens. From this combinations the optimum value of hybrid fibre was found as combination of RPET0.25ST0.75 fibres. Because of the steel fibre the optimization value of the concrete get increase and the RPET fibre gives a little contribution in strength. Compared to control concrete, hybrid fibre reinforced concrete compressive strength can improve 19%, its tensile strength can improve to 10% and its flexural strength can improve 13.80%.

In [18] mechanical properties of hybrid fiber reinforced self compacting concrete and mono fiber reinforced self compacting concrete which are subjected to sustained elevated temperature are investigated. Different fibers investigated are steel fibers (SF), polypropylene fibers (PPF), galvanized iron fibers (GIF), and waste plastic fibers (WPF). Then the hybrid fiber combinations used in the experimentation are (SF +PPF), (SF+GIF) and (SF+WPF). From investigation ,it is found that the resistance of hybrid fiber reinforced self compacting concrete to elevated temperature is better and effective than that of mono fiber reinforced self compacting concrete.

These inferences are made in light of the experimental findings [19]. The results were compared with those of a conventional concrete specimen using three different types of fibers at 4% volumetric fraction. Concrete that contains 4% steel fiber is rigid and challenging to compact, whereas concrete that contains 4% Endura-600 Macro synthetic polypropylene fiber is more slippery and challenging to compact. Additionally, shorter fiber concrete is easier to deal with than longer fiber concrete .Based on experimental investigation[19] , it is noted that when compared to conventional concrete there is a increase in compressive strength of SFRC to in range of 3 per cent to 60 per cent between 7 and 28 days , for compressive strength of PPFRC to increase between 10 per cent to 18 per cent between 7 and 28 days and in Hybrid concrete compressive strength was increased by 3 per cent to 22 per cent for 7 to 28 days. In conventional concrete, specimen splits into two halves exactly under the loaded area, but using SFRC, PPFRC, Hybrid fibers cylinders did not split into halves under the loaded area because of toughness it did not yield to sudden breakage. An increase in ductility of the specimens by the introduction of fibers was observed in this investigation. According to ASTMC 1202 criteria, Chloride Permeability for conventional concrete and Hybrid specimens was low and a SFRC and PPFRC specimen was medium. Water absorption results of SFRC and Hybrid specimens are equal to conventional concrete. But in the case of PPFRC it was 4% increase than conventional concrete.

This experimental work [20] deals with the use of glass fiber in concrete which is obtained from the glass industry as a waste product. The work is in initial stage but is promising, as the preliminary results satisfy the basic needs which the alternate material should fulfill in concrete. As expected, the compressive strength of concrete did not increase much, the flexural strength showed almost 30% increase in strength compared to the beam with 0% fibers. The slump value decreased with increase in fiber content. From this, it can be concluded that the use of fiber glass in concrete, not only improves the properties of concrete and also do a small cost cutting and provides an easy efficient disposal of this environmental hazard.

In [22] the durability properties of steel fibre reinforced Metakaolin blended concrete, when it is exposed to certain types of chemicals are investigated. Metakaolin is a thermally structured, ultra fine pozzolona, which replaces industrial byproducts such as silica fume, flyash, etc., An experimental work has been carried out to find the durability in terms of Chemical Resistance and weight loss of steel fibre reinforced concrete with and without Metakaolin for concrete of M20 grade. In this investigation [22], an attempt is made with chemicals like H2SO4 and HCl to find the durability characteristics of concrete. Crimped Steel fibres with 60 as aspect ratio at 0, 0.5%, 1.0% and 1.5% fibres of volume of concrete are used. The results indicate that the percentage of weight loss is reduced and compressive strength is increased in the case of Steel fibre reinforced concrete containing 10% of Metakaolin.

**2.3.** **NATURAL FIBRES**

In [23] investigation is done on utilization of some fibres as solid wastes for making economically-friendly and affordable green environment. As we know, natural fibre is 100% bio-degradable and recyclable. So if it is used in concrete , pollution will be eliminated, promote biodiversity and conservation of natural resources and thus environmentally friendly. Three fibres such as Jute, Oil palm and Polypropylene fibres were used as complement in concrete and its suitability , durability and influence on the properties of concrete were analyzed. The percentages of fibre used in concrete were 0.25 and 0.5 of cement content by weight. Totally 84 concrete cube specimens were prepared for standard tests which include compression test, slump test and compaction factor test. The test results indicate that for Jute and Oil palm fibres, the optimum fibre content was 0.25% and for Polypropylene fibre, the optimum fibre content was 0.5%. They all yielded increase in strength when it is compared to the control specimen and has proven to reduce reasonable environmental waste pollution.

In [24] it is deals with subject of addition of natural fibers to concrete in order to study the strength properties and also to observe if there is reduction in propagation of shrinkage crack problems. Basically natural fibers are of two types. One is natural inorganic fibers such as Basalt, Asbestos…etc and the other is natural organic fibers such as coconut , palm, kenaf, jute, sisal, banana, pine, sugarcane, bamboo…etc. Natural fibers are investigated by different researchers as construction materials that can be used in cement paste/mortar/concrete. This incestigation may include the fiber properties, characteristics and compatibility between themselves and also the comparisons and conclusion to be studied for different fiber-cement proportions. However all properties of concrete may not improve for the same proportions of different fibers. Some properties may be improved and same may be reduced, since each fiber has its own different properties. So totally the study deals with comparisons and differences between the different natural fibers. From this, they concluded that the slump is decreasing with the addition of fibers. If fiber-cement ratio is more, then there will be decrease in slump due to absorbency of water by fibers. Hence the use of proper super plasticizer which does not effect other properties except workability is recommended for higher fiber-cement ratio. Due to the addition of fibers compressive strength increased with 0.5% fiber-cement ratio and little increase for 1% of fiber-cement ratio compared to plain concrete. But at 1.5% of fiber-cement ratio, though the plasticizer is added in concrete, the compressive strength is in descending order compared to plain concrete. When the percentage of fibers is increased, the sudden brittle failure of sample is resisted and also voids in concrete thoroughly compacted.

According to this large experimental study[25], natural fibers improve the flexural performance and overall strength of concrete. On mechanical qualities including compressive strength, split tensile strength, rupture modulus, flexural performance, and microstructural properties, the impact of curing ages has been examined and discussed. In light of this investigation [25], it can be said that natural fibers like coir and sugarcane fibers improve all three mechanical strength properties, including compressive strength, split tensile strength, modulus of rupture, and flexural performance, at all curing ages. At earlier curing ages, natural fibers improve the strength qualities; nevertheless, at later curing ages, the rate of increments is slower than in conventional concrete samples.

Durability of vegetable fiber reinforced concrete[26] can be found by investigating its ability to resist both external (temperature and humidity variations, sulfate or chloride attack etc) and internal damage (compatibility between fibers and cement matrix, volumetric changes etc). The degradation of natural fibers immersed in portland cement , due to the high alkaline environment it dissolves the lignin and hemicellulose phases of fibre and weaken the fiber structure. While immersion of the fibers in a calcium hydroxide solution, it was noticed that original strength was completely lost after 300 days. Another path to decrease the durability of fiber reinforced concrete is the water absorption capacity of natural fibers. Water absorption leads to volume changes that can induce cracks in concrete. In order to improve the durability of fiber reinforced concrete following two paths could be used. First path is using low alkaline concrete adding pozzolanic by-products such as rice husk ash, blast furnace slag, silica fume and other is coating natural fibers with water repelling agents to avoid water absorption and free alkalis.

To improve the durability performance of sisal fibre reinforced cement based composites[27], Gram (1983) treated the sisal fibres with some chemical agents such as sodium silicate, sodium sulfite, magnesium sulfate, iron or copper compounds, barium and sulfite salts, but none of them improved the durability of the fibre.Then Gram treated the fibre with water repellent agent but apart from formine and stearic acid (that led to a retardation of the embrittlement tendency of the composites) all other treatments (PVA, amide wax, siliconoil, tar, rubber latex, asphalt) did not prevent the fibre from beingmineralized.

Stearic acid (octadecanoic acid) is a saturated fatty acid derived from animal fats and oils and also from vegetable fats and oils. In Malaysia, it is mainly produced by the palm oil industry. It is considered to be inert, inexpensive, water repelling agent and biocompatible, as well as of a low toxicity. The solubility of stearic acid was found to be the highest in ethyl acetate[28], followed by ethanol, acetone and methanol.

In [29] the use of natural fibers in fiber-reinforced composites has been studied because it can be a suitable replacement to man-made fiber and also help to opened up further industrial possibilities. Natural fibers have the following advantages low density, low cost, and biodegradability. However, the main drawback of natural fibers in composites is the poor compatibility between fiber and matrix and the relative high moisture absorption. Therefore, chemical treatments are considered which change the fiber surface properties. In [29], the different chemical modifications on natural fibers for use in natural fiber-reinforced composites are reviewed. Chemical treatments including alkali, silane, acetylation, benzoylation, acrylation, maleated coupling agents, isocyanates, permanganate and others are discussed. The chemical treatment of fiber aimed at improving the adhesion between the fiber surface and the polymer matrix may not only chnge the fiber surface but also improve fiber strength. Water absorption of composites is minimized and their mechanical properties are improved.

In [30] durability properties of Coconut fibre are investigated. First coconut fibre ropes were soaked in tap water for 4 h to remove coir dust and then dried in open air.To improve the coconut fibre durability ,it is treated by two types. First type is treating coir with boiling water and washing (i.e) soaked ropes were put in boiling water for 2 h and then it is washed with tap water until the colour of water became clear. Then the ropes were finally dried in the same manner as soaked ropes. These treated ropes are called boiled ropes and second type is treating coir with chemicals (i.e)soaked ropes were dipped in 0.25% Sodium Alginate (NaC6H7O6) solution prepared by distilled water for 30 min. Ropes were removed from the solution and then soaked in 1% calcium chloride (CaCl2) solution for 90 min. and these ropes were finally dried. These chemically treated ropes are called CaAl ropes.

**3.CONCLUSION**

Based on the literature following conclusions are made :

* It is observed that due to the addition of steel fibres ( metallic fibres)

Compressive strength of concrete increases from 11 to 24% .

Flexural strength of concrete increases from 12 to 49%.

Split tensile strength of concrete increases from 3 to 41%.

* It was found that the amount of steel fibers which can be added to the concrete be 1% by weight. Addition of steel fibers more than 1% generally affects the mechanical properties of concrete.
* Optimum silica fume replacement level for concrete is 10% and w/cm ratios should be ranging from 0.25 to 0.45 with varying dosages of a high-range of water-reducing admixture to maintain a fluid consistency.
* The use of two or more types of fibers (i.e.) metallic and non metallic fibres or metallic and natural fibres in a suitable combination may potentially improve the overall properties of concrete.
* Due to the addition of steel fibres in concrete, it is contributed towards the energy absorbing mechanism (bridging action) whereas, the non-metallic fibres resulted in delaying the formation of micro-cracks.
* The hybrid combination of metallic and non-metallic fibres can offer potential advantages in improving concrete properties as well as minimize the overall cost of concrete production.
* Natural fibre is 100% bio-degradable and recyclable so it can eliminate pollution, promote biodiversity and conservation of natural resources and thus environmentally friendly.
* But natural fibres get degraded while immersed in Portland cement, due to the high alkaline environment the lignin and hemicelluloses phases get dissolved and make the fiber structure weaker.
* Another path which decrease the durability of fiber reinforced concrete is the water absorbing capacity of natural fibers.
* In order to improve the durability of natural fiber reinforced concrete, following paths could be used.

First is using low alkaline concrete adding pozzolanic by-products such as rice husk ash, blast furnace slag, silica fume.

Other is coating natural fibers with water repelling agents to avoid water absorption and free alkalis.

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