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Performance and Application of Fibre-Reinforcing Bars: Literature Review and Case Studies

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***Abstract*— Concrete infrastructure, like roads, pavements, water retaining structures, and many more types experience heavy deterioration which may be triggered by corrosion of the reinforcement and the brittle nature of concrete. Fibre Reinforced Concrete (FRC) is seen as an excellent alternative to such conventional concrete applications due to its properties of enhanced control on cracks and increased durability. Although FRC has been used worldwide since the early 1900s, there is little guidance regarding its use and testing of FRP bars in India. There is also a lack of credible information about the new fibre products being introduced in the market. An attempt is made do literature survey to understand the past FRC experiences, and to improve the usability and design of FRC in road pavements as part of major infrastructure. The parameters studied ranged from the fibre type, dosage of fibres and monitoring the increase in flexural strength of concrete, increase in service life, and economic benefits of choosing FRC over conventional reinforced sections, with case studies in Maharashtra and Andhra Pradesh, India. The design-centric approach for a prescribed percentage of synthetic fibre reinforcement was studied as an alternative to achieve the economical and structural benefits by using various doses of fibre reinforcement in concrete.**

***Index Terms*— Fibre Reinforced Concrete, Macrofibres, Pavements, Durability.**

I. Introduction

Reinforced concrete, due to its relatively low cost, versatility, and availability of raw materials, finds extensive use worldwide. However, despite such advantages, concrete continues to suffer from inherent weaknesses like low tensile strength and very limited ductility. As concrete sets, there is formation of micro-cracks due to temperature changes and shrinkage, which can grow into larger cracks under service loads. Such crack progression reduces structural efficiency, promotes water ingress, and accelerates reinforcement corrosion. In pavements and other loaded members, this combination of cracking, corrosion, and repeated traffic loading can result in substantial reductions in performance that may ultimately lead to failure. One of the most common methods of improving tensile and flexural behaviour involves the addition of fibres to the mix, commonly referred to as Fibre Reinforced Concrete (FRC).

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FRC assists in controlling crack initiation and propagation. The improved durability and enhanced service life are thus the benefits derived from the incorporation of fibres. A wide range of FRC products is available, but their design, performance benefits, and cost-effectiveness have not been thoroughly evaluated in the Indian context. Advances in fibre technology and design methodologies now merit detailed study and codal integration to support large-scale infrastructure applications, enabling improved performance and reduced construction costs. This paper presents a literature review and examines some cases of FRC use in pavements and buildings in Maharashtra and Andhra Pradesh in India. Performance improvements, opportunities to replace conventional reinforcement, and the development of practical construction criteria are highlighted.

II. Fibres and Fibre Reinforcement In Concrete

A. Basics of Fibres

Concrete fibres are manufactured in several different materials and geometries. According to ACI 544 [1]and ASTM C1116[2], fibres are classified based on their material as either steel, glass, synthetic, or natural. In functional terms, two categories of fibres exist: microfibres and macrofibres. Microfibres primarily control plastic shrinkage and do not contribute to increasing the structural capacity of concrete; they are very fine with diameters of 0.02–0.04 mm and lengths of 6–25 mm. Macrofibres, on the other hand, contribute to shrinkage and temperature crack control and post-crack strength. Thus, with larger geometries, 0.5–0.7 mm diameter and 35–55 mm in length, they can, in part, replace light reinforcement and contribute to improving load and flexural performance (FRCA, 2007). Synthetic fibres, usually made from polypropylene or polyethene, exhibit very low thermal expansion and help provide resistance to thermal cracking. Macro synthetic fibres have been used rather widely as noncorrosive alternatives to steel and generally are added in volumes of 1.8–10 kg/m³ FRCA, 2007. Researchers have reported impressive gains in flexural strength [3]. Their use has been accepted in various projects including bridge decks, overlays, barriers, white topping, and full-depth pavements applications and these demonstrate that fibre dosage should be engineered and not fixed Performance tests, such as ASTM C1399[4], may be used to identify the minimum cost-effective dosage.

B. Properties of Concrete with Fibre Reinforcing Bars

Fresh Concrete Properties

Slump

Slump of FRC was usually measured by ASTM C143[5] or IS 456/IS 1199[6] and the same procedure was followed as for plain and reinforced concrete. It was reported that the addition of synthetic microfibres caused an average slump loss of around 50 mm[7] . The loss in workability was generally regained with the help of superplasticisers or water-reducing admixtures [8]. Fly ash was also used to improve paste volume and provide uniform fibre dispersion without a high initial slump [9].

Air Content

The air content was determined as per ASTM C138 [10]or IS 1199[6]. From the literature reviewed, it can be concluded that fibre addition did not significantly affect the air content in concrete[9].

Fibre Distribution

Fibre distribution was checked by determining the actual fibre content per cubic metre of concrete [8]. This typically consisted of washing out the concrete, separating and drying the fibres, and weighing them in order to assess uniformity in the matrix.

Mechanical and Durability Properties of Fibre Reinforced Concrete (FRC)

The compressive behaviour of FRC is usually assessed according to IS 516 [11] or ASTM C39[12]. The addition of fibres changes the fracture nature from brittle due to the bridging action of fibres across cracks that limit the separation of fragments and hinder propagation.

The beneficial influence of adding fibres on enhancing the post-peak behaviour and increasing the deformation capacity was confirmed by many (ACI, 1988)[13]. The gains in compressive strength were reported to lie within a wide range, from a limited increase of about 12% to as high as almost 90%, depending on fibre geometry, dosage, and matrix composition [14]. On the other hand, a slight loss in strength was observed in some studies under specific mix conditions [15]. Flexural behaviour is typically quantified using ASTM C1609 [16] third-point loading or IS 516 midpoint loading procedures. Test results have consistently shown that macrofibres tend to enhance post-crack stiffness and induce a controlled deflection-hardening response [17], [18]. Strength increases due to the addition of macrofibres in terms of flexural cracking strength usually lie in the range of 25–55% [19].

Residual strength, as defined under ASTM C1399[4], quantifies the ability of the material to carry load following matrix cracking. In the post-cracking regime, the primary load-resistance mechanism is provided by fibres, which enables a valid comparison between different fibre types. Most studies report a positive correlation between residual strength and fibre dosage; for instance, [15] measured an approximate increase in residual strength of 0.65 MPa for every 0.1% increase in steel fibre volume fraction.

Toughness, an FRC energy absorption capability, is usually derived from load–deflection curves by employing ASTM C1609[16], in which the area enclosed represents the absorbed energy (ACI, 1988). Tests of round panels under ASTM C1550 [20] have also been applied and might be more suitable for slab-type elements, even though their use can be limited practically. Over various studies, fibre reinforcement has tended to give increased post-crack load retention and increased deformation capacity [17]. Impact resistance has often been tested by using drop-weight techniques, with the test outcomes showing substantial improvements with fibre addition. These improvements are largely related to the enhanced crack growth resistance under dynamic stresses [21]. High-performance and ultra-high-performance variants of FRC also show excellent energy dissipation characteristics under dynamic compression and tension[21]. Specimens that withstand two million cycles are considered representative of pavement service life, and S–N curves are normally used to characterise the fatigue behaviour. Abrasion resistance is a crucial property for pavement and bridge deck applications, and it is commonly tested using a procedure specified in the ASTM C944 [22] or IS 9284 [23]. The addition of synthetic macrofibres has been reported to improve the abrasion resistance, reduce the surface wear by approximately 14% compared to control concrete, which is believed to be due to the improvement in fibre–matrix interaction and higher effective surface area covered by the fibres[7], [24]. It is seen that the FRC has consistently enhanced mechanical properties, post-cracking performance, energy absorption, impact resistance, fatigue endurance, abrasion resistance, and bonding behaviour, making it highly suitable for pavements, overlays, and other structural applications.

III. Prescribed Dosing of A New Blend of Synthetic Macro Fibres

The general literature review has shed a lot of light on the effects of using synthetic macro fibres in concrete for various applications. In this study, the focus is on highlighting the possibilities and advantages of using these fibres under a broader spectrum. Initially, fibres were used as secondary reinforcement for crack control only. Now, these are used as the main structural reinforcement is slab on grade, pavements, and as the structural base. With new materials being continuously developed, this study will focus on a new blend of materials, and a design concept will be developed for applications around the world in road pavements.

A. Material Characteristics

Various codes provide specifications and directions for further development in materials and technologies. Using these references, a particular blend of polyolefin and polypropylene was developed to improve the material characteristics of the synthetic fibres. As discussed in the previous sections, the concrete characteristics are indirectly dependent on the type and the performance of the fibres used in concrete. With improved material characteristics, it is possible to extract the best possible performance from the fibres and directly improve concrete performance. The material characteristics of the fibre composite used in MIDC work are presented in Table I.

Table I. Material Characteristics of Synthetic Macro Fibres

Material	Polyolefin polypropylene blend
Absorption	Nil
Specific Gravity	0.91
Alkali Resistance	Excellent
Melting Point	160 oC
Electrical Conductivity	Nil
Aspect Ratio	100
Equivalent Diameter	0.38mm
Length of Fibres	38mm, 50mm
Tensile Strength	-
Modulus of elasticity	-

B. Design Concept

Design tools in the form of spreadsheets and software packages to calculate the dosage rate of the macro synthetic fibres to match typical steel reinforcement in concrete, based on performance. The information required for such calculations is concrete compressive strength, pavement thickness, traffic consideration, and loading considerations. The calculations of macro synthetic fibres in pavements are based on ACI 360[25]. The information required for such calculations is usually the pavement thickness, compressive strength of concrete, subgrade type and modulus, and the applied loads, with different types of loads such as axle loads and the cyclic load consideration.

Economics of the Design With Fibre Reinforced Concrete

The above alternative of Fibre Reinforced Concrete for road pavement was suggested as an economic alternative to the conventional Steel Reinforced Concrete Pavement. The company had designed their road pavement based on the consideration that heavy truck load will be operating frequently over the pavement owing to the industrial nature of the traffic, and hence they went for conventional steel-reinforced concrete pavement. But they were able to design a percentage that would provide them with the same structural properties as the reinforced section, and provide better abrasion resistance, ductility and provide a three-dimensional reinforcement with structural synthetic fibres. The material cost comparison is shown in Table II.

TABLE II. COST COMPARISON BETWEEN CONVENTIONAL STEEL REINFORCED CONCRETE AND FIBRE REINFORCED CONCRETE FOR THE PROJECT IN MIDC PUNE, MAHARASHTRA

Fibre							
Sr No	Slab Thickness (m)	CuM of Concrete	Slab Area (SqM)	Fibre Dosage (Kg)	Rate of Fibre (Rs)	Rate per SqM	Rate per Sft
1	0.15	1.00	6.67	2.00	625.00	187.50	17.42
Reinforcing Steel							
Sr No	Slab Area (SqM)	Steel diameter (mm)	Spacing (mm)	Weight of steel (Kg/m)	Rate of Steel (Rs)	Rate per SqM	Rate per Sft
1	1	8.00	200.00	3.95	60.00	237.04	22.03

As seen in the above table, the cost of fibres is Rs. 4.61/-, less than that of reinforcing steel per square foot, based on the current market rates. That translates into direct savings on material costs of around 11%. Using FRC, the company also saved on labour costs, and the time required for the project was reduced by 20 days, for approximately 5,000 sqm of pavement area.

C. Replacing Steel Reinforcement in Reinforced Concrete for Buildings

Flexural Strength is considered one of the most important measurable parameters of FRC, which tells the capacity of the concrete to resist bending stresses acting on the section. It helps us determine how much bending moment or negative stresses can be handled by the concrete. To determine by how much the flexural strength can be increased using the macro synthetic fibres with polyolefin and polypropylene blend, a flexural beam test was carried out on 3 beams of M30, Self-Compacting Concrete with 2.4 kg/cum dosage of fibres for a separate application of Steel Deck/Composite Deck in a steel building (Table III).

TABLE III. MIX DESIGN AND TESTING RESULTS OF FRC BEAM

Mix Ingredients	Quantity of material in 1 cum
Cement Content OPC 53 (kg/cum)	330
Fly Ash (kg/cum)	150
10mm Coarse aggregate (kg/cum)	805
Fine Aggregate (Crushed sand) (kg/cum)	895
Water (kg/cum)	182
Admixture (kg/cum)	2.64
Macro Synthetic Fibres (kg/cum)	2.4
Compressive Strength 7 days (N/sqmm)	32.2
Compressive Strength 28 days (N/sqmm)	49.1
Flexural Strength 7 days (N/sqmm)	4.42
Flexural Strength 28 days (N/sqmm)	5.63

As per IS 456, the target means strength of M30 grade of concrete is 4.33 N/sqmm. As per the test results, there was a 30% increase in the mean flexural strength. A Live Load test was conducted on-site with the above concrete specifications to check the deflection values and the percentage recovery of deflection to determine the ductility and bending resistance of the slab with Synthetic Macro Fibres as the only reinforcing material in the steel deck/composite deck. The entire mock slab of 600 sqft was loaded in incrementing manner for 28 days. The total load was 8.75 kN/sqm (Live load + 1.25 x SDL). A load test was conducted using sandbags as loading material. Unloading was carried out immediately, and dial gauge readings were recorded and recovery percentage calculated. Below is the summary of the report (Figures 1-3).

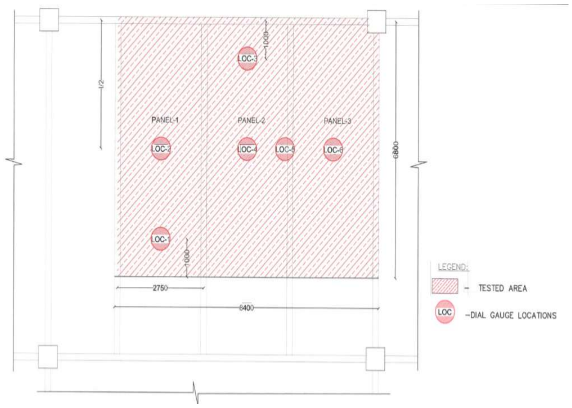

Figure 1. Layout of sample loading and results of deflection measured during loading and after unloading

Based on the different degrees of deflection throughout the span, the unfactored deflection was 5.9mm, whereas the permissible limit is11 mm (L/250). Also, the recovery of deflection was observed to be more than 70% with no cracking observed on the slab. Taking guidance and references from ACI 544, ACI 360[13], [25], and Steel Deck Institute ANSI-SDI-C-2017 and the above results for flexural strength and the recovery of deflection throughout the slab, the welded steel reinforcement bars provided for shrinkage and temperature stresses could be completely replaced by synthetic macro fibres. This helped reduce the slab cycle duration by 4 days per slab and reduced the cost comparison of steel by8% (Actual figures from a project executed by authors 2 and 3 for Phoenix Realty, Hyderabad).

D. Structural Applications of Macro Synthetic Fibres

Road Pavements

Fibre Reinforced Concrete with macro synthetic fibres has been used for concrete road pavement applications to provide a more durable pavement with improved cracking resistance and reduction in required slab thickness. The properties related to improved ductility and toughness have been stipulated in the IRC 46[26]. For all road pavement applications with synthetic macro fibres, a characteristic flexural strength of 5 to 8 MPa is used. With the improved polyolefin blend of macro synthetic fibres and the improved design concept, it is possible to improve the performance of the road pavements and to design and prescribe the required dosage based on the traffic condition and the loading considerations.

Figure 2. Typical view of test location Figure 3. Support conditions and incremental loading of the composite deck slab

(Figure 4) [27]. At the Cerro Sombrero Highway in Chile, a pavement consisting of macro synthetic fibres was constructed where the control steel reinforcement was completely replaced by synthetic macro fibres. The concrete strength was specified at 5.3 MPa at 90 days, with a defective fraction of 20% and a residual strength of 1.2 MPa L/150 according to ASTM C-1609-07 at 90 days. Over 42 tonnes of fibre were used at a rate of 2.5 kg/m3. In 2016, work began on a major substation project in central Sydney to support Ausgrid's [28] long-term goals for a safe and reliable electricity supply. The utility determined there was a need for a new sub-transmission substation to serve local commercial areas along with the Sydney Airport and related international nodes.

At the juncture where the facility joined the main access road, standard steel reinforcement was not permitted due to the possibility of electrical conduction. The presence of steel in the pavement system had the potential to provide a pathway for stray currents in the event of an electrical fault or surge and posed a risk to pedestrian safety.

Hence, the design team and project consultants were obliged to seek non-conductive reinforcement methods suitable for the pavement system. Given the heavy operational loads imposed by substation equipment, a dosage of 7.5 kg/m³ fibre was specified.

Figure 4. Construction work going on with FRC at Sombrero Highway, Chile

When constructed, the fibre-reinforced concrete mix was found to be compatible with conventional placement methods and was successfully pumped and finished with little extra effort from the on-site crew. To replace the original design using reinforcement of 16mm diameter bars, a design in accordance with the UK Concrete Society's Technical Report 34 (TR34) demonstrated that 7.5kg/m3 of macro synthetic fibre was a suitable alternative.

E. Some Works Executed in Maharashtra and Andhra Pradesh in MIDC Area

Internal Road works for Factories (Industrial Road, Baramati, Dist. Pune, Maharashtra)

Road Pavements are one of the key infrastructures in major industrial areas as they are the means for ferrying a high volume of heavy trucks. That demands the road pavements in industrial areas to be able to deliver more performance concerning higher flexural performance, higher abrasive resistance, and higher cyclic loading performance, prevention of cracks, negative curling stresses, and higher impact resistance. (Figure 5) The macro synthetic fibres were used as the sole replacement for conventional steel reinforcement with the help of guidelines provided under IRC 46, TR-34, and ACI 360. The thickness of the pavement was 200mm, and the dosage used as per the design was 1.8 kg/cum. The road design was optimised to minimize the thickness and provide the necessary performance for heavy truck movement. In 3 years of observations post-construction, the road pavement satisfies all design criteria and is in excellent condition.

Figure 5. Internal Road works for Factory in MIDC Pune

Composite / Metal Deck in Steel Building at Hyderabad (Andhra Pradesh)
Commercial Steel Building

Steel Buildings are known for their speedy construction and resistance to any natural disasters. The steel deck/composite deck in steel buildings is one of the most common places where FRC finds huge advantages. Traditionally, steel reinforcement is used over steel/composite deck as a nominal reinforcement to prevent cracking due to shrinkage and temperature stresses. (Figure 6). An effort was made to replace this reinforcing steel completely with synthetic macro fibres, which provide more ductility, excellent crack protection, and enhanced resistance to impact and abrasion. Replacing reinforcing steel with synthetic fibres also enabled the developer to decrease the slab cycle by almost 5 days, reduce labour cost and operational costs related to crane handling for transporting steel reinforcement to heights of over 20 floors, improved worker safety as it reduced tripping and falling of labours and gave an outright savings of more than 20% with respect to steel reinforcement on material cost. All these advantages cumulatively proved to be very beneficial to the developer, and the FRC option was successfully implemented in the Steel Building.

Figure 6. Metal/Composite Deck application at a project site in Hyderabad, India

IV. Conclusion

The study presents the huge potential and the current experiences with synthetic macro fibres in transportation pavement applications. A lot of private industries in India have utilised FRC as a suitable alternative for conventional reinforcement in applications like grade slabs and road pavements in industrial areas. These experiences provide useful case studies to understand and implement the use of prescribed and designed dosages of synthetic fibre reinforced in applications in the construction of road pavements, which will lower life cycle costs. The literature review presents the groundwork for previous studies and experimental data on FRC in various applications. That data, coupled with sound engineering design concepts, could prove to be very valuable to the future of road construction in India. Along with road pavements, a lot more applications are possible to be implemented with FRC, such as canal lining, high-speed track systems, and composite decks at Metro Stations. With a design-centric and performance-based approach, the suitability of fibre reinforcing bars can be determined, and codal validation can be performed.

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