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Evaluation of Ultra High Performance Concrete Exposed to Elevated Temperature

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***Abstract*— Abstract: In this study, an extensive literature review has been conducted on the material characterization of UHPC and its potential for large-scale field applicability. UHPC structures can be more vulnerable to fire and elevated temperatures due to its reduced porosity, which hinders the release of vapor pressure, leading to physical damage. However, the use of polypropylene (PP) fibers can mitigate this issue. The successful production of ultra-highperformance concrete (UHPC) depends on its material ingredients and mixture proportioning, which leads to denser and relatively more homogenous particle packing. A database was compiled from various research and field studies around the world on the mechanical and durability performance of UHPC. It is shown that UHPC provides a viable and long-term solution for improved sustainable construction owing to its ultrahigh strength properties, improved fatigue behavior and very low porosity, leading to excellent resistance against aggressive environments. The literature review revealed that the curing regimes and fiber dosage are the main factors that control the mechanical and durability properties of UHPC. Currently, the applications of UHPC in construction are very limited due to its higher initial cost, lack of contractor experience and the absence of widely accepted design provisions. However, sustained research progress in producing UHPC using locally available materials under normal curing conditions should reduce its material cost. Current challenges regarding the implementation of UHPC in full-scale structures are highlighted. This study strives to assist engineers, consultants, contractors and other construction industry stakeholders to better understand the unique characteristics and capabilities of UHPC, which should demystify this resilient and sustainable construction material.**

1. INTRODUCTION

Ultra-high-performance concrete (UHPC) is a novel construction material exhibiting enhanced mechanical and durability properties, which can lead to economical construction through reducing the cross sections of structural members with associated materials savings and lower installation and labour costs (Tang 2004). The relatively high initial cost of UHPC has restricted its wider use in the construction industry. However, ongoing research and investigations are filling knowledge gaps in order to commence innovative UHPC having reduced initial cost. Furthermore, the development and wide acceptance of an UHPC design code provisions should encourage stakeholders in the construction industry to implement large scale applications. This becomes even more relevant with the more recent push by organizations such as the American Concrete Institute, which identified using high-strength steel reinforcement in concrete as a top research priority. Combining UHPC and high-strength steel is expected to yield unique structures in the near future. UHPC potential applications include tall structures, rehabilitation works, structural and nonstructural elements, machine parts and military structures. Lighter weight structures owing to smaller cross sections can be made using UHPC. Therefore, UHPC can be effectively utilized in the precast concrete industry. Moreover, UHPC was widely used in pedestrian footbridges and highway bridges. For example, the first UHPC footbridge in Canada was constructed in 1997. In the United States, Wapello County Mars Hill was the first highway transportation bridge constructed with UHPC in 2006. In the Kinzua Dam Stilling Basin, UHPC was used for rehabilitation and strengthening purposes. Furthermore, architecturally and aesthetically appealing structures can be made using UHPC (Schmidt et al. 2004, 2012; Fehling et al. 2008). Table 1 summarizes some of the existing UHPC applications around the world. In the present study, an extensive review of literature on UHPC properties was conducted and summarized in tabular representation for a user friendly access to this scattered information.

2.OBJECTIVES OF THE PRESENT STUDY

i. To determine optimum proportion of raw materials to prepare UHPC by incorporating Hybrid Fibres. ii. To obtain UHPC of strength greaterthan150 MPa by varying percentage of fibres. iii. To determine optimum percentage of cementitious material to obtain UHPC,

a. Limestone powder.

b. Ground granulated blast-furnace slag or sugarcane bagasse ash. iv. Mechanical performance of UHPC under 2hours of standard fire or through electric oven.

3. METHODOLOGY

The concrete specimens are tested for various temperature i.e., 100°C, 200°C, 300°C and 400°C. The materials were weighed as per mix design were considered. The ingredients materials were mixed till homogeneous mix was achieved. The cubes of 150mm size and cylinders of 150mm diameter are casted and compacted using needle vibrator. The specimens were casted without reinforcements. After casting the concrete specimens, it is dried for 24 hours. After 24 hours of drying, it is subjected to curing for 7 hours and then cubes are demoulded and kept in normal temperature water for about 2 hours. The specimens should be ensured to dry completely as excess moisture content may lead to disintegration or spalling of concrete specimen during the time of heating, these is due to the excess pore vapor pressure developed inside the concrete specimens when subjected to temperature. After subjecting to elevated temperature specimens were allowed to cool for 24 hours to room temperature in air. The crack pattern, change in colour, mass loss of the specimen are studied after exposure to elevated temperature.
After cooling of the specimens destructive tests was carried out:

- UHPC_1 = UHPC_C_WF = UHPC without fibres.
- UHPC_2 = UHPC_C_SF = UHPC with 20% by its weight of steel fibre.
- UHPC_3 = UHPC_C_HF = UHPC with 20% by its weight of hybrid fibre (18% Steel fibre and 2% of cement of polypropylene fibre).
- UHPC_4 = UHPC_CLR_WF = UHPC with lime stone powder and sugarcane bagasse ash without fibres.
- UHPC_5 = UHPC_CLR_SF = UHPC with mineral admixtures like limestone powder and sugarcane bagasse ash and also 20% by its weight of steel fibre.
- UHPC_6 = UHPC_CLR_HF = UHPC with miner admixtures like limestone powder and sugarcane bagasse ash and also 20% by its weight of hybrid fibre (18% Steel fibre and 2% of cement of polypropylene fibre).

4. RESULTS AND DISCUSSIONS

Quantifying various parameters such as Compressive strength of UHPC before exposed to fire and after exposed to fire, workability and mass loss plays an important role along with the design mix. So, the evaluation of the same is crucial for accessing the efficiency of UHPC. The same is carried out and the results as obtained below.

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Table.1. Compressive strength of design mix exposed to elevated temperature

	Compressive strength in KN/m³					
Temp. in °C	**UHPC_1**	**UHPC_2**	**UHPC_3**	**UHPC_4**	**UHPC_5**	**UHPC_6**
30	112.3	123.63	121.77	97.6	116.99	109.51
50	80.7	98.6	100.3	70.87	93.4	85.7
100	56.04	77.34	81.8	49.75	72.56	68.04
200	-	63.47	68.9	-	54.18	48.56
300	-	-	54.2	-	-	37.82
400	-	-	-	-	-	29.43

Table.2. Final design mix adopted from the literature

Proportions	UHPC_1	UHPC_2	UHPC_3	UHPC_4	UHPC_5	UHPC_6
Cement (kg/m³)	1050	950	950	900	840	840
M-Sand (kg/m³)	1100	1100	1100	1100	1100	1100
Silica fume (kg/m³)	268	268	268	268	268	268
Steel fiber (kg/m³)	-	190	170	-	168	151
Polypropylene fiber (kg/m³)	-	-	19	-	-	16.8
Lime stone powder (kg/m³)	-	-	-	190	190	190
Sugarcane bagasse ash (kg/m³)	-	-	-	95	95	95
Water (kg/m³)	210	190	190	180	168	168

CONCLUSION:

1. The ultimate compressive strength achieved in the considered mix designs is 123.63 MPa for the design mix UHPC_2. The UHPC_2 was prepared using only steel fibres.
2. The optimum percentage of steel fibre adopted in UHPC_2 is 20% by weight of cement.
3. The ultimate compressive strength achieved in UHPC with hybrid fibre was 121.77 MPa (UHPC_3) and this mix contained 18% steel fibre and 2% polypropylene fibre.
4. The ultimate compressive strength achieved in UHPC_5 with limestone and sugarcane bagasse ash is 116.99 MPa and the mix consists of steel fibres of 20% by weight of cement.

In this study on the distinctive features of UHPC. The unique properties of UHPC have several advantages over normal strength concrete (NSC) owing to its material ingredients and composition. The key factor in producing UHPC is to improve the micro and macro properties of its mixture constituents to ensure mechanical homogeneity and denser particle packing. UHPC yields high compressive strength (i.e. [150 MPa] (22 ksi)) due to its improved internal micro- and macrostructure, leading to denser concrete. The application of thermal curing further densifies UHPC, which results in higher compressive strength properties. The typical heat treatment applied for UHPC is 90–400 C (194–752 F) for 2–6 days. The specimen size significantly affects the measured compressive strength of UHPC. Smaller size specimens can be used if the test machine capacity is limited.

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