FIBER REINFORCEMENT FOR DRYING SHRINKAGE MITIGATION IN CONCRETE: A COMPREHENSIVE REVIEW

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Abstract- A comprehensive review presents a detailed review of the key challenges and advanced solutions addressing drying shrinkage in concrete structures. Drying shrinkage is a major issue in concrete, often resulting in cracking and decreased durability. There are many factors which affect the creation of drying shrinkage cracks like water to binder ratio, cement type and environmental conditions. The integration of fiber into concrete offers promising solutions yet its effectiveness is based on its type, quantity and density. This study systematically evaluates drying shrinkage governing properties and use of different fibers to mitigate it. The use of rice straw, basalt fiber, vegetable fiber, cotton fabric and textile waste, non-cellulose and steel fibers are discussed. The blending approach is the key to achieving best results like basalt fiber and nanosilica. A comprehensive literature review exploring different research computing experimentally shrinkage effects, it governs parameters and controlling through fiber reinforcement. Fibers are assessed based on their density, tensile strength, shrinkage reduction and improving ductility. Data was reviewed to look at the performances of different fibers used alone or in combination for performance and serviceability. Steel and Nanocellulose fibers are found most effective in mitigating drying shrinkage while natural fibers offer moderate benefits. Basalt and nanosilica fiber provided excellent ductility and tensile strength. Cotton knitted fiber and textile waste fiber significantly increase flexural strength and toughness. Introduction of fibers improves concrete mechanical properties and provide enhanced performance and longevity.

Keywords- Drying Shrinkage Cracks, Durability, Cotton Knitted Fibre, Steel Fibre, Sustainability, Textile Waste

1 Introduction

Concrete is the backbone of modern infrastructure due to its strength, availability and flexibility. It has some persistent challenges which compromises its durability and strength in the longer period of time. One of the persistent defects is drying shrinkage which compromise its integrity and longevity. Such cracks are especially problematic in large structural elements like slabs, canal lining and rigid pavements, where they can substantially compromise long-term structural performance and serviceability. Water to binder ratio, type of cement, weather conditions, properties of aggregates, curing methods and admixture can be important factor producing drying shrinkage if not properly addressed. Recent studies have investigated a range of innovative strategies to mitigate the adverse effects of drying shrinkage, with particular emphasis on optimizing mix designs[1] through the inclusion of alternative binders [3], recycled aggregates, and supplementary cementitious materials [16][9] [4]. For example, the addition of blast furnace slag [5], fly ash [3], and geopolymer components [6] has shown potential in reducing shrinkage by modifying moisture transport mechanisms and enhancing the material's microstructural characteristics. Furthermore, studies on unique methods for treatment for recycled aggregates [4] and controlled low-strength materials (CLSMs) [2] have highlighted the need for sustainable solutions in this area of study.

An important avenue of recent research involves the application of fibre reinforcement as a means of controlling drying shrinkage. A wide range of fibres, including synthetic, steel, [7] vegetable-based, [8] nanocellulose, [9]and hybrid types, have proven effective in controlling shrinkage by bridging microcracks and promoting a more uniform distribution of internal stresses within the concrete mix. In addition to restricting initiation and propagation of shrinkage-induced cracks, these fibres contribute to enhanced mechanical performance and improved long-term durability of concrete. Each fibre type display unique properties to concrete paste improving mechanical properties and enhancing performance. Rice straw [8] reduces shrinkage cracks by 15% to 30%. It is low cost and sustainable but can be less durable in wet conditions. The natural fibres can be biodegradable, and care is required during application. Nano Silica and Basalt fibre [9] can be excellent for reducing drying shrinkage due their durability. Steel fibres [7] can reduce main reinforcement and their ductile behaviour can improve tensile strength in micro structure. Synthetic fibres with its consistent properties and chemical resistance improves durability and strength. But fibres can be expensive, and its application require complex methodology which limit its commercial use in the construction industry. This literature review produces global research on FRC's role in addressing shrinkage, prioritizing practicality and innovation. By comparing fibre properties and environmental impacts, it identifies optimal strategies for diverse construction needs.

The review explores how fibre selection control's concrete ability to resist shrinkage, making a balance between innovative ideas and real-world applications. Researchers have used natural fibres[10] like coconut fibre [11], banana fibre[12], wheat straw [13] and jute fibres [14] for improving mechanical properties. While vegetable fibres [8] are economical, their weakness to moisture and bacterial decay demands chemical treatments, complicating implementation in large scale projects. Synthetic fibres deliver reliable performance but have larger carbon footprint, as they rely on non-renewable petroleum resources. Developing material like nanocellulose [9] and basalt fibres [9] showcase potential of ecofriendly and high strength alternative. The study argue that no single fibre can fully address shrinkage challenge. Hybrid systems or specific fibre blend may bridge gaps in durability, cost and sustainability. For advance fibre reinforced concrete (FRC), the industry must blend material innovation with environmental responsibility and economic capability, nurturing strong infrastructure suited to diverse needs. Comparative analysis of synthetic versus bio-based fibres might clarify their long-term environmental trad-offs. Exploring regional sourced fibres, such as agriculture waste and locally mined basalt, could optimize affordability. By aligning material science with economic and environmental realities, FRC can evolve into a foundation of strong, adaptive construction practices.

2 Structural Defect

Concrete is an obvious choice in current structural and infrastructural projects due to its strength, flexibility and easy availability. Despite its numerous advantages, there are many defects or flaws present in the concrete. As concrete hydrates and start to lose its moisture, it shrinks in volume due to hydration. During summers due to high temperature, water in concrete dries quickly and causing this defect more often. If water sprinkling or curing is not done properly surface of the concrete shrinks rapidly and small cracks appear on the surface. Please see figure-1 showing drying shrinkage cracks. These cracks affect appearance and durability of the structural element. In larger element like slab these cracks can affect performance in the long run significantly. The major issue is creep which initiates at early stage due to water insertion which can cause steel rusting. These small cracks expand with the passage of time and give way to deterioration of the surface. The longevity and service of the structural element is badly affected if these cracks are not avoided in initial construction stage. Most of the time drying shrinkage cracks appears immediately after concreting due to hydration. Immediate curing and water sprinkling or curing compounds should be applied to avoid drying.

Kipkemboi and Miyazawa [5] explored how drying shrinkage affects the cracking resistance of massive self-compacting concrete (SCC) containing blast furnace slag, using a combination of experimental testing and 3D finite element modelling. Their finding shows that higher slag replacement ratios (50%-70%) effectively reduce the temperature rise and improved resistance to cracking. Blast furnace slag is an important addition to concrete which can reduce cracking. Peng and Dai [2] explored the use of construction waste in producing controlled low-strength materials (CLSMs), which offer a sustainable option for applications like backfilling and foundation support. Despite their benefits, CLSMs are weak to shrinkage and cracking in dry conditions potentially affecting structural stability (Figure 1). Their research focused on how drying influence the crack development and strength reduction. Their results showed increasing Portland cement or adding bentonite helps minimize cracking and strength loss. Deng et al. [6] studied on developing a drying shrinkage model for modified ceramsite geopolymer concrete (MCGC) through two sets of experiments. The first, ceramsite was treated with

6% silicone resin to reduce water absorption, improve compressive strength and workability, and lower drying shrinkage. The second ceramsite was produced with varying factors like water to binder ratio, Na2O content and metakaolin content effect on strength and shrinkage. Results showed that while higher water and Na_2O contents increased shrinkage, 8% Na_2O enhanced strength, whereas 10% reduced it. These study shows drying shrinkage is a constant problem even with addition of chemicals.

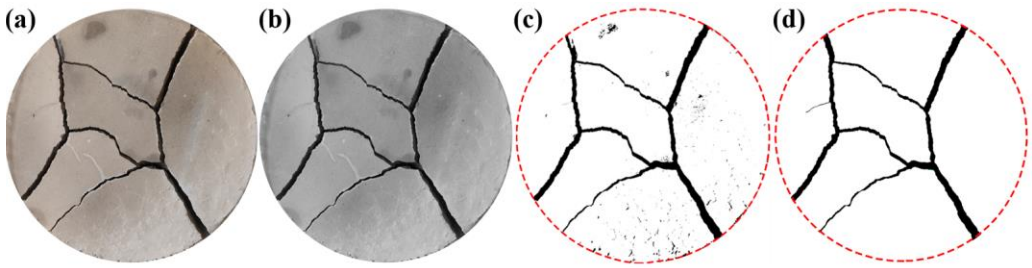

*Figure 1: Image processing (**a**)original crack image, (**b**)grayscale image, (**c**) image of crack after binarization and (**d**) binarized image after removing spurious points* [2]

Liu et al. [15] studied, how to improve the durability of geopolymer made from a mixture of slag and recycled powder, obtained from finely grinded brick and recycled concrete materials, an environmentally friendly approach to recycling construction waste. While such materials often suffer from drying shrinkage and efflorescence, the research found that adding slag significantly reduces both issues. Yang and Lee [4] explored a new method of treating recycled concrete aggregate (RCA)(Table 1) by coating it with a cement paste decomposition additive (CPDA) to improve the quality of RCA concrete. The results showed that using CPDA-coated RCA improved the concrete's durability by reducing both drying shrinkage and chloride penetration, regardless of the mixing method or amount of recycled concrete aggregate used. There is many research works are being done on sustainability and durability of concrete but drying shrinkage is key factor affecting the serviceability and long-term strength of concrete elements.

Table- 1: Basic aggregate properties [4]

Items tested	RA	RP	NCA	Fine Agg. A	Fine Agg. B
Specific gravity	2.54	2.60	2.69	2.58	2.60
Absorption (%) rate	4.51	2.62	0.54	0.52	0.59
RMC	-	20.0	-	-	-

Fan et al. [3] compared the performance of fly ash (FA) and ground granulated blast-furnace slag (GGBS) in concrete with equal strength levels. By adjusting water-to-binder ratios and superplasticizer dosages, the researchers maintained consistent strength and workability across samples. Both FA and GGBS improved resistance to chloride ion penetration and reduced drying shrinkage, especially at higher replacement levels (30–40%). The drying shrinkage remains one the most impactful and constant challenge in all research works to improve durability and strength. For more sustainable and large-scale concrete applications, drying shrinkage must be avoided to get long-term effects. The researchers are using innovative material and procedures to address this issue. By incorporating blast furnace slag, fly ash, optimizing mix design and brick powder, each study contributes valuable insights to minimize shrinkage and improve durability. These studies not only refine construction practices but also work for broader goal of achieving sustainability. These advancements hold the potential for meaningfully influence the shape of future concrete work. Drying shrinkage is the main flaw which effect the durability and longevity of the concrete elements.

3 Governing Parameter of drying shrinkage

There are several factors which influence drying shrinkage. The important factors which determine how much and how quickly concrete shrinks when water evaporates from it. The water to binder ration plays an important role: higher ratio leads to more porous concrete, allowing more water loss and increased shrinkage. The lower water to binder ratio can decrease shrinkage but on the cost of workability of concrete mix. Less workable concrete means hydration initiates at early stage. The type and content of cement used is also a factor because different cement hydrates differently. For example, cement with fly ash or slag can help reduce shrinkage. The aggregate properties are also a significant factor, well graded aggregates with low absorption can reduce shrinkage. The most crucial role is played by curing, insufficient or late curing may lead to moisture loss at higher rate, which accelerates shrinkage. Proper curing at right time hydrates concrete and reduce the chance of substantial shrinkage stresses. Environmental conditions such as high temperature and low humidity during summers, accelerates evaporation and water loss. High wind also promotes drying.

Shrinkage reducing admixtures can also play important part in minimizing shrinkage stresses by low capillary tension in concrete pours. Superplasticizer can reduce water content without decreasing workability which helps in drying shrinkage reduction. Cementitious material like fly ash, silica fume and metakaolin can also play important role in reducing drying shrinkage if added in proper quantity. The smaller and flatter concrete elements tend to dry faster due to a large area is under environmental conditions and dry faster. The age of concrete at start of drying is also critical. To control shrinkage and prevent damage it is required to timely and affectively cure the concrete surface. Araujo et al. [16] explored the use of Alkali-Activated Binders (AAB) as a full replacement for ordinary Portland cement (OPC), focusing on a formulation using fly ash and steel slag with sodium-based activators. The research explored the impact of steel slag aggregates and curing temperature on the fresh and hardened properties, as well as the durability, of a high-performance, self-compacting AAB concrete. Excellent mechanical strength (64 MPa), good workability and self-compacting standards are the results achieved. Banyai et al. [17] investigated the potential of employing recycled concrete aggregates (RCA) from various kinds of construction and demolition wreckage to create concrete that meets standard performance criteria. It is notable that a mix that contained 30% RCA (from pure concrete waste) outperformed the reference mix with natural aggregates (51.4 MPa) in terms of compressive strength and water resistance.

Šmilauer et al. [18] examined the shrinkage and creep behaviour of an industrially produced hybrid cement (H-cement) containing only 20% Portland clinker, which combines hydration and alkali activation processes. H-cement showed lower autogenic shrinkage after 7 days and similar drying shrinkage over time. Due to its distinct capillary structure, H-cement experienced quicker water loss during drying. Ghafoori et al. [19] evaluated the characteristics of high early-strength concretes made with Type V, Type III, and rapid hardening calcium sulfoaluminate cements at multiple curing days, with opening time, 24 hours, and 28 days. Amongst the mixes, the high early strength concrete with fast setting cement reached the required minimum strength in the least time, followed by those with Type III and Type V cements. Kim et al. [1] examined how the quality of recycled aggregates declines with repeated recycling, which in turn affects concrete performance. It compared standard mix design with the equivalent mortar volume method for concretes made with 50% and 100% replacement of recycled coarse aggregates across multiple recycling cycles. The figure -2 shows different recycled aggregates. The findings highlighted that with the right mix design and replacement ratio, the negative effects of using multiple recycled aggregates in concrete can be effectively mitigated.

Figure 2: Recycled concrete aggregates with different recycling generation. [1]

Babaei et al. [20] introduced a new analytical framework designed to estimate reversible drying shrinkage strain in OPC-based materials using minimal input data. The required inputs included cement composition, microstructural details, and mechanical properties of the hydrated cement paste. At the core of the framework was a pore network model, which quantitatively supported the shrinkage calculations. The framework's predictions were compared with literature data, showing good agreement for non-virgin materials and offering qualitative insights into microstructure-related irreversible deformation in virgin materials. Drying shrinkage in concrete is multifaced phenomenon governed by a combination of material characteristics, environmental condition and design considerations. Factors such as the water-to-binder ratio, cement type, aggregate properties, curing and environmental conditions, use of admixtures and SCMs, and element geometry all contribute to the extent and rate of shrinkage. Emerging research on alternative binders, recycled aggregates, and hybrid or alkali-activated systems highlights the complexity and evolving nature of shrinkage behaviour in sustainable concretes. It is required to control these parameters through collective investigation and through practical implementation of these researches.

4 Fiber reinforcement to reduce drying shrinkage

Fiber reinforcement in concrete can play important role in reducing dry shrinkage by mitigating formation and propagation of micro cracks. As concrete dries concrete undergoes volumetric reduction through evaporation which induces tensile stress in hardened mixture. When these stresses exceed tensile capacity of the concrete, shrinkage crack develops. These drying shrinkage cracks reduce serviceability and performance of concrete in long run. The introduction of fiber whether synthetic, steel or natural, into the mixture helps distribute these stresses more evenly. The fibers act as micro reinforcement that bridge cracks limiting width and extent. Fiber therefore limits the determinable effects of drying shrinkage. In addition to crack control fibers can also modify internal stress state and improve the overall ductility of the concrete. This enhanced ductility allows the concrete to accommodate drying shrinkage strain more effectively without undergoing sudden failure. The presence of fiber contributes to more uniform stress distribution over the concrete medium. The typical areas high tension which are prone to cracking, is reduced with inclusion of fiber.

Dostkami et al. [21] explored the reuse of rice straw, an agricultural waste typically burned or buried, by incorporating rice straw fibers into concrete as microfibers. The experimental work involved preparing rice straw fibers and comparing fiber subjected to three treatment techniques—two chemical (alkaline) and one thermal. Overall, the study demonstrated that concrete could effectively encapsulate rice straw fibers while achieving the necessary strength levels for various engineering applications (>30 MPa). Borito et al. [9] explored the cumulative impact of nanosilica (NS) and basalt fibers (BF) on the mechanical and microstructural characteristics of superabsorbent polymer modified concrete. NS, replacing 0–1.5% of the cement weight, and BF, at a volume fraction of 0–1.2%, were added to optimize the compressive, flexural, and split-tensile strengths of the concrete. Scanning Electron Microscopy analysis showed that NS filled the spaces created by SAP while BF restricted crack spreading, resulting in a stronger and more durable concrete mix. Montez and Echevarria [8] examined the increasing use of vegetable fibers (VFs) in cement-based composites, which gained attention due to their low environmental impact and desirable properties. The study revealed a strong focus on optimizing the mechanical properties and durability of VF composites, and it reviewed influential studies on VF classification, durability enhancements, and advanced applications.

Agunbiade and Mangat [22] investigated the influence of nanocellulose fiber (CF) derived from wood pulp on the hydration, mechanical, shrinkage, and pore properties of ordinary Portland cement mortar. CF was incorporated into mortar mixes at dosages ranging from 0.15% to 1.5% by weight to evaluate its effects on physical, mechanical, and microstructural characteristics. The study demonstrated that CF was a viable sustainable additive for cementitious materials, with an optimal dosage of 0.45% balancing workability, mechanical properties, and durability for sustainable construction applications. Chousidis (2025) [7] examined the effect of steel fibers and carbon nanotubes on the performance of cementitious composites by gauging three mix types: a reference mix, a steel fiber-reinforced concrete and a combined mix of both SF and CNTs. The study demonstrated reduced porosity and water captivation, showing amplified density and lower penetrability, while SEM analysis validated a denser microstructure with improved crack-bridging abilities. These findings highlighted the potential of combined reinforcement strategies to produce high-performance fiber concrete with enhanced toughness for challenging construction applications. Statkauskas et al. [23] investigated the efficiency of various shrinkage reducing additives in ordinary Portland cement concrete and their impact on mechanical properties. Concrete mixtures were modified with an organic-based shrinkage reducing additive (SRA), quicklime, polypropylene fiber, and hemp fiber. Although hemp fiber did not notably reduce shrinkage, it was recognized as an environmentally friendly additive that improved flexural strength. Furthermore, the incorporation of 3.0 kg/m³ of polypropylene fiber increased flexural strength by 11.7%.

Bartulovic et al. [24] examined the influence of cotton knitted fabric waste on concrete properties. They had used 1.7% to 3.5% cotton knitted fabric waste in 10 different mixes with same amount of cement. It was found that flexural strength was increased 38% but compressive strength decreased to 20%. Sadrolodabaee et al. [25] did experimental study of textile waste fiber reinforced concrete by adding 6-10% short random fibers and non-woven fabric in 6-7 layers as textile waste reinforcement. The best composite was recognized to be the one reinforced with 6 layers of non-woven fabric, with flexural strength of 15.5 MPa and a toughness of 9.7 KJ/m2. The research presented above clearly showed that incorporating various types of fibers, whether synthetic, steel, vegetable, cotton and fabric waste, nanocellulose, or hybrid combinations, can effectively reduce drying shrinkage cracks in concrete. The use of fibers not only improves the mechanical properties of concrete but also enhances its durability by mitigating the shrinkage-induced cracking. Shrinkage can lead to further issues such as water ingress, creep and subsequent degradation. In addition, fiber reinforcement improves mechanical properties, durability, and overall performance of cementitious materials. Fiber reinforcement offers a sustainable and cost-effective solution for high-performance concrete applications. Some of the advantage and limitations are tabulated in table -2.

Table- 2: Advantage and limitation of different fibres

Research	Fiber type	Usage	Key Properties	Advantages	Limitations
Dostkami et al. (2025)	Rice straw	79 mm length, 1.1mm diameter, not > 10kg/m3	Natural, low-cost, improve strength up to 30MPa	Improves crack resistance	Low durability in wet conditions, uneven dispersion
Borito et al. (2025)	Nanosilica and Basalt Fiber	0.9% NS and 1.2% BF	High tensile strength, durability, sustainability	Excellent durability, thermal stability	Higher cost than some synthetic fibers
Montez and Echevarria (2025)	Vegetable fiber	1% or less by weight of cement	Lightweight, renewable	Sustainable, low density	Prone to degradation, absorbs water
Agunbiade and Mangat (2025)	Nanocellulose Fiber	0.45% or lesser	Nano-sized, high surface area	Ultra-high strength, reduces microcracks	Expensive, complex production process
Chousidis (2025)	Steel Fiber and carbon nanotubes	Steel fiber =2% t Carbon nanotubes = 0.2%	Superior tensile strength, ductility	Enhances load capacity, durable	Corrosion risk, heavy, high cost
Statkauskas et al. (2022)	Polypropylene fiber	3 kg/m3	Increase flexural strength by 11.7%	Consistent quality, resistant to chemicals	Strength reduces if SRA increases
Bartulovic et al. (2022)	Cotton knitted fabric waste	1.7%-3.5%	Increase in flexural strength by 38%	Sustainability, environmentally friendly	Degradation if exposed to water or air
Sadrolodabaee et al. (2021)	Textile waste fiber	6-10% and in 6 layers	Flexural strength 15.5Mpa, Toughness 9.7 KJ/m2	Reduce waste, eco-friendly	Low mechanical strength

5 Conclusion

Following conclusions can be drawn from the conducted study:

1. The defect of drying shrinkage in concrete can pose significant affect in durability and serviceability of concrete. Research consistently shows incorporating materials like slag, fly ash (30%-40%) and recycled aggregates can significantly reduce shrinkage cracks. Material design and curing methods are essential to more sustainable concrete mixes.
2. Mitigating governing parameters of drying shrinkage by inducing proper alkali activated binders, fly ash, recycled aggregates and curing conditions. The parameters like water to binder ratio, curing methods and weather conditions produces drying shrinkage in concrete if not handle properly.
3. The inclusion of fiber in concrete improves mechanical properties, durability and performance by improving concrete toughness and strength by bridging crack as micro reinforcement. The fiber in combination is also good addition to the concrete paste which enhance mechanical properties immensely. The use of cotton knitted fiber

waste (1.7%-3.5%) and textile waste fiber (6%-10%) can perform better to reduce drying shrinkage and improve flexural strength with sustainability. In Summary, adding fiber reinforcement to concrete is potential way to reduce drying shrinkage. Cotton knitted fiber can be used for the crack control and reductions in slabs. While carbon nanotubes and steel fiber are being used in joint less façade and precast elements. Despite considerable achievements in our understanding of mechanical properties and performance of fiber-reinforced concrete, there are still knowledge gaps that require further investigation. Future research can aid in creation of more resilient and sustainable concrete structures by emphasizing innovative materials and long-term performance. Future research required to be done on hybrid fibers for strength and workability. Adding multiple fiber enhances the strength as well as ease in construction. The careful review and constructive suggestion by the anonymous reviewers are gratefully acknowledged.

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