AN OVERVIEW ON THE PERFORMANCE OF STEEL FIBER REINFORCED COMPOSITES IN RESTRAINING CONCRETE PLASTIC SHRINKAGE CRACK IN SLAB

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Abstract- Early-stage plastic shrinkage cracks can shorten the lifespan of concrete slabs by providing direct pathways for aggressive agents to enter and hastening environmental attack-related deterioration, especially in hot and windy conditions. For concrete constructions to be long-lasting and sustainable, these fissures must be fixed. To enhance the sustainability and resilience of concrete structures, this study evaluates the performance of steel fiber reinforced composites (SFRC) in mitigating early age plastic shrinkage and micro-cracking under various environmental conditions. In accordance with ASTM C1579, the plastic shrinkage tests were conducted in a specially constructed chamber. The effects of various environmental factors on compressive strength and fracture potential are investigated. The SFRC is preferable because it is more evenly distributed throughout the concrete volume, and it has been demonstrated to be effective in reducing microcracks and plastic shrinkage through the application of the crack reduction ratio (CRR). Results from previous researches also indicates that a dosage of 30 kg/m³ of SFRC is effective in preventing or significantly reducing cracking, even under extreme conditions. These findings contribute to the development of more durable concrete slabs capable of withstanding climate-induced stressors.

Keywords- Steel Fiber Reinforced Composites (SFRC), Plastic Shrinkage Cracks, Concrete Shrinkage, Concrete Durability

1 Introduction

One major problem that impacts concrete durability and shortens the lifespan of concrete structures is early-age cracking brought on by autogenous and plastic shrinkage [1]. Roughly 80% of early-age cracking in reinforced concrete buildings is thought to be caused by plastic shrinkage cracking. The majority of structural elements are susceptible to plastic shrinkage fractures, although big surface area constructions like slabs, pavements, and walls are more prone to experience them [2]. Volume changes that take place during the plastic stage, or before the concrete solidifies, are the cause of plastic shrinkage fractures. These include water evaporation and bleeding, aggregate plastic settling, and air void ejection [3]. Water menisci form between solid particles as the layer of bleeding water at the concrete's surface evaporates, starting the buildup of capillary pressure. Cracks appear when the capillary pressure reaches a certain limit [4]. These fissures can be large and extend deep into the concrete surface, depending on the initial water content and the rate of evaporation [5]. Cracks that start in the plastic stage might develop into drying shrinkage cracks once they reach the final setting period. Concrete degradation is accelerated by cracks, which can allow pollutants to enter the concrete. It is well acknowledged that concrete fractures of this kind ought to be prevented or managed [6].

Numerous researchers have examined the behavior of plastic shrinkage cracks and discovered that, after drying starts, capillary pressure increases quickly [7]. However, as soon as air enters the pores, the capillary pressure abruptly decreases before the initial setting time starts. The normal phenomenological behavior of plastic shrinkage is schematically accompanied by the formation of capillary pressure [8]. Bleeding slows down when initial setting time (TIS) begins and may be regarded as ending by final setting time (TFS) [9]. The onset of cracking (TCO) starts shortly after the first setting time, and the crack width grows until the final setting time. The crack propagation slows down when the final setting time is approached. The combination of drying shrinkage, autogenous shrinkage, and temperature causes this following crack growth [10].

2 Mechanism of Crack Formation

A frequent early-age concrete fault is plastic shrinkage cracks in slabs as shown in Figure 1, which often show up in the first few hours after pouring while the concrete is still plastic (wet and workable) [11]. These fractures form when surface moisture evaporates more quickly than bleed water can rise to the surface. As a result, the concrete underneath continues to expand or settle as the surface dries out and shrinks [12]. Random, shallow surface fractures are caused by the stress that is formed. It usually shows as on exposed flat surfaces, such as roof slabs (before curing), industrial floors, slabs on grade, and pavement panels [13]. It frequently forms a scattered pattern with occasionally parallel lines that are a few inches to several feet apart. It frequently occurs in hot, dry, or windy weather, particularly when there is warm formwork or subgrade, low humidity, high wind speed, and high temperatures [14]. After implantation, it typically develops one to six hours later. Cracks are shallow (only visible on the surface), thin (hairline to ~1 mm), and frequently go away under finishing before resurfacing later [15].

Figure 1 Shrinkage cracks in Slab [5]

While the evaporation rate exceeds 1.0 kg/m2/h, plastic shrinkage cracking is anticipated to form; this is most likely to happen in hot weather while concrete is being laid in dry locations [16]. The denser solid component materials have a tendency to sink and may lose their ability to retain surplus mixing water during the first two to four hours of setting after casting [17]. Some of this water seeps out of the mixture onto the surface as it migrates towards the top. The cement's water content, viscosity, particle size distribution, and rate of hydration all affect how quickly it bleeds [18]. The rate of water bleeding stabilizes and finally stops after the first setup time. The cement's hydration raises the surface temperature during the last set (4–8 hours), which might lead to a higher evaporation rate than bleeding [19]. Plastic shrinkage cracking before the final set is finished might result from a rapid rate of evaporation, which is further exacerbated by wind and dry circumstances [20].

3 Governing Parameters

A concrete slab's governing qualities, particularly its longevity, serviceability, and, in some situations, structural performance, can be greatly impacted by shrinkage cracks. Shrinkage cracks impact the durability, serviceability, structural integrity, crack control, reinforcement performance, and long-term deflections and deformations as shown in Table 1. In durability, cracks allow moisture, chlorides, and chemicals to penetrate the slab. Consequences that occur due to durability are accelerated corrosion of reinforcement, freeze-thaw damage in the cold cycle, and reduced service life due to chemical attack. In serviceability issues, even small cracks affect slab performance under normal use. Its impact is uneven surfaces in floors, water leakage in roofs or wet surface areas, and noise transmission or vibration issues.

Table 1 Governing Properties

Impact of Shrinkage crack	Effect	Consequences
Durability	Allow moisture, chlorides, and chemicals to penetrate.	Freeze-thaw damage Reduced service life
Serviceability	Small cracks affect slab performance under normal use.	Water leakage in the roof Uneven surface on the floors
Structural Integrity	Minor with shrinkage cracks.	Restrained slab Reduce the load-carrying capacity
Crack control and reinforcement performance	Reduce the bond between concrete and reinforcement.	Debonding The effectiveness of steel decreased
Long-term deflection	Slab flexibility increases.	Uneven slab behavior

Shrinkage cracks are often considered minor in terms of structural integrity; their impact can become significant in certain conditions. In heavily cracked or restrained slabs, these cracks may reduce the load-carrying capacity and act as stress concentrators, potentially leading to further crack propagation under applied loads. In pre-stressed concrete members, shrinkage-induced cracks can contribute to a loss of pre-stress force. Regarding crack control and reinforcement performance, the presence of cracks weakens the bond between the reinforcement and concrete. This may result in slippage or de-bonding, particularly when cover is insufficient, and could lead to localized failures in critically cracked areas. Over the long term, such cracking increases the flexibility of the slab, leading to greater deflections and irregular slab behavior.

4 Fiber Selection and Optimization

One of the main factors in determining how well concrete elements operate is minimizing time-dependent features, such as volume changes in concrete mixes. Commercial fibers come in a variety of forms to control volume variations that cause concrete mixes to break. Table 2 illustrates that fiber may effectively increase the mixture's ability to regulate cracks, which will lower the breadth and length of cracks. Furthermore, steel fiber-reinforced concrete (SFRC) has superior mechanical properties, including fatigue resistance, impact resistance, and shear and flexural strength. Concise overview of how different steel fiber forms influence concrete properties is provided.

Table 2 Comparative Performance of Steel Fiber Types in SFRC

Fiber Type	Primary Mechanical Properties Enhanced	Shrinkage Control Efficiency (Plastic, Drying)	Workability Impact
Straight	Tensile strength, flexural strength, Compressive strength (notably higher than hooked-end in some studies), toughness, ductility	Moderate to good	Usually manageable, but decreases with increasing aspect ratio and volume
Crimped	Mechanical anchorage, flexural strength, toughness	Good	Adequate reduction in slump as compared to plain concrete
Hooked-End	Flexural strength (significant enhancement), tensile strength, toughness, impact resistance, pull-out resistance	Effective in reducing plastic shrinkage and micro-cracks, and most efficient for drying shrinkage control	Adequate reduction in slump, but generally less than RTSF at similar dosages

As shown in Figure 2, Straight steel fibers are noted for enhancing compressive, tensile, and flexural strengths, along with ductility and toughness, while offering moderate shrinkage control and manageable workability that can decrease with higher aspect ratios or volumes. Crimped fibers primarily improve mechanical anchorage, flexural strength, and toughness, providing good shrinkage control with a moderate impact on slump. Hooked-end fibers are highlighted for significantly boosting flexural and tensile strengths, toughness, impact, and pull-out resistance, proving most efficient for drying shrinkage control and effective against plastic shrinkage and micro-cracks, typically causing a moderate slump reduction.

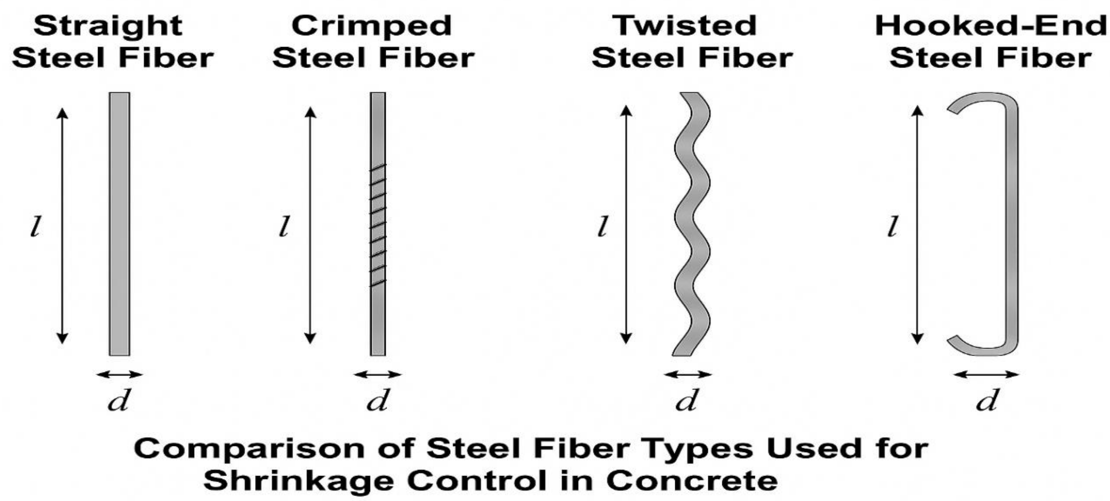

Figure 2 Visual comparison of common steel fiber types used in plastic shrinkage crack control in concrete [8]

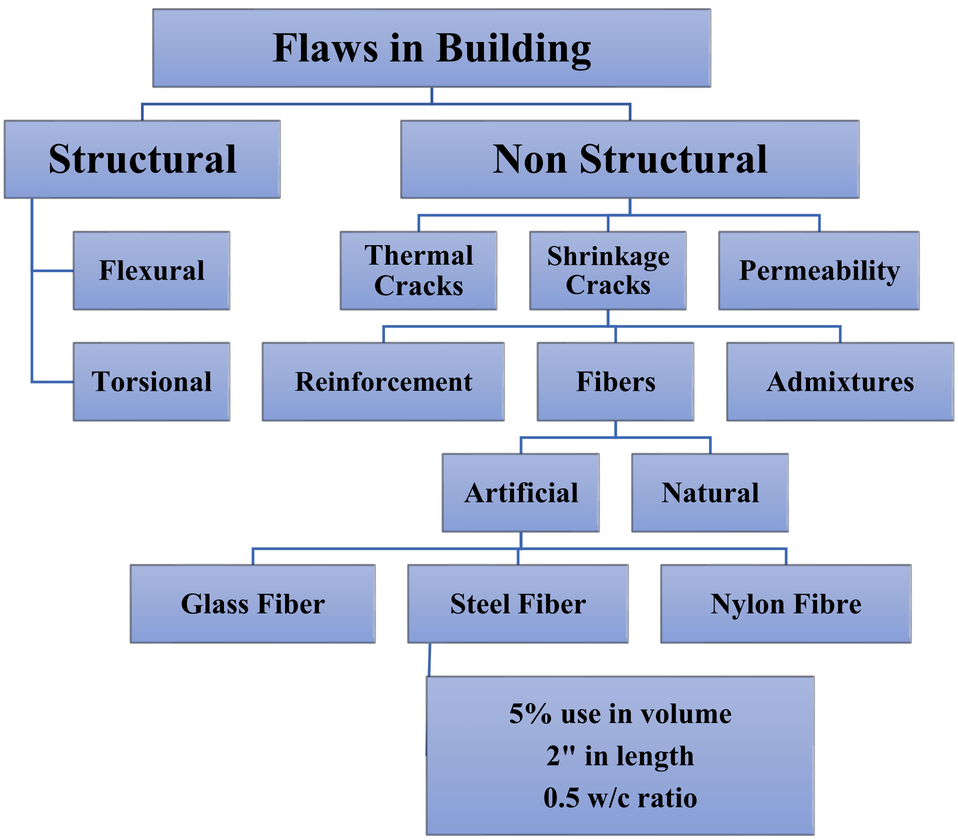

Figure 3 Flowchart for fiber selection

Figure 3 presents a flowchart outlining the systematic approach used to select appropriate steel fibers for minimizing plastic shrinkage cracking in concrete. The flowchart integrates key selection parameters such as fiber type, geometry (including aspect ratio and shape), dosage, and performance characteristics. From previous researches we came to know that a fiber dosage of 30 kg/m3 ($V_f = 0.38\%$) may be used to totally prevent plastic shrinkage cracking, although the right fiber volume should be chosen based on mix design and overall performance. Similar to how they work against drying shrinkage, this study offers strong experimental proof that SFRC is a sustainable and efficient substitute for MSF in avoiding plastic shrinkage fractures. In addition to having a positive impact on reducing plastic shrinkage cracks, the use of finer fibers is anticipated to improve sustainability, durability, and structure—especially in the harsher climatic circumstances brought on by climate change.

5 Conclusion

This research studies the effect of different doses of SFRC on limiting concrete plastic shrinkage and micro fractures at the fresh stage. Plain concrete and fiber-reinforced concrete slab specimens are evaluated according to the test technique provided in ASTM C1579 under controlled environmental circumstances, and their crack initiation and development is investigated, along with other physical characteristics. The following conclusions may be made based on the study of the findings in this paper:

- Cracking starts around two hours after casting, which is the first setting time, and it essentially stops after six hours, which is the final setting time.
- The concrete's hydration rate and 24-hours strength increased by exposure to the greater temperature in the chamber; however, the 28-day strength was not significantly affected. The fibers' impact on compressive strength is negligible.
- The experimental investigation through previous researches confirms that incorporating steel fibers at a dosage of 30 kg/m³ significantly reduces or entirely prevents plastic shrinkage cracking in concrete during the early-age setting period.

In order to lessen or avoid plastic shrinkage cracking in concrete, future research should look at the synergistic benefits of employing sustainable fiber alternatives, such the RTSF employed in the study reported in this paper, with various cement and aggregate substitutes as well as different curing techniques.

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Reference

[1] Y. Zhang *et al.*, "Early-Age Cracking of Fly Ash and GGBFS Concrete Due to Shrinkage, Creep, and Thermal Effects: A Review," vol. 17, no. 10, p. 2288, 2024.
[2] G. L. J. B. Golewski, "The phenomenon of cracking in cement concretes and reinforced concrete structures: the mechanism of cracks formation, causes of their initiation, types and places of occurrence, and methods of detection—a review," vol. 13, no. 3, p. 765, 2023.
[3] D. M. Meyer, "Plastic shrinkage cracking in concrete investigated with novel testing methods," Stellenbosch: Stellenbosch University, 2021.
[4] R. Deysel, "Controlling Capillary Pressure in Concrete to Prevent Plastic Shrinkage Cracking," University of Pretoria (South Africa), 2022.
[5] Y. Wei, W. Guo, and Q. J. D. T. Zhang, "A model for predicting evaporation from fresh concrete surface during the plastic stage," vol. 38, no. 16, pp. 2231-2241, 2020.
[6] S. Uthaman and V. J. J. o. B. E. Vishwakarma, "Assessment of causes and consequences of concrete deterioration and its remediation," vol. 79, p. 107790, 2023.
[7] S. Ghourchian, M. Wyrzykowski, M. Plamondon, P. J. C. Lura, and C. Research, "On the mechanism of plastic shrinkage cracking in fresh cementitious materials," vol. 115, pp. 251-263, 2019.
[8] Y. Zou, "Modelling of the dynamic effects in capillary pressure in coupling with deformation on the desiccation of porous materials," École centrale de Nantes, 2020.
[9] R. C. Rodgers and J. Levin, "A critical reappraisal of the bleeding time," in *Seminars in Thrombosis and Hemostasis*, 2024, vol. 50, no. 03, pp. 499-516: Thieme Medical Publishers, Inc.

[10] B. Tutkun, E. S. Barlay, Ç. Yalçınkaya, H. J. C. Yazıcı, and B. Materials, "Effect of internal curing on shrinkage and cracking potential under autogenous and drying conditions," vol. 409, p. 134078, 2023.
[11] M. Safiuddin, A. A. Kaish, C.-O. Woon, and S. N. J. A. S. Raman, "Early-age cracking in concrete: Causes, consequences, remedial measures, and recommendations," vol. 8, no. 10, p. 1730, 2018.
[12] S. Subash, S. J. I. S. I. P. Subash, Design,, and Applications, "Scaling in Concrete–Causes, Prevention, and Repair," pp. 341-356, 2024.
[13] M. Odijk, "Industrial floors," 2019.
[14] S. Kodippily, J. Yeaman, T. Henning, S. J. R. M. Tighe, and P. Design, "Effects of extreme climatic conditions on pavement response," vol. 21, no. 5, pp. 1413-1425, 2020.
[15] S. Agrawal, *Complication and Failure in Implantology*. BFC Publications, 2022.
[16] J. E. Van Zyl, "The influence of temperature on the cracking of plastic concrete," Stellenbosch: Stellenbosch University, 2021.
[17] A. Chakrabarti, *Casting technology and cast alloys*. PHI Learning Pvt. Ltd., 2022.
[18] F. Saleh, R. Rivera, S. Salehi, C. Teodoriu, and A. Ghalambor, "How does mixing water quality affect cement properties," in *SPE International Conference and Exhibition on Formation Damage Control*, 2018, p. D021S010R001: SPE.
[19] L. Gu *et al.*, "Temperature-dependent water retention and bleeding of fresh cement-based materials with VEAs," vol. 130, p. 104539, 2022.

[20] G. Moelich, J. Van Zyl, N. Rabie, R. J. C. Combrinck, and C. Composites, "The influence of solar radiation on plastic shrinkage cracking in concrete," vol. 123, p. 104182, 2021.