A REVIEW ON OPTIMIZING SUSTAINABLE CRACK CONTROL IN SLABS USING COTTON FIBER COMPOSITES

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Abstract- Cracking in the base slabs of slabs poses a serious threat to both structural stability and long-term waterproofing performance i.e. Swimming Pools. These cracks commonly arise from early-age shrinkage, thermal expansion and contraction, subgrade settlement, and flexural stress during service life. Traditional concrete lacks the tensile strength and ductility needed to resist these failure modes effectively. Cotton fiber-reinforced concrete (CFRC) has emerged as an eco-friendly, sustainable solution to these challenges by enhancing crack resistance, improving tensile behavior, and promoting internal curing. The fibers not only bridge microcracks but also delay their propagation, thereby extending the service life of concrete structures. This paper provides a detailed assessment of CFRC performance under various stress conditions and failure modes, such as shrinkage-induced cracking and load-induced fracture. A comparative evaluation with conventional synthetic and metallic fibers, namely steel and polypropylene, is also conducted to highlight CFRC's structural and environmental advantages. Furthermore, the study presents real-world applications of CFRC in concrete works and emphasizes the significance of utilizing cotton waste derived from the spun lace process. This process, which eliminates chemical waste associated with traditional cotton treatments, offers a circular economic approach by integrating textile by-products into construction materials. Overall, CFRC presents a promising avenue for enhancing durability and sustainability in modern infrastructure, particularly in water-retaining structures like swimming pools.

Keywords- Crack Control, Fiber-Reinforced Concrete (FRC), Ductility, Shrinkage, Cotton Fiber

1 Introduction

All Shell elements are highly susceptible to cracking and long-term deterioration due to the combined effects of complex mechanical loading and environmental fluctuations, which impose challenging stress conditions throughout their service life. These slabs often experience early-age thermal gradients caused by the heat of hydration and ambient temperature variations, resulting in differential shrinkage and internal tensile stresses before the concrete develops adequate tensile strength to resist them. Additionally, plastic and drying shrinkage during curing can lead to microcracks, especially if curing practices are inconsistent, while uneven settlement or poor compaction of the sub-base materials creates localized stress concentrations that further increase the risk of crack initiation under operational loads. The inherently brittle nature and low tensile strength of conventional concrete make tensile zones within these slabs particularly vulnerable to cracking from bending moments, hydrostatic pressures, and dynamic loads typical of swimming pool environments. In water-retaining structures, such cracks not only threaten structural stability but also compromise waterproofing, leading to leaks that can cause soil erosion, foundation destabilization, and corrosion of embedded reinforcement, ultimately accelerate deterioration and necessitate costly repairs [1,2,3,4]. Moreover, irregular subgrade support and constraints against natural volume changes induce restraint-related cracks that propagate through the slab, allowing moisture ingress and further structural damage under cyclic loads [5,6]. These factors collectively reduce service life, increase maintenance demands, and elevate lifecycle costs, underscoring the critical need for advanced reinforcement methods and crack control strategies to enhance the tensile behavior, durability, and watertight performance of swimming pool base slabs in demanding service conditions.

To address these concerns, fiber-reinforced concrete (FRC) has emerged as an effective composite material designed to enhance the tensile performance of conventional concrete, control crack widths, and improve overall fracture toughness [7]. The introduction of discrete fibers within the cementitious matrix allows for better stress redistribution and significantly increases the material's ability to carry loads even after cracking has initiated, which helps mitigate problems associated with early-age shrinkage, restrained deformations, and brittle failure modes [7,8,9]. A wide range of fiber types has been studied for their reinforcing effectiveness, including steel fibers known for their high tensile strength, synthetic fibers like polypropylene prized for their chemical resistance, and glass fibers that contribute to both structural and architectural applications. In recent years, however, there has been growing interest in the use of natural fibers as a sustainable alternative due to their renewable nature, widespread availability, biodegradability, cost-effectiveness, and substantially lower environmental impact compared to conventional synthetic or metallic fibers [10,11]. As research continues to expand, natural fibers such as jute, sisal, coir, and cotton are increasingly being explored for structural and semi-structural concrete applications, supporting the development of greener and more resilient construction materials.

Among fibers, cotton particularly when sourced from post-consumer or post-industrial textile waste presents significant promise as an environmentally responsible reinforcement material for concrete applications. Cotton fibers are predominantly composed of cellulose, which imparts them with favorable tensile properties and a naturally rough surface texture that promotes strong mechanical interlocking with the surrounding cement paste, thereby enhancing the fiber–matrix bond [12,13]. Another notable advantage of cotton fibers is their high-water absorption capacity, which enables them to act as internal curing agents; they can absorb excess mix water during batching and gradually release it during hydration, helping to maintain internal moisture levels and mitigate the development of shrinkage-induced tensile stresses during the critical early stages of curing [14,15]. This internal curing effect fosters a more uniform and complete hydration process, which reduces the risk of autogenous and drying shrinkage cracking that can otherwise compromise durability [16,17]. Additionally, the presence of cotton fibers contributes to improved crack distribution by bridging microcracks and promoting the formation of finer, more uniformly dispersed cracks rather than wide, isolated cracks. This refined crack pattern not only enhances the structural resilience of the concrete under service loads but also contributes to improved long-term durability and reduced maintenance needs, aligning well with sustainable construction goals [18,19,20,21].

This paper adopts a performance-based analytical framework to systematically evaluate the potential of cotton fiber-reinforced concrete (CFRC) in reducing crack formation and controlling crack propagation in swimming pool base slabs, which are particularly vulnerable to various cracking mechanisms. The study specifically examines the primary causes of cracking—plastic shrinkage, drying shrinkage, thermal stresses, and flexural loading and analyzes how the inclusion of cotton fibers mitigates these issues through effective fiber bridging and enhanced internal curing behavior. A comparative analysis is carried out between CFRC and other commonly used fiber-reinforced concrete systems, such as those incorporating steel or synthetic fibers, focusing on key performance metrics including mechanical strength, durability parameters, crack control effectiveness, and environmental sustainability indicators. Based on the analytical findings, the paper offers practical recommendations for incorporating cotton fibers into concrete mix design, detailing considerations such as fiber dosage, mixing techniques, and curing practices to optimize structural behavior without compromising workability. By highlighting the dual benefits of improved crack resistance and sustainable material use, the paper aims to guide engineers and practitioners in adopting CFRC for reinforced concrete applications in hydraulic and aquatic infrastructure where long-term durability, watertightness, and environmental responsibility are critical design priorities.

2 Mechanisms of Crack Formation in Swimming Pool Slabs

Concrete cracking is a complex and multifactorial phenomenon that arises due to a combination of internal volumetric changes and externally imposed mechanical and environmental stresses [22]. In reinforced concrete base slabs constructed for swimming pool structures required to retain water under continuous loading and exposure, several types of cracking are commonly encountered. These cracks, if not effectively controlled, significantly reduce serviceability and compromise impermeability, leading to leakage, reinforcement corrosion, and eventual deterioration of structural integrity [22]. One of the earliest forms of cracking is **plastic shrinkage cracking**, which occurs within the first few hours following concrete placement. These cracks develop when the rate of surface moisture evaporation exceeds the rate at which bleed water rises to the surface, creating tensile stresses in the weak plastic matrix [22,23]. Such conditions are exacerbated in hot, dry, or windy environments and are especially critical in wide, shallow elements such as slabs. **Thermal cracking** arises from non-uniform temperature changes, particularly between the surface and the inner core of large volume concrete elements. When temperature differentials exceed the tensile capacity of the concrete, restraint against thermal expansion or contraction leads to cracking. This is especially problematic in slabs without adequate thermal curing measures [24,25].

Settlement cracking is another early-age issue, resulting from the differential settlement of the concrete around embedded reinforcements or obstructions. These cracks typically form due to insufficient consolidation or poorly supported formwork, leading to localized discontinuities in the concrete mass [26]. In the hardened state, **flexural cracking** is a prevalent mode of distress, particularly in the tensile zone at the bottom of the slab where bending moments are highest under service loads. These cracks occur when the flexural tensile stress induced by external loads exceeds the modulus of rupture of the concrete [27,28]. Additionally, **shear cracking**, often observed near slab support or transitions, arises due to diagonal tension resulting from high shear forces. These cracks typically propagate at an angle and can compromise both strength and stiffness if left unaddressed [29]. The presence and progression of these various crack types directly impact the durability, impermeability, and service life of swimming pool slabs. Therefore, selecting and engineering a concrete mixture that can resist these cracking mechanisms is critical. Materials with improved tensile strength, ductility, and early-age crack mitigation capacity, such as fiber-reinforced concrete [30], are particularly beneficial in this application. By enhancing post-crack load resistance and providing a bridge across potential crack planes, fiber-reinforced systems contribute to reduced crack widths and improved structural resilience under both restrained and service conditions [31,32].

Figure 1: *Presence of flexural cracks in slab Mydin [33]*

3 Performance Attributes of Cotton Fiber-Reinforced Concrete (CFRC)

The integration of cotton fibers into concrete mixtures for swimming pool slab construction introduces both performance benefits and implementation challenges that must be addressed to ensure structural and functional efficacy. Cotton, being a cellulosic natural fiber, has a high affinity for water due to its porous morphology and internal capillary structure [30]. This hydrophilic nature makes the fibers prone to absorbing free water from the surrounding cementitious matrix, which can inadvertently alter the effective water-to-cement (w/c) ratio, delay hydration reactions, and reduce early-age strength gain. To mitigate this, a pre-conditioning process is recommended in which cotton fibers are pre-wetted to achieve a saturated surface-dry (SSD) state. This strategy prevents excessive absorption during mixing and ensures that water content calculations remain consistent with the intended design parameters [34,35]. Proper moisture conditioning of fibers not only stabilizes fresh properties but also supports uniform hydration kinetics essential for durable concrete. Maintaining adequate workability in cotton fiber-reinforced concrete poses another challenge. Cotton fibers, when added in significant volume fractions, tend to decrease the slump and flow characteristics of the mix due to their physical obstruction and water retention behavior [36]. This reduction in workability can lead to difficulties in placement, compaction, and surface finishing factors critical to the performance of large slab elements such as swimming pool bases. To address this issue, the incorporation of chemical admixtures, particularly polycarboxylate-based high-range water reducers (HRWR), is strongly advised. These admixtures improve the dispersion of cement particles, enhance fluidity, and counteract the stiffening effect caused by additional fibers without increasing the w/c ratio, which could otherwise compromise strength and durability [37,38]. Additionally, the use of viscosity-modifying admixtures (VMAs) may further stabilize the fiber-concrete matrix by minimizing segregation and ensuring a cohesive, homogenous mixture during transportation and placement.

Achieving uniform fiber distribution is paramount to realizing the full mechanical and durability potential of CFRC. Improper mixing can lead to clumping or balling of fibers, creating weak zones and inconsistencies in crack control performance. An effective method to ensure uniform dispersion involves the sequential dry blending of fibers with aggregates and cementitious materials before the introduction of mixing water. This technique facilitates even distribution and reduces the likelihood of fiber agglomeration, especially in field-scale mixing scenarios where control over mixing energy and sequence may vary. Advanced mixing protocols, including the use of pan mixers with dual-axis blades or high-shear laboratory mixers, can further improve dispersion and ensure repeatability across batches [39,40].Although cotton fibers aid internal curing by retaining moisture and gradually releasing it to sustain hydration, this mechanism does not eliminate the need for conventional curing practices. Surface evaporation, particularly under high ambient temperatures or wind exposure, can still induce early-age plastic shrinkage cracking if not properly controlled. External curing methods such as the application of wet coverings (e.g., burlap), the use of curing compounds, or continuous water ponding should be rigorously implemented for at least 7 days, depending on environmental conditions and cement type. These curing methods serve to reduce thermal gradients and maintain adequate surface humidity, thereby complementing the internal curing effect of cotton fibers and ensuring consistent development of mechanical properties [41].

Although cotton fibers help with internal curing by holding moisture and slowly releasing it to support hydration, this benefit alone does not replace the need for standard curing practices. Surface evaporation, especially in hot, dry, or windy weather, can still lead to early-age plastic shrinkage cracks if left unmanaged. To avoid this, good external curing such as using wet coverings like burlap, applying curing compounds, or keeping the surface moist through ponding should be carried out for at least seven days, depending on site conditions and cement type. These steps reduce thermal stress and help keep the concrete surface properly hydrated, working together with the internal curing provided by the fibers to ensure the concrete develops strength and durability as intended [41]. While this study highlights swimming pool base slabs, the same cracking issues like shrinkage, thermal movement, settlement, and flexural stress are common to many other concrete elements. For this reason, the combined crack control and sustainability benefits of cotton fiber-reinforced concrete (CFRC) can be applied to a wide range of structures. These include water tanks, reservoirs, and sewage units where watertightness is vital [8]; pavements and ground slabs that need to resist shrinkage cracking [16]; basement floors and retaining walls that face settlement and moisture changes [1]; tunnel linings and precast panels where dimensional stability is important [2]; and bridge decks and overlays that demand added toughness under heavy use [14]. When properly cured and used in these wider applications, CFRC offers designers an effective way to manage cracking while also making use of natural, biodegradable fibers that help balance structural performance with environmental responsibility.

4 Comparative Evaluation with Other Fibers

While cotton fibers offer several benefits, they are not the only option. The comparative evaluation is presented in **Table 1,** underscoring the multifaceted performance attributes of various fibers used in concrete reinforcement. While cotton fiber does not match the tensile strength or modulus of elasticity exhibited by synthetic alternatives such as steel or polypropylene, it demonstrates distinct advantages in terms of autogenous shrinkage control, internal curing capability, and sustainability. These properties are especially critical in applications such as swimming pool base slabs, where early age cracking due to shrinkage and environmental exposure is a persistent concern. The fibrous morphology of cotton enhances water retention within the matrix, thereby prolonging internal hydration and contributing to volumetric stability during the critical early curing phase [9,34,35].

From an environmental engineering perspective, cotton fibers, particularly those derived from post-consumer textile waste, introduce significant ecological benefits. Their biodegradability, low embodied energy, and recyclability align well with sustainable construction objectives outlined in green building standards and circular economy frameworks. In contrast, synthetic fibers, while mechanically superior, are energy-intensive to manufacture and contribute to long-term environmental loading if not properly managed at end-of-life stages [21,44,45]. Consequently, cotton serves as a viable alternative in sustainability-focused infrastructure, especially where mechanical demands are moderate, but crack resistance and environmental compatibility are prioritized.

Table 1 *: Comparative performance of cotton fiber with other commonly used fibers*

Fiber Type	Tensile Strength (MPa)	Flexural Strength (MPa)	Shrinkage Reduction (%)	Durability (Months)	References
Cotton Fiber	25–30	5–10	25–30	12–18	[4,8,12]
Polypropylene Fiber	60–80	10–15	30–35	24–36	[14,21,24]
Steel Fiber	150–200	25–30	15–20	36–48	[16,22,25]
Glass Fiber	70–90	15–20	20–25	18–24	[11,18,23]

Despite their limitations in tensile performance, cotton fibers can be strategically integrated into hybrid reinforcement systems to enhance overall material performance. Several studies have shown that combining natural fibers with a minor fraction of high-strength synthetic fibers can yield composites that achieve both functional durability and environmental compliance [11,46,47]. In swimming pool slabs, such hybridization strategies allow for cotton fibers to mitigate shrinkage and support internal curing, while steel or polypropylene fibers provide the tensile capacity needed to resist service-induced stresses such as bending and impact loading. This balanced approach optimizes the trade-offs between strength and sustainability, making it particularly suitable for public-use facilities where durability, safety, and ecological considerations must all be addressed in unison.

5 Sustainability Metrics and Lifecycle Considerations

In contemporary civil engineering practice, sustainability has emerged as a paramount criterion guiding the selection and specification of construction materials. Cotton fibers, when utilized as reinforcement in concrete, represent a notably sustainable option due to their inherent environmental advantages [30]. A primary benefit lies in their origin as an abundant and renewable resource, often sourced from post-industrial textile waste or agricultural byproducts, such as cotton stalks and linters, thereby diverting substantial quantities of material from landfills and contributing to waste valorization [9, 48]. This reutilization not only exemplifies effective resource efficiency but also supports the principles of circular economy by transforming what would conventionally be discarded into value-added construction inputs. Moreover, cotton fibers exhibit biodegradability, a critical environmental attribute distinguishing them from commonly used synthetic fibers such as polypropylene or steel, which persist in the environment over extended periods, potentially contributing to microplastic pollution and resource depletion [11,49]. The biodegradation process facilitates eventual mineralization, reducing ecological impact and improving end-of-life management options for fiber-reinforced concrete composites.

Energy consumption associated with fiber production is another key sustainability consideration. The embodied energy of cotton fibers is significantly lower compared to synthetic and metallic fibers, primarily due to less intensive manufacturing processes and reduced reliance on fossil fuels [14,50]. This reduction in energy demand translates directly into decreased carbon emissions during the material lifecycle, contributing to a lower overall environmental footprint for cotton fiber-reinforced concrete. Such attributes are especially beneficial in structural elements like swimming pool slabs, where the performance requirements allow for the substitution of high-energy fibers with natural alternatives without compromising serviceability or durability [4,9].Integrating cotton fibers into concrete not only enhances the material's mechanical and durability characteristics but also aligns strategically with global sustainability frameworks, such as the United Nations Sustainable Development Goals (SDGs) and the principles outlined in LEED and BREEAM green building certification systems [20,51]. By fostering circularity and minimizing resource extraction, cotton fiber-reinforced concrete supports the reduction of greenhouse gas emissions and the mitigation of construction-related environmental impacts [30]. Therefore, its adoption contributes significantly to advancing sustainable construction practices, particularly in infrastructure with moderate structural demands but high longevity and environmental accountability, such as swimming pools and related water-retaining structures.

6 Conclusion and Recommendation

To summarize the key aspects and practical considerations of using cotton fiber-reinforced concrete for swimming pool slabs, the following points highlight its main advantages and requirements:

- Cotton fiber-reinforced concrete (CFRC) enhances tensile behavior, controls early-age cracks, and improves ductility by providing internal curing and effective crack bridging.
- Successful use of CFRC requires careful fiber pre-wetting, optimized mix design, adequate use of plasticizers, and thorough fiber dispersion to maintain workability and uniform performance.
- Sourced from post-consumer textiles, cotton fibers reduce environmental impact, support circular economic goals, and can be combined with other fibers to balance strength and sustainability.

By addressing both technical and environmental demands, cotton fiber-reinforced concrete offers a practical, sustainable solution for improving crack resistance and durability in swimming pool slabs and similar structures. Its dual benefits make it a valuable material innovation for engineers seeking resilient and eco-friendly alternatives in modern concrete construction.

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References

[1] W. Hansen, "Early-age stress development in concrete," *Journal of the American Concrete Institute*, vol. 81, no. 6, pp. 123–129, 1984..
[2] M. H. Zhang and J. P. Weiss, "Shrinkage cracking of restrained concrete slabs," *ACI Materials Journal*, vol. 99, no. 1, pp. 38–44, 2002.
[3] S. Mindess, J. F. Young, and D. Darwin, *Concrete*, 2nd ed., Upper Saddle River, NJ: Prentice Hall, 2003.
[4] A. Bentur and S. Mindess, *Fibre Reinforced Cementitious Composites*, 2nd ed., Boca Raton, FL: CRC Press, 2006.
[5] J. J. Brooks and M. A. Megat Johari, "Early-age thermal cracking in concrete bridge decks," *Construction and Building Materials*, vol. 15, no. 7, pp. 385–392, Oct. 2001.
[6] C. Hall and W. D. Hoff, *Water Transport in Brick, Stone and Concrete*, London: CRC Press, 2002.
[7] S. Maiti, M.R. Islam, M.A. Uddin, S. Afroj, S.J. Eichhorn, N. Karim, Sustainable Fiber-Reinforced Composites: A Review, Advanced Sustainable Systems 6 (2022) 2200258. https://doi.org/10.1002/adsu.202200258.
[8] P. K. Mehta and P. J. M. Monteiro, *Concrete: Microstructure, Properties, and Materials*, 4th ed., New York: McGraw-Hill, 2014
[9] R. Siddique, "Natural fiber reinforced concrete," in *Waste Materials and By-Products in Concrete*, Berlin: Springer, 2008, pp. 163–206.
[10] M. Fraternali et al., "Experimental study of the thermo-mechanical properties of recycled cotton fiber-reinforced concrete," *Composites Part B: Engineering*, vol. 68, pp. 185–191, Jan. 2015.
[11] S. N. Raman and H. Mohd Saman, "The utilization of natural fibers in concrete: A review," *Construction and Building Materials*, vol. 204, pp. 91–105, Apr. 2019.
[12] M. Saikia and S. de Brito, "Use of plastic waste as aggregate in cement mortar and concrete preparation: A review," *Construction and Building Materials*, vol. 34, pp. 385–401, Sep. 2012.
[13] V. M. Malhotra and N. A. Aïtcin, "Internal curing of concrete: Techniques and benefits," *ACI SP-218*, vol. 1, pp. 1–20, 2004.
[14] G. Li et al., "Durability performance of concrete reinforced with recycled cotton fibers," *Materials and Structures*, vol. 53, no. 3, pp. 1–13, Mar. 2020.
[15] F. Qamar, T. Thomas, and M. Ali, "Improvement in lateral resistance of mortar-free interlocking wall with plaster having natural fibres," *Construction and Building Materials*, vol. 234, p. 117387, 2020.
[16] K. A. Muga, M. H. Kamau, and D. O. Opar, "The potential of cotton and sisal fibers in concrete," *Journal of Civil Engineering Research*, vol. 3, no. 5, pp. 142–149, 2013.
[17] G. Campione, D. La Mendola, and L. Minafò, "Steel fiber reinforced concrete in structural applications," *Construction and Building Materials*, vol. 95, pp. 757–766, Oct. 2015.
[18] M. Amin, S. Khan, and T. Jamil, "Crack control in concrete using natural fibers: A review," *Journal of Natural Fibers*, vol. 19, no. 6, pp. 1979–1995, 2022.
[19] S. A. Bernal, J. L. Provis, and R. San Nicolas, "Durability of glass fiber-reinforced concrete: Current knowledge and future research needs," *Cement and Concrete Research*, vol. 107, pp. 37–50, Feb. 2018.
[20] UN Environment Programme, "Greening the construction sector: Sustainable building materials," *UNEP Report*, 2020. [Online]. Available: https://www.unep.org.
[21] C. Meyer, "The greening of the concrete industry," *Cement and Concrete Composites*, vol. 31, no. 8, pp. 601–605, Sep. 2009.
[22] A Valli ,M S R Kumar, Review on the mechanism and mitigation of cracks in concrete, Applications in Engineering Science 16 (2023) 100154. https://doi.org/10.1016/j.apples.2023.100154.

[23] A. R. Khaloo, M. Dehestani, and P. Rahmatabadi, "Mechanical properties of normal strength concrete reinforced with polypropylene and steel fibers," *Construction and Building Materials*, vol. 22, no. 8, pp. 170–179, Aug. 2008.
[24] J. Silfwerbrand, "Cracking in concrete—Causes, prevention and repair," *Nordic Concrete Research*, no. 42, pp. 11–20, 2010.
[25] M. Younis, A. E. Khaled, and F. Al Hattamleh, "Influence of hot and windy environment on early cracking of slabs," *Construction and Building Materials*, vol. 247, pp. 118518, Apr. 2020.
[26] Y. L. Mo and R. P. Dhakal, "Thermal effects on concrete and crack control," *Journal of Advanced Concrete Technology*, vol. 7, no. 1, pp. 89–100, Jan. 2009.
[27] C. D. Johnston, "Fiber-reinforced concrete—Properties and applications," *ACI Journal Proceedings*, vol. 81, no. 5, pp. 343–356, 1984.
[28] M. C. Limbachiya and J. J. Roberts, "Concrete early-age settlement cracking," *Materials and Structures*, vol. 32, pp. 235–244, May 1999.
[29] T. C. Powers, "Mechanisms of shrinkage in portland cement paste," *Journal of the American Ceramic Society*, vol. 41, no. 1, pp. 1–6, 1958.
[30]. P. Rawat, S. Liu, S. Guo, M. Zillur Rahman, T. Yang, X. Bai, Y. Yao, B. Mobasher, D. Zhu, A state-of-the-art review on mechanical performance characterization and modelling of high-performance textile reinforced concretes, Construction and Building Materials 347 (2022) 128521. https://doi.org/10.1016/j.conbuildmat.2022.128521.
[31] E. G. Nawy, *Reinforced Concrete: A Fundamental Approach*, 6th ed., Upper Saddle River, NJ: Pearson, 2008.
[32] A. M. Neville, *Properties of Concrete*, 5th ed., Harlow, UK: Pearson Education Limited, 2011.
[33] B. V. Rangan, "Design of fiber reinforced concrete elements," *Concrete International*, vol. 13, no. 6, pp. 25–32, 1991.
[34] M. H. Balaguru and S. P. Shah, *Fiber Reinforced Cement Composites*, New York: McGraw-Hill, 1992.
[35] Mydin, M. A. O., Nawi, M. N. M., & Munaaim, M. A. C. (2017). Assessment of waterproofing failures in concrete buildings and structures. MCRJ Spec, 2017, 2.
[36] W. Ma, Y. Qin, Y. Li, J. Chai, X. Zhang, Y. Ma, H. Liu, Mechanical properties and engineering application of cellulose fiber-reinforced concrete, Materials Today Communications 22 (2020) 100818. https://doi.org/10.1016/j.mtcomm.2019.100818.
[37] M. Mermerdaş and Y. Toklu, "Effect of pre-wetted cotton fibers on workability and shrinkage behavior of concrete," *Construction and Building Materials*, vol. 280, pp. 122452, Mar. 2021.
[38] K. Bilim and A. Atis, "Effects of pre-soaked natural fibers on concrete shrinkage," *Indian Journal of Engineering & Materials Sciences*, vol. 20, no. 3, pp. 207–214, 2013.
[39] S. Mindess, "Admixtures and concrete durability," in *Developments in the Formulation and Reinforcement of Concrete*, Cambridge: Woodhead Publishing, 2019, pp. 121–139.
[40] M. Ali, "Role of post-tensioned coconut-fibre ropes in mortar-free interlocking concrete construction during seismic loadings," *KSCE Journal of Civil Engineering*, vol. 22, no. 4, pp. 1336–1343, 2018
[41] L. B. Rowell, "Mechanical properties of natural fibers in composites," *Handbook of Engineering Biopolymers*, Munich: Carl Hanser Verlag, 2003, pp. 297–324.
[42] H. K. Lee, M. S. Kim, and Y. S. Kim, "Mixing techniques for fiber reinforced concrete," *Materials Science Forum*, vol. 534–536, pp. 1233–1236, 2007.
[43] ACI Committee 308, *Guide to Curing Concrete*, ACI 308R-01, Farmington Hills, MI: American Concrete Institute, 2001.
[44] H. M. Selmy and M. M. Elmoaty, "Performance of cotton-fiber reinforced concrete overlays for crack control," *International Journal of Civil Engineering and Technology*, vol. 8, no. 9, pp. 1693–1704, 2017.
[45] M. U. Farooqi and M. Ali, "Effect of fibre content on compressive strength of wheat straw reinforced concrete for pavement applications," in *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 422, no. 1, p. 012014, Sep. 2018.
[46] M. Horvath, "Embodied energy in building materials: A primer," *Green Building Digest*, vol. 16, pp. 1–7, 2004.
[47] M. U. Farooq and R. J. Thomas, "Hybrid fiber reinforced concrete: A review of performance and applications," *Construction and Building Materials*, vol. 265, pp. 120350, May 2020.
[48] T. Liu, J. Hu, and X. Li, "Recycling waste cotton fiber in cement composites: Environmental implications and mechanical performance," *Journal of Cleaner Production*, vol. 221, pp. 768–777, Jun. 2019.
[49] F. Pacheco-Torgal and S. Jalali, "Cementitious building materials reinforced with vegetable fibers: A review," *Construction and Building Materials*, vol. 25, no. 2, pp. 575–581, Feb. 2011.
[50] D. D. L. Chung, "Low-cost carbon fiber reinforced concrete for smart structures," *Smart Materials and Structures*, vol. 12, no. 4, pp. 430–432, 2003.
[51] U.S. Green Building Council, *LEED v4 for Building Design and Construction*, Washington, DC, 2013.