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Short Communication

Review of Experimental Ultra-High Performance Concrete Mixes with Extreme Strengths

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Abstract

Ultra-High-Performance Concrete (UHPC) has redefined the strength limits of cementitious materials over the past two decades. This brief communication synthesizes experimental studies reporting record-breaking non-proprietary UHPC mixes developed since the mid-2000s. The focus is on mix designs that achieve compressive strengths ranging from 200 to 300 megapascals (MPa) and direct tensile strengths of up to 15 MPa (flexural strengths of up to 45 MPa). The key parameters that contribute to these strengths are systematically examined, including cementitious content, silica fume proportion, supplementary powders, fine sand gradation, superplasticizer dosage, and steel fiber type and volume fraction. The influence of curing regimes, ranging from ambient conditions to extended steam and high-temperature treatments, is also compared. The findings of the study substantiate that particle packing optimization, low water-to-binder ratios (0.16–0.22), and strategic fiber reinforcement are pivotal to attaining exceptional performance. These findings offer a concise evaluation of the current state of UHPC strength achievements and indicate future innovations, including nano-modified binders, advanced fiber geometries, and sustainable cement replacements that have the potential to further enhance strength and durability.

Keywords: *Ultra-High-Performance Concrete; Fiber Reinforcement; Compressive Strength; Tensile Strength; Curing Regimes.*

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Introduction

Ultra-High-Performance Concrete (UHPC) is a sophisticated class of cementitious composite distinguished by compressive strengths that frequently exceed 150 MPa and augmented tensile capacity achieved through fiber reinforcement (Kravanja et al., 2024). The extant studies that were reviewed herein were identified through a systematic literature search that employed keywords such as "Ultra-High-Performance Concrete," "non-proprietary UHPC," "extreme compressive strength," and "fiber reinforcement." From 2005 to 2025, publications were prioritized, with an emphasis on experimental works reporting compressive strengths above 200 megapascals (MPa).

Conventional proprietary UHPC formulations have demonstrated compressive strengths of 150–200 megapascals (MPa) and direct tensile strengths of 5–10 MPa under optimized curing conditions (Graybeal, 2006; Kravanja et al., 2024). However, research over the past two decades has increasingly focused on developing non-proprietary UHPC mixtures capable of surpassing these limits through refined particle packing, the use of supplementary cementitious materials, and innovative curing techniques. This brief communication offers a concise synthesis of experimental UHPC mixtures reported since 2005 that have achieved record mechanical properties, particularly compressive strengths ranging from 200 to 300 megapascals (MPa) and tensile strengths nearing 15 MPa. The emphasis is placed on laboratory-developed, non-commercial mixes, highlighting their mix proportions, curing regimes, and resulting performance.

By consolidating these benchmark achievements, this study offers a focused reference for researchers seeking to advance UHPC mix design, optimize curing strategies, and expand the structural applications of this high-performance material.

UHPC Mix Designs Achieving Ultra-High Strengths

A series of seminal studies have demonstrated the potential of non-proprietary UHPC mixes to exceed conventional strength limits.

Wille et al. achieved compressive strengths above 200 MPa under ambient curing conditions by optimizing particle packing and using 25–30% silica fume with fine quartz powder and low water-to-binder ratios (~0.22). When reinforced with 2–2.5% steel fibers, these mixes reached direct tensile strengths of 12–15 MPa, indicating that fiber geometry and distribution are as critical as fiber dosage (Wille et al., 2011, 2012).

Shin et al. (2018) further advanced the understanding of compressive strength, reporting 341 MPa in a quartz-rich UHPC mortar through multi-stage heat curing (5 days steam + 1 day dry heat) at a very low water-to-binder ratio (~0.17). While tensile performance was not the primary focus of this matrix-only mixture, it did establish an upper limit for compressive strength.

Rong et al. (2020) developed an RPC-type UHPC that achieved 250 MPa compressive strength when specimens were first steam cured and then exposed to 300 °C, illustrating how aggressive post-curing can significantly enhance matrix densification. However, improvements in tensile capacity were modest. Other studies have demonstrated that approximately 30% silica fume replacement, optimized fine sand gradation, and steel fiber reinforcement at approximately 2% volume consistently yield compressive strengths of 200–250 megapascals and tensile strengths of 10–15 megapascals (Kravanja et al., 2024; Ullah et al., 2022).

In extreme cases, steel fibers have demonstrated compressive strengths exceeding 800 MPa under laboratory confinement (Rong et al., 2020), although these outcomes remain experimental outliers. As demonstrated in **Figures 1, 2 and 3**, the compressive and tensile strengths of UHPC mixes reported in key studies are illustrated. The key parameters governing record UHPC strength are also demonstrated, as are the effects of curing regimes on UHPC compressive strength.

The role of steel fibers in the control of crack initiation and propagation in ultra-high-performance concrete (UHPC) is of critical importance. The presence of these elements serves to bridge microcracks, delay crack opening, and provide post-cracking ductility. In particular, the presence of twisted or deformed fibers has been shown to enhance pull-out resistance, leading to the formation of multiple fine cracks rather than a single, wide crack. This crack-arresting mechanism is a primary reason UHPC achieves higher tensile capacity and enhanced durability compared to plain high-strength matrices (Wille et al., 2014; Yoo et al., 2020; Yoo & Banthia, 2016).

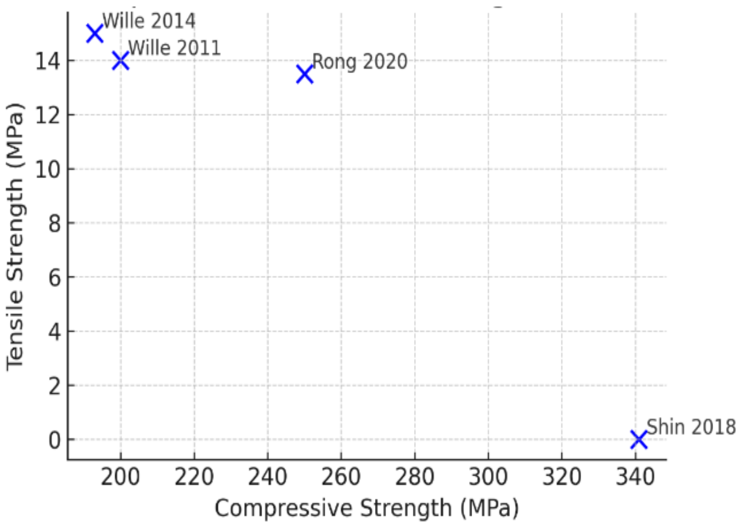

Figure 1. Compressive vs. Tensile Strength (Based on Cited Studies).

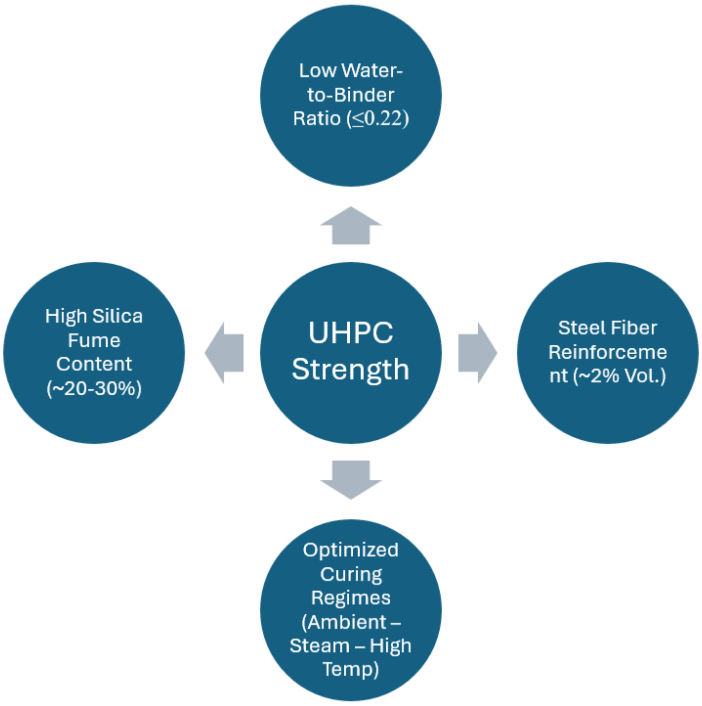

Figure 2. Key Parameters Governing UHPC

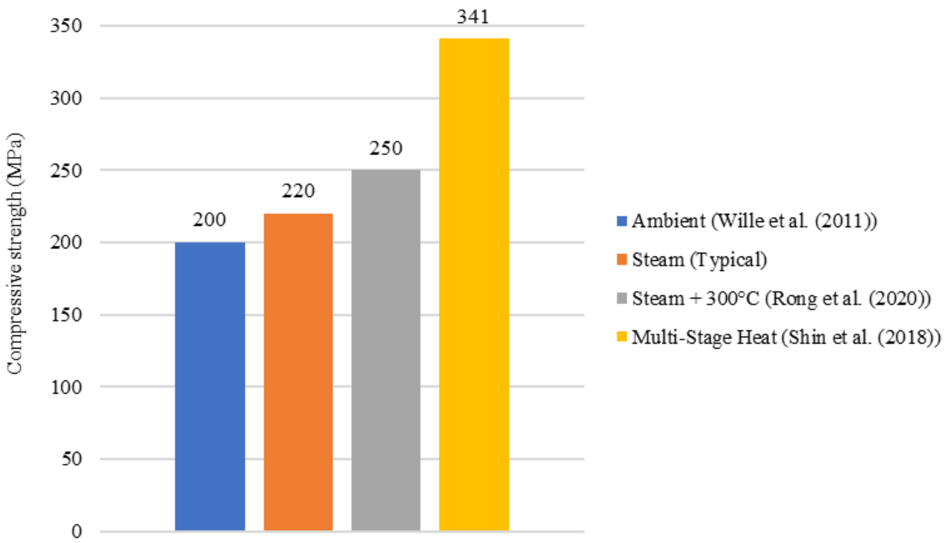

Figure 3. Effect of Curing Regimes on UHPC Compressive Strength

Discussion

A review of the extant literature reveals several principles that consistently underpin record UHPC performance. Initially, the utilization of remarkably low water-to-binder ratios (0.16–0.22) in conjunction with elevated cementitious content and the incorporation of silica fume replacement at a ratio of 20–30% results in the formation of a dense, high-strength matrix. Secondly, the absence of coarse aggregate, along with the incorporation of fine quartz sand or powders, has been demonstrated to enhance particle packing and homogeneity. Thirdly, curing regimes have been demonstrated to play a decisive role in the mechanical behavior of the materials. Ambient curing has been shown to yield compressive strengths of approximately 200 megapascals (MPa), while extended steam or high-temperature treatments are required to exceed 250–300 MPa.

Tensile performance is contingent upon the degree of fiber reinforcement. The tensile strengths of straight or twisted steel fibers, when present at approximately 2% by volume, have been observed to be in the range of 10–15 megapascals. It has been demonstrated that the deformation of these fibers enhances their resistance to pull-out and augments their strain-hardening capacity. Higher fiber volumes have been shown to enhance tensile strength; however, they can also compromise workability and slightly reduce compressive performance. Therefore, achieving an optimal balance of fiber type, volume, and dispersion is imperative for attaining both high strength and ductility in UHPC.

For instance, while the incorporation of silica fume has been demonstrated to enhance matrix densification and compressive strength, it concomitantly reduces workability, thereby necessitating higher dosages of superplasticizer. Conversely, an elevated fiber content has been shown to enhance tensile capacity; however, it concomitantly reduces compaction efficiency, resulting in the formation of voids that can impede compressive performance.

Conclusion

Recent experimental studies have demonstrated that non-proprietary UHPC can reliably achieve compressive strengths ranging from 200 to 300 megapascals (MPa) and direct tensile strengths of up to 15 MPa, provided that optimal mix design and curing strategies are employed. The following factors must be considered: low water-to-binder ratios (≤0.22), 20–30% silica fume incorporation, optimized particle packing, and ~2% steel fiber reinforcement. While ambient curing can yield strengths of approximately 200 megapascals (MPa), the application of extended steam or elevated temperatures is necessary to exceed 250 MPa.

These benchmark results indicate that the performance of UHPC can be systematically enhanced through mix proportioning and curing optimization. In the future, advances in fiber technology, nanomodification, and sustainable binder alternatives are expected to further expand the mechanical capabilities and practical applications of UHPC.

Declarations

Author Contribution

S.M.H: Methodology, Writing of the original draft, Writing – review & editing.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declaration on the Use of Generative AI and AI-Assisted Technologies

No generative AI or AI-assisted technologies were used in the preparation of this manuscript.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgement

The authors declare that there is no acknowledgement to be made.

Ethics

This study did not involve human participants or animals; hence, no ethical approval was required.

References

Graybeal, B. (2006). Material Property Characterization of Ultra-High Performance Concrete. *FHWA-HRT-06-103*, 1–176.

Kravanja, G., Mumtaz, A. R., & Kravanja, S. (2024). A Comprehensive Review of the Advances, Manufacturing, Properties, Innovations, Environmental Impact and Applications of Ultra-High-Performance Concrete (UHPC). *Buildings*, *14*(2), 382. https://doi.org/10.3390/buildings14020382

Rong, Q., Hou, X., & Ge, C. (2020). Quantifying curing and composition effects on compressive and tensile strength of 160–250 MPa RPC. *Construction* *and Building Materials*, *241*, 117987. https://doi.org/10.1016/j.conbuildmat.2019.117987

Shin, H.-O., Yoo, D.-Y., & Lee, J.-H. (2018). Development of 300 MPa ultra-high-strength mortar through a special curing regime. *Construction and Building Materials*, *171*, 312–320. https://doi.org/10.1016/j.conbuildmat.2018.03.134

Ullah, R., Qiang, Y., Ahmad, J., Vatin, N. I., & El-Shorbagy, M. A. (2022). Ultra-High-Performance Concrete (UHPC): A State-of-the-Art Review. *Materials*, *15*(12), 4131. https://doi.org/10.3390/ma15124131

Wille, K., El-Tawil, S., & Naaman, A. E. (2014). Properties of strain hardening ultra high performance fiber reinforced concrete (UHP-FRC) under direct tensile loading. *Cement and Concrete Composites*, *48*, 53–66. https://doi.org/10.1016/j.cemconcomp.2013.12.015

Wille, K., Naaman, A. E., El-Tawil, S., & Parra-Montesinos, G. J. (2012). Ultra-high performance concrete and fiber reinforced concrete: achieving strength and ductility without heat curing. *Materials and Structures*, *45*(3), 309–324. https://doi.org/10.1617/s11527-011-9767-0

Wille, K., Naaman, A. E., & Parra-Montesinos, G. J. (2011). Ultra-High Performance Concrete with Compressive Strength Exceeding 150 MPa (22 ksi): A Simpler Way. *ACI Materials Journal*, *108*(1), 46–54. https://doi.org/10.14359/51664215

Yoo, D.-Y., & Banthia, N. (2016). Mechanical properties of ultra-high-performance fiber-reinforced concrete: A review. *Cement and Concrete Composites*, *73*, 267–280. https://doi.org/10.1016/j.cemconcomp.2016.08.001

Yoo, D.-Y., Sohn, H.-K., Borges, P. H. R., Fediuk, R., & Kim, S. (2020). Enhancing the tensile performance of ultra-high-performance concrete through strategic use of novel half-hooked steel fibers. *Journal of Materials Research and Technology*, *9*(3), 2914–2925. https://doi.org/10.1016/j.jmrt.2020.01.042