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ORIGINAL CONTRIBUTION

Investigating the Strength Against Fire and Microstructure of Ultra-High-Performance Concrete

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***Abstract*— This study aims to produce Ultra-High-Performance Concrete utilizing locally available material. The experimental study includes silica fume with rice husk ash in combination with steel fibers. Various trials were made using different volumes of local materials and steel fibers to produce UHPC. Different properties were evaluated, such as compressive strength, tensile strength, and Scanning Electron Microscopy (SEM). Results show that UHPC can be produced using locally available materials as both the properties were examined with and without heating at higher temperatures and providing satisfactory strength. SEM tests were also performed to evaluate the microstructural study of the ultra-high-performance concrete. SEM observations discovered that the transition zone between fine aggregates and the cement paste is improved by using silica.**

***Index Terms*— Concrete, Strength, Rice husk ash, UHPC, Fire resistance, SEM**

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I. INTRODUCTION

Producing Ultra-High-Performance concrete has become easier with the development of the latest plasticizing concrete admixtures and fine pozzolanic materials [1]. The materials extensively used in the manufacturing of UHPC are silica fumes, rice husk ash, fly ashes, and ground granulated blast furnace slag [2]. The estimated consumption of concrete is 12 billion per ton per year globally [3]. Except for water, humans consume a greater quantity of concrete. Due to the increase in the development of modern admixtures, this statement is true [4]. In the 20th century, concrete manufacturing changed because of the expansion in minerals and organic chemistry [5]. The induction of steel fibers in concrete has very positive outcomes on strength properties, flexure strength, and a huge impact on the durability of the concrete [6].

Ultra-High-Performance Fiber Reinforced Concrete (UHPFRC) is the latest development in modern research centers. Higher elastic limit, higher compressive strength, and high durability are the properties of this concrete. These properties of concrete are achieved by the induction of steel fibers into the concrete [7]. Back in the 1950s, a compressive strength of 5100 psi, when achieved, was considered higher strength whereas a compressive strength of 9500 psi was considered high-strength concrete and was used in high-rise buildings in the late 1980s [8]. The UHPC is the latest technology having a compressive strength of more than 17500 psi. This invention led to the building most economic sections in high-rise buildings [9]. The specialty of UHPC is that it has a very high packing density and has low water-to-cement ratio. Elimination of coarse aggregates results in a high packing density [10].

Silica fume is an essential component in the manufacturing of UHPC because of its extreme fineness and amorphous silica content [11]. Regarding the filler and pozzolanic effect, 25% of the silica content by the cement weight is ideally used [12]. Besides silica fumes and fly ashes, one possibility is rice husk ash. This material is an agricultural waste that can be obtained easily by burning rice husks [13]. After the research studies of the rice husk ash, it was discovered to be highly pozzolanic and an outstanding supplementary cementing material [13]. The addition of RHA shows improvement in compressive strength at later ages. Ultra-high-performance concrete is a type that is not too much different from regular concrete, but in UHPC, coarse aggregates are not utilized [14]. Compressive strength of an average of 22000psi is declared by the US Department of Transportation [15]. Different researchers have utilized the introduction of pozzolanic materials such as fly ashes and silica fumes, to produce UHPC and improve the durability of concrete. Utilizing fibers into the mix prevents the existing and upcoming cracks generated, ultimately increasing fracture toughness [16]. Including any fiber in the concrete mix does not enhance the compressive strength of the concrete, whereas the residual strength improves [17]. Waste materials are also utilized in the design mix of UHPC.

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It is examined that agriculture waste products were rice husk ash replacing silica fume in the blend to produce UHPC. Results showed a compressive strength of more than 22000 psi [18]. UHPC has a very low number of pores which helps resist chloride attacks or any other destructive substances [19].

The main objectives of this research work are

- To produce ultra-high-performance concrete
- To perform workability & strength of ultra-high performance concrete
- To perform microstructure analysis test of ultra-high performance concrete

II. METHOD AND MATERIAL

The detail of the experimental setup carried out in this research and the required materials utilized in this research for the production of UHPFRC is also explained in this section. To attain an ideal mix, a series of tests were conducted. Research work was carried out in 2 phases. In the 1st phase, an ideal blend was first achieved with the help of a locally manufactured mixer. For optimization, all the ingredients were used separately. Suitable content was selected for each dose, considering its strength and workability. The compressive test of the cubes and mini flow test were influential during the 1st phase. Several trials were conducted in the 1st phase of the research to determine the peak compressive strength and mini flow. After the ideal mix was obtained based on these trials, UHPFRC was obtained by mixing steel fibers in the 2nd phase of the research phase. Renewed and tough features of the concrete were evaluated. Flexural testing of beams, compressive testing of cubes, and SEM tests were conducted in the 2nd phase of the research work.

A. Mixture Design of UHPC

UHPC with water to binder ratio (w/b) of 0.18 and silica fume content of 20% to 25%, by mass of cementations materials, can obtain a satisfactory bond to steel fiber reinforcement and mechanical properties. Therefore, a UHPC mixture with a w/b of 0.18 and silica fume content of 25% was used in this study with a 15% replacement of cement with RHA. The SP dosage was fixed at 2% by the mass of the binder. To investigate the hybridization of short and long fiber reinforcements on quasi-static and dynamic properties of UHPC, a reference mixture with no fiber reinforcement and five mixtures with a single type of fiber reinforcement or hybrid fiber reinforcements at a total content of 2%, by volume of the concrete, were used.

B. Ingredients

Ultra-High-Performance concrete is produced using the following ingredients.

- Cement
- Quartz powder
- Rice Husk Ash
- Silica Fume
- Fine Sand
- Superplasticizers

The binder components of the blend are RHA, Silica fume, and Cement, while Quartz powder and sand are the aggregate components of the blend. Superplasticizers are added to the blend because the w/c ratio is maintained lower. The effects of coarse aggregates and fibers are also studied. A comprehensive explanation of the ingredients mentioned above is given in this section.

C. Silica Fume

Due to its unique nature and pozzolanic reactivity, it greatly influences the compressive strength and durability of the concrete [20].

- Due to its very minute particle size, it has an excellent filler effect packing between the cement grains, increasing the material's density.
- Many larger pores are eliminated.
- Using SF decreases the bleeding phenomenon, which ultimately reduces the dosage of HRWRA needed for the workability of concrete.

The use of silica fume in UHPC has many effects on the durability of the concrete, and the durability of concrete is studied from many different aspects such as scaling, freeze and thaw resistance, etc. Freeze and thaw resistance is greatly improved by adding silica fume content in the concrete while reducing scaling [21].

TABLE I
SILICA FUME'S CHEMICAL AND PHYSICAL PROPERTIES

S. No.	Property	Value
1	Specific surface	Minimum 17 cm^2/g
2	Moisture Content	Maximum 2.5%
3	Density	245 to 650 kg/m^3
4	LOI	Maximum 4%
5	SiO_2	Minimum 85%
6	Oversize percent retained on 45- um (325 sieve)	Maximum 5%

D. Cement

Compared to conventional concrete, cement is present in a greater ratio than other components as it is the basic binder of UHPC. Cement embraces the fine aggregate materials in the hard-bitten concrete together and counters with the mineral components. In this investigation study following type of cement was used. Cement having high silica content results in higher strength. Ordinary Portland Cement (OPC) manufactured by the Cherat cement factory is used during the experiments.

TABLE II
CHEMICAL AND PHYSICAL PROPERTIES OF OPC

S. No.	Chemical Property	Value	Physical Property	Value
1	Initial setting time (min)	153	Sulphur Trioxide (SO_3)	2.58
2	Final setting time (min)	235	Lime (CaO)	64.68
3	Density (g/cm^3)	3.18	Alumina (Al_2O_3)	4.95
4	Cement Type	Type 1	Silica (SiO_2)	20.22
5	Consistency (%)	28	Magnesia (MgO)	1.1
6	Compressive strength at 28 days (MPa)	46.01	Iron Oxide (Fe_2O_3)	4.05
7	Average particle diameter (um)	<31		

E. Aggregates

Fine and coarse aggregates act as stiff skeletons in regular concrete. At the paste and aggregate interface, cracks are created by applying force. Conclusions were made based on the experimental work that better mechanical properties can be achieved compared to normal concrete using coarser fine aggregates. Research has confirmed that concrete, excluding coarse aggregates, produces much higher compressive strength [22].

F. Quartz Powder

Powder Quartz was used for manufacturing of Ultra-High-Performance concrete. Quartz at ±22ºC remains inert and acts as a filler material. These fillers are present in two forms, i.e., as a byproduct and waste product [23]. The powder quartz is produced by crushing quartz into fine powder. The size ranges between 10um- 100um. A high temperature is required to activate these fillers, and these fillers help improve the packing density of the material [24, 25].

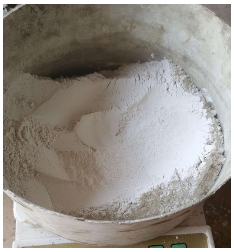

Fig. 1. Quartz Powder

TABLE III
COMPOSITION OF QUARTZ FILLERS

S. No.	Ingredients	Chemical Formula	Typical % by Weight	Physical Property	Value
1	Crystalline Silica (Quartz)	SiO_2	95.0-99.0	Appearance	White or tan sand; Sub angular grains crushed
2	Aluminum Oxide	Al_2O_3	< 0.8	Boiling Point	4046°F/2230°C
3	Titanium Oxide	TiO_2	< 0.1	Vapor Density (Air = 1)	None
4	Iron Oxide	Fe_2O_3	< 0.3	Solubility in water	Insoluble in water
5	N/A	N/A	N/A	Odor	None
6	N/A	N/A	N/A	Specific Gravity (water = 1)	2.65
7	N/A	N/A	N/A	Evaporation Rate (Butyl Acetate = 1)	None
8	N/A	N/A	N/A	Melting Point	3310°F/1710°C
9	N/A	N/A	N/A	Vapor Pressure (mm Hg)	None

G. Rice Husk Ash

RHA is a surplus of farming which is attained by burning rice husks. Many researchers have used RHA to develop UHPC as it contains greater unstructured silica content. RHA is replaced with silica fume to obtain better results regarding the compressive strength and durability of the concrete. RHA is abundant in numerous rice-farming nations, e.g., China, India, etc. When burned under appropriate conditions, RHA possessed very high pozzolanic reactivity as silica [13]. RHA is also a significant constituent in this research work for the manufacturing of UHPC.

Fig. 2. RHA Before and After Burning

H. Superplasticizers

This plays a vital role in the flow ability of concrete. Different ingredients in UHPC have features such as increasing the silica fume content decreases the workability of concrete. Therefore, superplasticizers are required for the improvement of the workability of UHPC. UHPC contains fine-graded materials, enhancing particle packing density [26]. Master Glenium ACE 30, a PCE-based superplasticizer, is used in this research work.

I. Steel Fibers

Steel fibers coated with copper were used for the manufacturing of UHPFRC. The steel fibers' length was 13 mm and a thickness of 0.3 mm. Ultra-high-performance concrete is normally made up of silica fume, quartz sand, OPC, HRWRA, and utilizing of steel fibers. Adding steel fibers into the concrete mix improves the durability and flexure strength of the concrete resisting cracking spread [27]. Steel fibers coated with copper were used for the manufacturing of UHPFRC. The steel fibers' length was 13 mm and a thickness of 0.3 mm. The figure shows the steel fibers used during trials.

Fig. 3. Steel Fibers

III. RESULTS AND DISCUSSION

Comparative research based on experimentation was performed to govern the viability of consuming different materials accessible locally as part of Reactive Powdered Concrete (RPC). Therefore, to determine the effectiveness of the concrete, it is important to research the different properties before concluding. The features examined in this study include:

1. Workability
2. Compressive Strength
3. Split Tensile Strength
4. Scanning Electron Microscope (SEM) Analysis

A. Workability

The ASTM C143 slump test determined the workability. According to the tests, the slump was 80mm.

Fig. 4. Slump Sample

B. Compressive Strength

The average compressive strength of the cylindrical samples produced by each mixture is listed in the tables below. Three samples of every one of the six different mixtures were tested to find complete results, and the average results were recorded. The compression strength was calculated after twenty-eight days of curing in water at room temperature with and without heating.

TABLE IV
COMPRESSIVE STRENGTH AFTER 28 DAYS OF CASTING WITHOUT HEATING

Compressive Strength fc´(Psi)				
Type of Concrete	C1	C2	C3	Average
UHSC	6035	6102	6177	6104

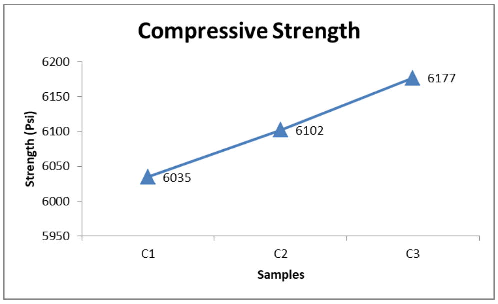

Fig. 5. Compressive Strength after 28 Days of Casting Without Heating

IV. DISCUSSION

RPC's compression strength is generally very strong, which can be related to removing coarse aggregates to increase RPC uniformity. It similarly involves high apparent intensity of the RPC combination of solid particles. The packing density of binder particles greatly influences the effectiveness of concrete mixtures. Since the RPC does not include aggregates, the void content of most of the particles in the paste is reduced, and a small quantity of H_2O is required to seal gaps among constituents; therefore, RPC strength is always high.

TABLE V
COMPRESSIVE STRENGTH AFTER 28 DAYS OF CASTING AFTER HEATING AT 300 °C

Compressive Strength fc´(Psi)				
Type of Concrete	C1	C2	C3	Average
UHSC	5812	5991	5735	5846

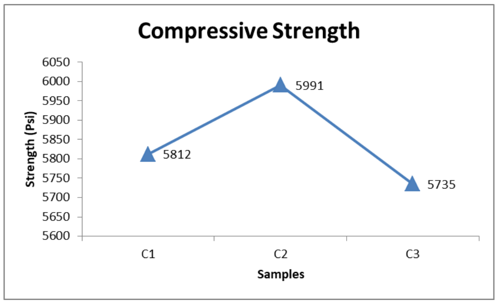

Fig. 6. Compressive Strength After 28 Days of Casting After Heating at 300 °C

TABLE VI
COMPRESSIVE STRENGTH AFTER 28 DAYS OF CASTING AFTER HEATING AT 600 °C

Compressive Strength fc´(Psi)				
Type of Concrete	C1	C2	C3	Average
UHSC	5232	5189	5202	5207

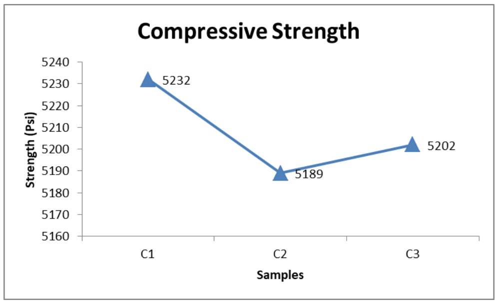

Fig. 7. Compressive Strength After 28 days of casting After Heating at 600 °C

A. Split Tensile strength

The final test conducted was checking the concrete samples' split tensile strength. The sample was put into the UTM machine with its vertical surface submitted to force. Each of the samples was measured for split tensile strength.

TABLE VII
SPLIT TENSILE STRENGTH AFTER 28 DAYS OF CASTING

Split Tensile Strength				
Type of Concrete	C1	C2	C3	Average
UHSC	875	887	855	872

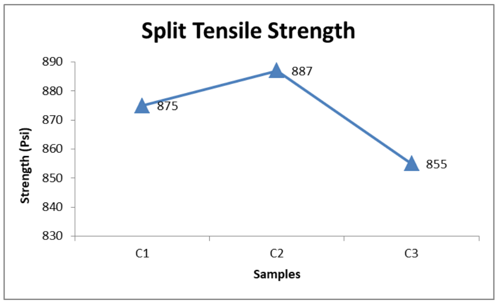

Fig. 8. Split Tensile Strength After 28 Days of Casting

TABLE VIII
SPLIT TENSILE STRENGTH AFTER 28 DAYS OF CASTING AFTER HEATING AT 300 °C

	Split Tensile strength			
Type of Concrete	C1	C2	C3	Average
UHSC	643	648	664	651

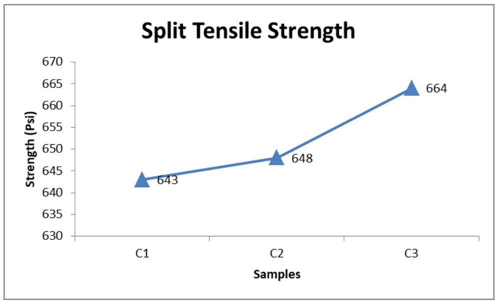

Fig. 9. Split Tensile Strength After 28 Days of Casting After Heating at 300 °C

TABLE IX
SPLIT TENSILE STRENGTH AFTER 28 DAYS OF CASTING AFTER HEATING AT 600 °C

	Split Tensile strength			
Type of Concrete	C1	C2	C3	Average
UHSC	575	587	589	583

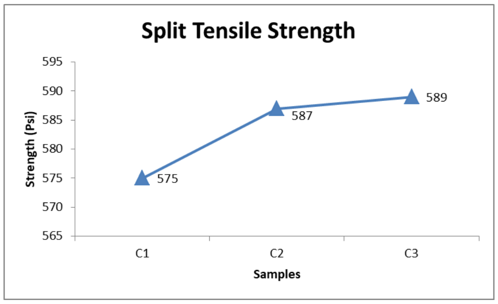

Fig. 10. Split Tensile strength after 28 days of casting after heating at 600 °C

B. Scanning Electron Microscopy (SEM)

The RPC microstructure was examined by scanning electron microscopy using a JEOL JSM-IT 100 utilizing electrons to create an image. SEM electron scanning beam is centered on the surface of the specimen to be studied. SEM study was performed using a 20 kV accelerated voltage. The SEM image is shown on the screen of the computer.

The intense packaging concentration of joining elements significantly influences the concrete mixture's performance. Because RPC does not involve coarse aggregates, the void content of the bulk particles in the paste is minimized. To fill the gaps between the particles, a small amount of water is needed; therefore, the RPC strength is always high. SEM observation can confirm fine RPC particles' uniformity and high packing density, as shown in Figure, where no clear Interfacial Transition Zone (ITZ) and small or no gaps are found. The matrix is more uniform.

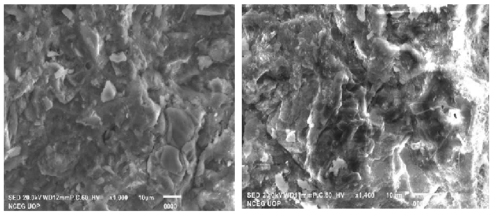

Fig. 11. RPC Sample Microstructure

Fig. 12. Gradation of Coarse Aggregate

CONCLUSION

The prime objective of this research was to develop UHPC using locally manufactured ingredients.

The current research was intended to analyze the impact of using RHA as a fractional substitution of cement in concrete blends. For this, 15% RHA was presented in cement blends. Also, the quartz powder was used as the aggregate component of the blend. Silica fume was used for 25% of the mass of cementing materials. Properties of the concrete mix, like its compressive and split tensile strength and microstructure, were evaluated at 28 days. The aftereffects of these experiential examinations have been dissected, and the significant findings of this investigation are introduced as follows.

- The compressive strength of the 3 concrete samples was observed at room temperature and heating at 300 and 600 C, which was 6104, 5846, and 5207 psi, respectively. Steel fibers and superplasticizer were used in the blend because steel fibers provide ductility to concrete, and while RHA and steel fibers diminish concrete workability, superplasticizer helps the concrete to be flowable and easy to work with.
- Concrete tensile strength is around 14–15% of its compressive strength. Adding steel fibers with superplasticizer in concrete, in which cement is replaced with RHA in different percentages, improved concrete tensile strength remarkably compared to concrete compressive strength.
- 15% replacement of cement with RHA was considered good, as it did not affect concrete much, and introducing steel fibers and admixtures like superplasticizers can make concrete a more economically viable option for the construction industry.

- The reason for attaining such a high strength is due to the filler action of the quartz powder and low water cement ratio.
- Observations of the scanning electron microscopy analysis revealed that the silica fume improved the transition zone between fine aggregates and the cement paste.

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