Strength Analysis of Ultra-High-Performance Concrete Incorporated with Palm Oil Fuel Ash

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Abstract: *Ultra-High-Performance Concrete (UHPC) is a discrete form of concrete that is well-acknowledged for its remarkable strength, long lifespan, and improved mechanical properties when compared to traditional concrete. UHPC is characteristically composed of a significant extent of fine materials, including silica fume, quartz flour, and extremely fine aggregates, along with specific additives that are designed to augment its exceptional characteristics. With the ability to achieve strengths surpassing 150 MPa and exceptional tensile strength, UHPC demonstrates exceptional durability that sets it apart from other types of concrete. Currently, UHPC is being widely utilized in the construction industry, particularly in the development of bridge structures where its superior qualities are highly beneficial. This research study adds to the existing body of knowledge regarding the performance of UHPC when combined with palm oil fuel ash (POFA), presenting new insights and perspectives on the subject matter. By exploring the utilization of POFA in UHPC, this investigation aims to contribute to the ongoing advancements in the field of construction materials and sustainable practices.*

Key Words: *Ultra-High-Performance Concrete, Palm Oil Fuel ash.*

1. INTRODUCTION

Ultra-high-performance concrete (UHPC) was familiarized as a novel category of concrete in France in the 1990s, renowned for its exceptional characteristics such as excellent workability, impressive compressive strength, heightened ductility, and exceptional resistance to conservational elements **[1].** The elimination of large aggregates was deemed a critical element by the creators concerning the internal makeup and overall performance of Reactive Powder Concrete (RPC), with the goal of reducing the variability in composition between the cement adhesive and the aggregates **[2].** It is commonly observed that UHPC has a notably low water-to-cement ratio, resulting in limited cement hydration. Moreover, evidence suggests that the manufacturing of Portland cement leads to a comparable level of carbon dioxide emissions, posing a significant burden on the environment **[3].** In a world increasingly focused on adopting environmentally sustainable construction methods, there exists the possibility of substituting a portion of the cement component with alternative materials that provide superior durability, increased flexibility, and enhanced resistance to corrosion and chemical damage **[4].**

2. LITERATURE REVIEW

Typical compositions of Ultra-High-Performance Concrete (UHPC) typically consist of momentous proportions of cementitious materials, fine sand, and high volumes of steel fibres, combined with a thoughtful amalgamation of chemical admixtures such as high-range water-reducing admixtures, shrinkage-reducing admixtures, extensive agents, and viscosity-modifying admixtures. These mixtures are categorized by an enormously low water-to-binder ratio that stereotypically falls within the range of 0.15 to 0.25, in addition to a high particle packing density **[5].** The fundamental principles that govern the design of UHPC revolve around the reduction of porosity, the enhancement of microstructure, the improvement of uniformity, and the augmentation of toughness **[6].** To further optimize its properties, Supplementary Cementitious Materials (SCMs) like fly ash, ground granulated blast-furnace slag, silica fume, metakaolin, limestone powder, steel slag powder, and rice husk ash are incorporated into UHPC to reduce cement consumption, decrease carbon emissions, and improve flowability without compromising mechanical performance **[7].** UHPC stands out for its exceptional strength, toughness, and durability in comparison to conventional concrete; nevertheless, its utilization is hindered by the high costs associated with production and the stringent maintenance requirements it demands **[18].** A recent addition to the realm of construction materials, Ultra-High-Performance Concrete (UHPC) represents a novel category of innovative cementitious composites that boast suggestively superior mechanical strength and durability traits when contrasted with outmoded concrete. Typically, UHPC is formulated by blending fine aggregate, cement, silica fume, micro-steel fibres, and high-range water-reducing additives (HRWR), resulting in a material distinguished by its appropriate workability, high toughness and strength, low porosity, and exceptional durability **[21,22].** Notably, UHPC tends to consume a notably higher quantity of cement in comparison to conventional concrete **[25,26,27,28],** thereby leading to a substantial increase in construction costs **[25,29,30]**. As a response to these challenges, current strategies aimed at mitigating the antagonistic pecuniary and conservational implications of UHPC encompass the integration of manufacturing by-products, referred to as inanimate admixtures **[25,31,32,33,34].** For example, Ultra-High-Performance Concrete (UHPC) has garnered recognition as an advanced classification of cement-based materials that exhibit remarkable strength, ductility, durability, and energy dissipation capacity **[35,36,37].**

3. UHPC MIX CONSTITUENTS

3.1. Cementitious Materials

3.1.1. Ordinary Portland Cement (OPC 53)

Ordinary Portland Cement (OPC 53) is a widely utilized type of cement in the structure industry due to its incomparable versatility and robustness, making it a popular choice among builders and engineers. The manufacturing process involves the grinding of clinker, gypsum, and various additives until a fine powder is formed, ensuring a homogenous mixture with desirable properties. The numerical designation "53" within its nomenclature signifies the minimum compressive strength, typically measured in megapascals (MPa), that the cement can attain following a 28-day curing period. This specific attribute of OPC 53 renders it particularly suitable for endeavours necessitating the creation of enduring and steadfast concrete structures that can withstand various environmental conditions and loads. Its prevalence extends to a broad spectrum of construction ventures, encompassing both residential and commercial projects, owing to its consistent performance and structural reliability.

FIGURE 1. Ordinary Portland Cement

3.1.2. Fly Ash

Class C fly ash represents a valuable component in enhancing the performance and sustainability of concrete when employed as a substitute for cement. Originating as a residue from coal combustion, it emerges as an environmentally conscientious alternative to conventional cement, thereby diminishing the reliance on pristine materials and diminishing the emission of greenhouse gases linked to cement manufacturing processes. A notable advantage associated with integrating Class C fly ash into concrete formulations is its capacity to prompt substantial early strength development in the mixtures, thereby expediting construction timelines and facilitating the premature removal of formwork, ultimately contributing to heightened project efficiency.

Presently, more than half of the concrete compositions in the United States incorporate fly ash, underscoring its established significance in the realm of construction materials and practices. Beyond the advantages pertaining to the fresh and toughened characteristics of concrete, the employment of fly ash contributes to cost savings, reduction in carbon footprints, and **[23].**

FIGURE 2. Fly Ash (Class C)

3.1.3. Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) is a residue formed from the burning of palm oil waste, mainly originating from palm oil mills. The POFA is characterized by the presence of fine particles that have the ability to plug the voids amongst cement particles, resulting in a more compact concrete mix with decreased permeability. This densification process contributes to an increased resistance against the penetration of chloride ions, sulphate attack, and alkali-silica reaction, thereby prolonging the lifespan of concrete structures significantly. It has been a common practice to utilize POFA as a substitute for cement in the manufacturing of concrete to mitigate the expenses, health hazards, energy usage, and environmental impact associated with cement production **[8].** The high SiO_2 content in POFA interacts with $Ca(OH)_2$ produced during the hydration phase to create C-S-H gels, which in turn enhances the microstructure and compressive strength of concrete, especially as it ages **[8,9].**

FIGURE 3. Palm Oil Fuel Ash (POFA)

3.2. Chemical Admixtures

UHPC Ultra-high-performance concrete (UHPC) formulations necessitate the application of relatively high amounts of chemical admixtures, predominantly high-range water reducers (HRWR) frequently stated to as super-plasticizers. Among these, poly carboxylate-based HRWR are preferred due to their superior ability to maintain the desired slump of the concrete mixture over extended periods **[1,10,11,12].** The impact of PCE-category super-plasticizers on the zeta latent of particles, spread flow, setting time, autogenous shrinkage, and chemical shrinkage of Ultra-High-Performance Concrete (UHPC) pastes is thoroughly examined in the study, as well as the spread flow, slump lifespan, and premature strength progress of UHPC **[38].** These poly carboxylic ethers (PCEs) grounded super-plasticizers, which emerged as a new generation in the 1980s, have the remarkable capability to achieve a water reduction of up to 40% **[38,39].** The workability of UHPC can be effectively characterized through the initial spread flow and fluid-retaining aptitude, predominantly influenced by the diffusing capacity and holding properties of super-plasticizers. The advancements in super-plasticizer technology have revolutionized the field of concrete technology, enabling significant enhancements in flow properties, workability, and strength development of UHPC **[38].**

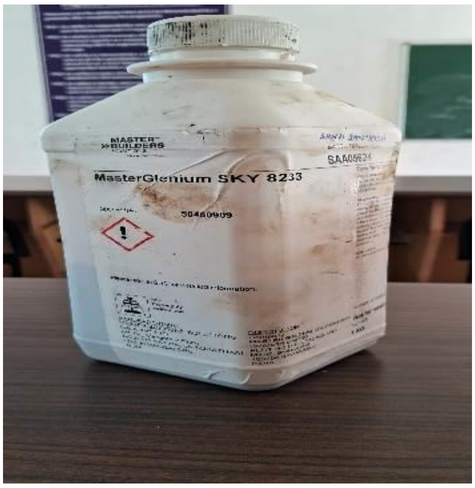

FIGURE 4. Chemical Admixture

3.3.Steel Fibre

In the case of UHPC mixes, the inclusion of micro straight steel fibres at a rate of 2-2.5% by volume has been found to be beneficial **[13,14].** In the United States market, the standard UHPC composition typically includes 2% by volume of micro straight steel fibres characterized by a diameter of 0.2mm and a length of 13mm **[19,20].** The incorporation of steel fibres in UHPC is a common strategy aimed at enhancing various properties of the material, as recognized in the relevant literature **[24].**

FIGURE 5. Steel Fibres

FIGURE 5. shows crimped steel fibre of 0.5 mm diameter and 30 mm extent with an aspect ratio of 60 is used.

4. FLOWING ABILITY OF UHPC

The flowing ability of UHPC comes under the fresh property test of concrete. This is verified by slump flow test using slump cone apparatus. Generally UHPC possesses a slump diameter greater than 600mm. Where upsurge in slump diameter designates the flowing aptitude of UHPC and its self-compaction which aids to makes a dense structure. The UHPC incorporated with palm oil fuel ash and fly ash gives a slump flow of 875 mm at control mix.

FIGURE 6. Slump Flow of 875mm

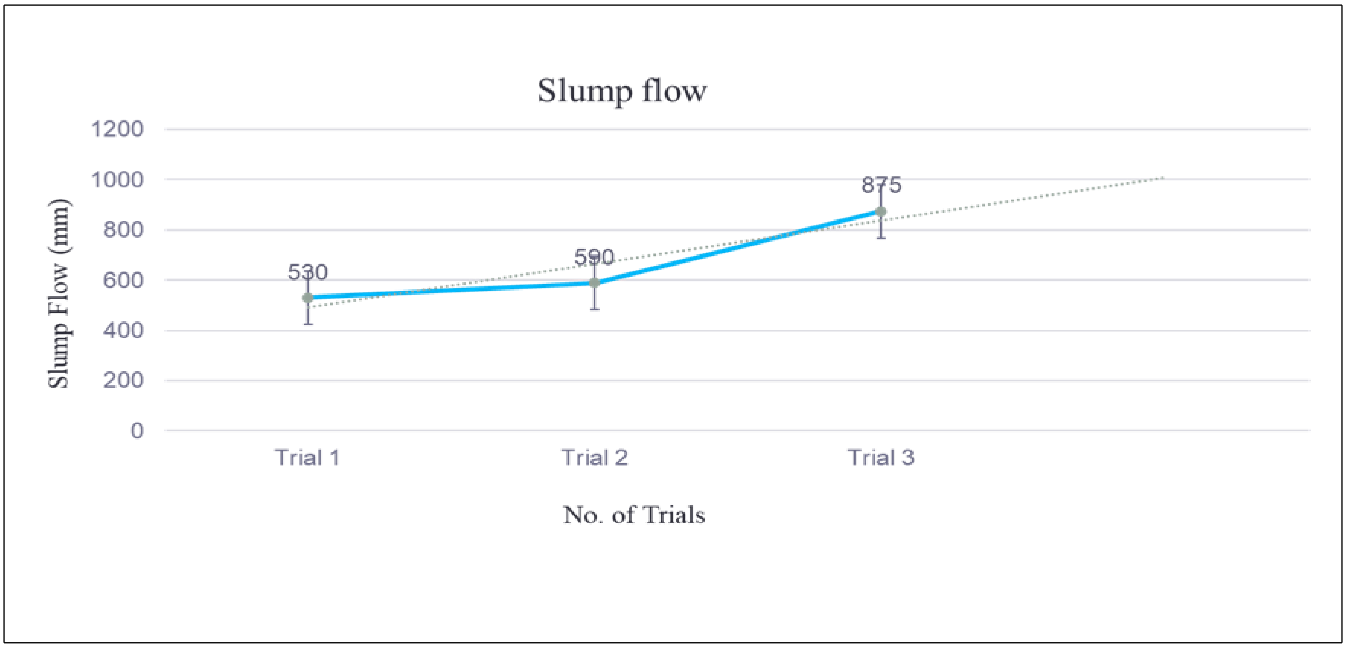

FIGURE 7. Slump Flow variations

FIGURE 7. indicates slump flow variants of trial mixes. The UHPC slump diameter of 875 mm acquired at third trial mix.

5. COMPRESSIVE STRENGTH

FIGURE 8. demonstrates the variation in compressive strength of ultra-high-performance concrete substituted with 25% fly ash and 0,5,10,15,20 percentages of palm oil fuel ash.

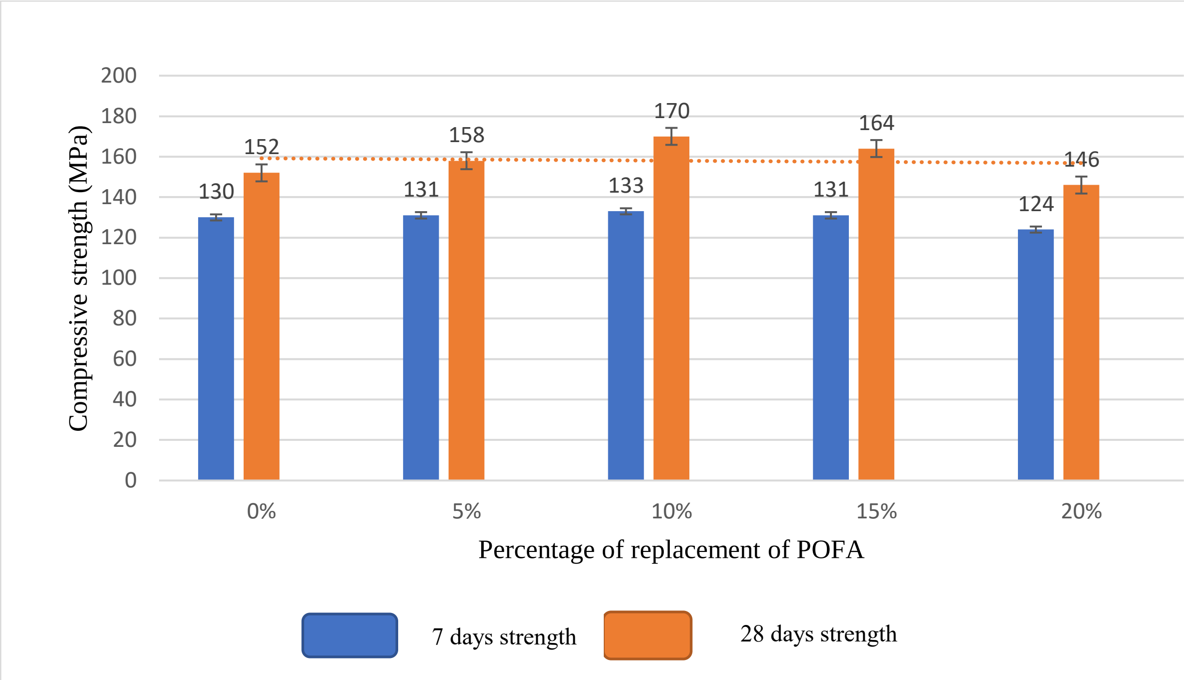

FIGURE 8. Compressive strength of UHPC at different POFA percentages

As shown in the FIGURE 8. the 25% replacement of binder content in UHPC with fly ash provides a compressive strength of 130 MPa and 152 MPa at 7days and 28 days correspondingly. With the percentage of addition of POFA shows an upsurge in the compressive strength up to 10% replacement and then manifest a decrease in strength.

TABLE 1. Compressive Strength test results of Palm Oil Fuel Ash incorporated UHPC

Sl. No.	Percentages of Replacements	Results		ASTM Standards
		7 days strength (MPa)	28 days Strength (MPa)	
1	0%	130	152	ASTM C39/C39M
2	5%	131	158	
3	10%	133	170	
4	15%	131	164	
5	20%	124	146	

6. UHPC APPLICATIONS

Ultra-high-performance concrete (UHPC) exhibits exceptionally high compressive strength, remarkable ductile properties, and outstanding durability, distinguishing it significantly from traditional concrete materials. A wide array of research studies have delved deeply into various facets of UHPC **[15],** shedding light on its unique characteristics and potential applications in the field of construction. The utilization of UHPC in pre-stressed bridges presents a ground breaking solution to longstanding engineering challenges, offering the prospect of achieving extended spans, augmented girder spacing, reduced superstructure depth, minor cross-sectional dimensions, and enhanced longevity of structural elements. By enabling the application of higher levels of pre-stressing forces, UHPC empowers bridge girders to attain superior structural capacities compared to those constructed using conventional concrete materials. Consequently, there is a growing interest among engineers in leveraging UHPC for the fabrication of pre-stressed bridge girders, as evidenced by the compelling findings presented in various scholarly works **[15,16].** Furthermore, the integration of UHPC in the construction of pre-stressed concrete highway bridge girders holds great promise due to its potential to mitigate or eliminate the need for transverse shear reinforcement, given the inherent high tensile and shear strengths imparted by steel fibres incorporated into the mixtures. The exploration of UHPC's capabilities in enhancing the performance and resilience of bridge structures represents a significant avenue for advancing the field of civil engineering and addressing key design challenges in infrastructure development. In light of these advancements, the adoption of UHPC stands as a transformative approach that not only elevates the efficiency and durability of pre-stressed concrete elements but also opens up new possibilities for achieving enhanced structural performance and sustainability in bridge construction projects **[15,17].**

7. CONCLUSION

UHPC exhibits superior compressive strength of 152 MPa at 28 days of curing shows a inclusive assortment of applications in special structures. The cement content in UHPC is more than that of normal concrete, it results to high carbon dioxide emission. Incorporation of fly ash and palm oil fuel ash in ultra-high-performance concrete helps to reduce the cement usage, thereby reduces the carbon foot-print. UHPC incorporated with fly ash and palm oil fuel ash exhibits a compressive strength of 133 MPa and 170 MPa at 7 days and 28 days of curing. UHPC with 25% of fly ash and 10% palm oil fuel ash shows an increase in strength. This exceptional strength of UHPC with ecological by-products helps the construction sector in many imperative area of applications. The practice of agronomic wastes such as palm oil fuel ash moderates the cement practice in concrete and thereby diminutions the carbon dioxide emanation to the environment.

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