AN EXPERIMENTAL INVESTIGATION INTO THE COMPRESSIVE STRENGTH BEHAVIOR OF ULTRA HIGH PERFORMANCE CONCRETE

[a] Muhammad Ubair Javed*, and [b]Muhammad Akbar Malik*

a Department of Civil Engineering, The Islamia University, Bahawalpur, Pakistan. ubairce2024@gmail.com.
b: Department of Civil Engineering, The Islamia University, Bahawalpur, Pakistan. m.akbarmalik@iub.edu.pk
* Corresponding author. ubairce2024@gmail.com; m.akbarmalik@iub.edu.pk

Abstract- This study investigates the behavior of Ultra High-Performance Concrete (UHPC), a material renowned for its exceptional strength and durability. UHPC has garnered global attention for its potential to enhance sustainability and prolong the lifespan of buildings and infrastructure. Despite its growing prominence, challenges such as limited knowledge, the absence of standardized design codes, and high production costs hinder its universal acceptance. To address these challenges, research initiatives have been undertaken globally, including substantial programs in Germany, South Korea, and Malaysia. This research work encompasses comprehensive mix design, sample preparation, and compressive strength testing. Notably, UHPC specimens achieved an average compressive strength of 80 MPa at 7 days and 121 MPa at 28 days, significantly outperforming conventional concrete. The factors contributing to this exceptional strength include high-performance cement, low water-to-cement ratio, silica fume and class F flyash. These findings underscore the potential of UHPC to revolutionize the construction industry, and ongoing research efforts aim to develop sustainable formulations that reduce environmental impact and production costs.

Keywords Ultra High Performance Concrete (UHPC), Compressive Strength, Sustainable Construction, Mix Design Optimization

1 Introduction

Ultra-High Performance Concrete has made significant progress in construction materials, known for its exceptional strength and durability. Over the last twenty years, UHPC has been acknowledged as a possible method for enhancing sustainability and extending the lifespan of global buildings and infrastructure [1]. It has demonstrated versatility across diverse sectors, being employed in building elements, bridges, offshore structures, and other applications. These advancements have been made possible due to extensive research and development efforts aimed at understanding the behavior, properties, and potential applications of UHPC [2].

Despite its widespread adoption in certain regions like Europe and parts of Asia, challenges persist in achieving universal acceptance and implementation due to limited knowledge, absence of standardized design codes, and high production costs[3-6].

Recognizing its transformative potential globally led to research initiatives aimed at addressing key challenges while promoting innovation such as Germany's multimillion-dollar program focused on expanding awareness about UHPB making it economically feasible for widespread use along with similar endeavors in South Korea and Malaysia focusing on specific applications such as cable-stayed bridges or rural infrastructure development projects[7-9].

The journey witnessed demonstrable progress marking transformational progression within the built environment industry. While persevering through persistent obstacles ongoing research aims at pushing boundaries hence paving the way forward toward more progressive, sustainable variants opening new opportunities.

2 Material

2.1 Cement:

52.5 R CEM cement is employed for its outstanding early strength and durability characteristics, and it is added to UHPC mixtures to improve mechanical properties and overall effectiveness.

2.2 Superplasticizer:

A polycarboxylic acid based superplasticizer is added to concrete mixes to enhance workability and fluidity while maintaining strength. This chemical is recognized for its efficient dispersion of cement particles, leading to improved flow and decreased water content in the mix.[10].

2.3 Supplementary Cementitious Materials:

Class F fly ash and silica fume are used as alternatives to cement in concrete blends. They improve the ease of handling, longevity, and robustness of the material, while also lessening ecological ramifications by repurposing industrial by-products[11-14].

2.4 Aggregates:

Fine aggregates that have been sieved through a 1.18 mm sieve are applied in concrete mixes to fill spaces and enhance manageability. Fine aggregates significantly contribute to maximizing the density of concrete packing and improving its mechanical properties.[15].

2.5 Water-to-Cement Ratio:

A 0.2 water-to-cement ratio is employed in UHPC formulas to attain high strength and reduce permeability while retaining suitable workability. This reduced water-to-cement ratio decreases porosity and guarantees effective hydration of cement particles, leading to compact and long-lasting concrete with excellent mechanical attributes.[16].

3 Methodology

The research methodology for Ultra-High Performance Concrete starts with a detailed mix design process according to specific specifications shown in table 1. This involves determining the proportions of essential components such as cement, silica fume, fine aggregates, water, high-range water reducer, and fibers.

Table:1 Composition of UHPC

Material	Conventional Concrete kg/m3	UHPC Proportion kg/m3
Cement	300	600
Fly ash	-	120
Silica Fume	-	153.5
Sand	1000	630
HRWR	10	17
Water	180	131

Sample preparation is carried out precisely to weigh each component accurately. The dry ingredients are combined in a mixing container and thoroughly blended for a homogeneous mixture for 5 minutes. Then, the mixing water and high-range water reducer are gradually added while continuously blending to create a uniform UHPC slurry for 3-4 minutes.

The casting procedure follows a systematic approach where the UHPC mixture is poured into prepared molds ensuring complete filling. After casting, specimens undergo curing covered with plastic sheets during the initial curing period lasting 24 hours then transferring them to a curing tank for 7 days and 28 days. For comparison the conventional control cube specimens of 50x50x50 mm sizes were also prepared.

Following the requisite curing period, the compressive strength of the UHPC specimens is determined using a compressive testing machine. This machine measures the maximum load withstood by the cube until failure, which is then recorded as the compressive strength. The material casting and testing procedure is illustrated in Figure [1], which provides a visual representation of the process.

Figure:1 Casting and Testing of specimens

4 Discussion and Results

The section discusses the results of testing the compressive strength of UHPC specimens at 7 days and 28 days using ASTM C109/C109M. The average compressive strength, recorded as 80 MPa and 121 MPa at 7 and 28 days respectively, is accompanied by the standard deviation to illustrate data variability as shown in figure 2.

A 0.2 W/B ratio indicates a very low amount of water, resulting in a dense microstructure and reduced porosity, leading to higher strength. Silica fume's high pozzolanic reactivity enhances the binding properties, contributing to increased strength. Class F fly ash's low calcium content and high silica content promote a slow and steady pozzolanic reaction, improving strength over time. The use of 1.18 mm fine aggregate allows for a dense packing, reducing voids and increasing strength. The HRWR admixture enables the achievement of a low W/B ratio while maintaining workability, ensuring a dense and strong microstructure.

The significant strength gain between 7 and 28 days (from 80 MPa to 121 MPa) can be attributed due to Continued pozzolanic reactions between silica fume and Class F fly ash. Ongoing hydration of cement and fly ash. Increased bonding between aggregate and paste due to continued cement hydration. The mix design probably involved high-performance cement and a low water-to-cement ratio, both promoting rapid early-age strength development [17].

In comparison with conventional concrete typical 35 MPa compressive strength at 28 days Figure [2], these results underscore substantial advantage offered by UHPC. While impressive, further exploration into long-term strength development as well as other mechanical properties would offer a more comprehensive assessment of the UHPC mixture's performance.

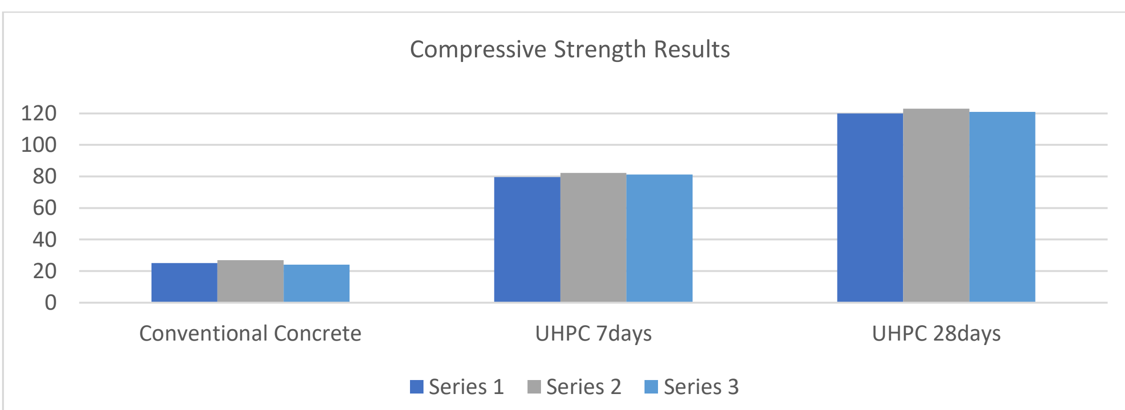

Figure 2: Comparison of UHPC and Conventional Concrete

Possible future testing includes assessing later-stage (56 days) strengths to track evolution; evaluating additional mechanical properties like tensile and flexural strengths; or exploring influences from different mix design parameters on UHPC's mechanical behavior.

5 Conclusion

In conclusion, the Ultra High Performance Concrete (UHPC) specimens demonstrated exceptional compressive strength, reaching 80 MPa at merely 7 days and further increasing to 121 MPa at 28 days. This investigation into the properties and behavior of UHPC has yielded significant findings. Notably, UHPC exhibits outstanding compressive strength, surpassing traditional concrete by a substantial margin. The use of high-quality materials and a low water-to-cement ratio confers enhanced durability and resistance to environmental degradation. Ongoing research endeavors aim to develop sustainable UHPC formulations, mitigating environmental impact and production costs. Despite its favorable attributes, the widespread adoption of UHPC is hindered by the absence of standardized design codes, limited understanding of its properties, and higher initial costs relative to conventional concrete.

Future areas for study involve improving mixture designs to boost sustainability and cost-effectiveness, evaluating long-term resilience in different conditions, advocating for standardization initiatives, and performing thorough life-cycle cost evaluations to showcase its financial advantages.

Acknowledgment

I extend my sincere gratitude to my academic advisors, colleagues, family, and friends for their unwavering support and encouragement throughout this research journey. Their guidance, feedback, and understanding have been invaluable.

Reference

1. Bajaber, M. and I. Hakeem, *UHPC evolution, development, and utilization in construction: A review.* Journal of Materials Research and Technology, 2021. **10**: p. 1058-1074.
2. Zhou, M., et al., *Application of ultra-high performance concrete in bridge engineering.* Construction and Building Materials, 2018. **186**: p. 1256-1267.
3. Azmee, N.M. and N. Shafiq, *Ultra-high performance concrete: From fundamental to applications.* Case Studies in Construction Materials, 2018. **9**: p. e00197.
4. Randl, N., et al., *Development of UHPC mixtures from an ecological point of view.* Construction and Building Materials, 2014. **67**: p. 373-378.
5. Křížová, K. and R. Hela, *Options of UHPC in the Czech Republic.* Key Engineering Materials, 2017. **722**: p. 292-297.
6. Abbas, S., M. Nehdi, and M. Saleem, *Ultra-high performance concrete: Mechanical performance, durability, sustainability and implementation challenges.* International Journal of Concrete Structures and Materials, 2016. **10**: p. 271-295.
7. Phillips, P.S., et al., *A UK county sustainable waste management programme.* International Journal of Environment and Sustainable Development, 2002. **1**(1): p. 2-19.
8. Quitoras, M.C.L. and J.E. Abuso, *Best Practices of Higher Education Institutions (HEIs) for the Development of Research Culture in the Philippines.* Pedagogical Research, 2021. **6**(1).
9. Alsulami, S., et al., *Perception of academic stress among health science preparatory program students in two Saudi universities.* Advances in medical education and practice, 2018: p. 159-164.
10. Macijauskas, M. and G. Skripkiūnas. *The influence of superplasticizers based on modified acrylic polymer and polycarboxylate ester on the plasticizing effect of cement paste*. in *Materials Science Forum*. 2017. Trans Tech Publ.
11. Bajpai, R., et al., *Environmental impact assessment of fly ash and silica fume based geopolymer concrete.* Journal of Cleaner Production, 2020. **254**: p. 120147.
12. Mustapha, F., et al., *The effect of fly ash and silica fume on self-compacting high-performance concrete.* Materials Today: Proceedings, 2021. **39**: p. 965-969.
13. Gil, D.M. and G.L. Golewski. *Potential of siliceous fly ash and silica fume as a substitute for binder in cementitious concretes*. in *E3S Web of Conferences*. 2018. EDP Sciences.
14. Sankar, L.P., et al., *Investigation on binder and concrete with fine grinded fly ash and silica fume as pozzolanic combined replacement.* Materials Today: Proceedings, 2020. **27**: p. 1157-1162.
15. Zhao, Y., et al., *Characterization of coarse aggregate morphology and its effect on rheological and mechanical properties of fresh concrete.* Construction and Building Materials, 2021. **286**: p. 122940.
16. Kim, S., et al., *Experimental and theoretical studies of hydration of ultra-high performance concrete cured under various curing conditions.* Construction and Building Materials, 2021. **278**: p. 122352.
17. Ullah, R., et al., *Ultra-high-performance concrete (UHPC): A state-of-the-art review.* Materials, 2022. **15**(12): p. 4131.