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Organization of Islamic Cooperation (OIC)
Board Bazar, Gazipur, Bangladesh.

Influence of Jute Fiber inclusion on the properties of UHPC

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A THESIS SUBMITTED FOR THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELORS OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

ISLAMIC UNIVERSITY OF TECHNOLOGY

2024

PROJECT APPROVAL

This is to certify that the thesis entitled "Influence of Jute Fiber inclusion on the properties of UHPC" submitted by Md. Tanjim Shahriar, Rafiur Rahman Sohan and Md. Abrar chowdhury has been approved as partial fulfillment of the requirement for the Degree, Bachelor of Science in Civil Engineering at Islamic University of Technology (IUT).

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DECLARATION

We hereby declare that the undergraduate research work presented in this thesis has been conducted by Md. Tanjim Shahriar, Rafiur Rahman Sohan and Md. Abrar Chowdhury under the guidance and supervision of Assistant Professor Dr. Tanvir Ahmed. We assure you that the findings and conclusion presented in this work are the result of our own investigation and have not been duplicated or submitted previously for any other purpose.

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DEDICATION

We would like to highlight that the completion of this study is dedicated to our parents, who over time assisted us by the means of time support and labor so that we can achieve what we wish to. They have inspired us to develop ourselves and supported us wherever they could, enabling us to pursue our technical goals without ever looking back.

We also want to convey our sincere appreciation to Dr. Tanvir Ahmed, our esteemed supervisor, for his continuous encouragement and motivation. Without his consistent upliftment, this endeavor would have not been possible.

ACKNOWLEDGEMENT

"In the name of Allah, Most Gracious, Most Merciful"

Our gratitude is to Almighty Allah for blessing us with a chance to complete this thesis and for enabling us in resolving issues that emerged throughout our project work. We would like to express our sincere appreciation to our supervisor, Dr. Tanvir Ahmed, Assistant Professor, Department of Civil and Environmental Engineering, Islamic University of Technology, for his kind supervision, helpful advice, and continuous support. His creative and technical guidance was essential to the success of this research project. The paper would never have been completed without his help and direction.

Furthermore, we have our mindful gratitude to all the faculty members for their meaningful recommendations throughout this thesis work. We would like to express our gratitude to the Lab Instructors for their assistance and support.

ABSTRACT

This study investigates the influence of jute fiber inclusion on the properties of Ultra-High Performance Concrete (UHPC). UHPC is renowned for its superior mechanical properties and durability, but its high cost and environmental impact necessitate exploration of sustainable and cost-effective reinforcement alternatives. Jute fiber, a natural, biodegradable, and abundantly available material, was incorporated into UHPC mixtures at varying percentages of 0%, 0.25%, 0.5%, 0.75% and 1% by volume. The mechanical properties is determined by compressive strength and durability aspects are determined by water absorption, Sorptivity, and Shrinkage test. Results indicate that the inclusion of jute fibers significantly enhances the tensile and flexural strengths of UHPC while maintaining its high compressive strength. Furthermore, the addition of jute fibers improves the material's durability by reducing water absorption and porosity, thereby increasing its resistance to environmental degradation. These findings suggest that jute fiber is a viable eco-friendly reinforcement material for UHPC, potentially leading to more sustainable construction practices without compromising performance.

Keywords: Jute Fiber, Packing Density, Sorptivity, Ultra- High Performance Concrete.

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CHAPTER 1: INTRODUCTION

1.1 General

Ultra-high performance concrete (UHPC) stands out in civil engineering for its remarkable strength, durability, and workability, making it an ideal option for numerous infrastructure projects. Its development and application in bridge engineering have been the focus of extensive research, with scientists investigating various techniques to further improve its performance. Jute fiber, a natural, biodegradable, and abundantly available material, was incorporated into UHPC mixtures to improve its tensile and flexural strength while maintaining its high compressive strength. Jute fibers improved strength and durability aspect but decreased the fluidity of concrete in a similar way to synthetic fibers(Ahmad, J., Arbili, M. M., Majdi, A., Althoey, F., Deifalla, A. F., & Rahmawati, C). The fiber length and volume showed a positive influence on hardened concrete properties at early and extended curing ages, respectively(Islam, M. S., & Ahmed, S. J). Sand mining, a major global industry, has significant environmental consequences.(The environmental impacts of river sand mining, 2022) . Incorporating different proportions of jute fibers into UHPC, to assess their impact on compressive strength, tensile strength, flexural strength, and durability. The inclusion of jute fibers in UHPC could potentially improve its mechanical performance, reduce environmental impact, and contribute to the development greener construction materials. The findings of this research will contribute to the understanding of how natural fibers like jute can be utilized to enhance UHPC, paving the way for more sustainable and efficient construction practices. Through this investigation, the potential for jute fiber-reinforced UHPC to revolutionize the construction industry will be explored, offering insights into new possibilities for environmentally friendly and high-performance building materials.

1.2 Background of the study

The development of Ultra-High Performance Concrete (UHPC) represents a leap forward in the realm of construction materials. Characterized by its high compressive strength, superior durability, and enhanced workability, UHPC is an advanced form of concrete that addresses many of the limitations inherent in traditional concrete(Islam, A., & Ahmed, S. F. (2018). UHPC achieve compressive strengths exceeding 120 MPa and exhibit remarkable durability(Ullah, R., Yuan, Q., Ahmad, J., Vatin, N., & El-Shorbagy, M. A. (2022). Historically, fibers such as steel, glass, and synthetic materials have been used to improve various properties of concrete, including its tensile strength and crack resistance. However, the focus has shifted towards the use of natural fibers, driven by the growing emphasis on sustainability and environmental impact. Natural fibers, such as jute, coir, and sisal, offer several advantages: they are renewable, biodegradable, and often have a lower environmental footprint compared to synthetic fibers. Jute is one of the most widely available natural fibers, primarily cultivated in regions such as South Asia. It is known for its high tensile strength, low cost, and biodegradable nature. These attributes make jute an attractive option for reinforcing concrete. The use of jute fibers can potentially enhance the mechanical properties of UHPC while also contributing to the reduction of environmental impacts associated with construction materials.

1.3 Objectives of the study

In this study, we tried to explore the possibility of using Jute as replacement of sand. The objectives of this study will be:

- Determine the impact of varying proportions of jute fiber on the compressive strength of UHPC.
- Compare the performance of jute fiber-reinforced UHPC with UHPC reinforced with other types of fibers, such as steel, glass, and synthetic fibers.
- Examine the influence of jute fibers on the workability and consistency of UHPC mixtures.
- Measure the density and porosity of jute fiber-reinforced UHPC.
- Study the effect of jute fibers on the shrinkage properties of UHPC.

1.4 Research Flow Diagram

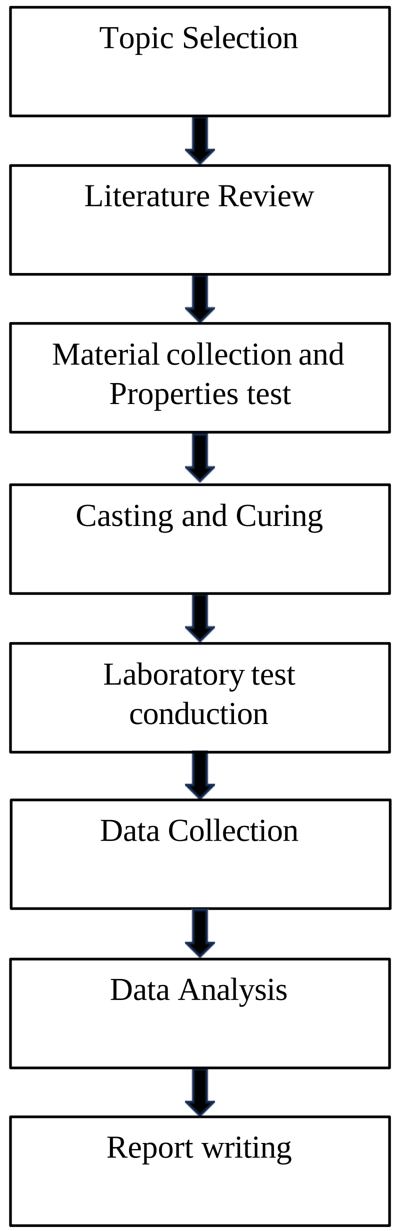

Figure 1.0.1 Research flow diagram

1.5 Layout of the thesis

The thesis consists of the following layout:

Chapter 1:

Introduction - The current chapter, that discusses about the theory, background, objectives, scope of the study and research flow diagram.

Chapter 2:

Literature Review - The chapter describes the related research in the field of our study by former authors and their findings.

Chapter 3:

Methodology - This chapter describes the procedures and steps that were followed to conduct our study.

Chapter 4:

Results and Discussion - Collected data and processing of the data, results were included in the chapter.

Chapter 5:

Conclusion and Recommendations - General discussion, limitations, recommendations and future scopes of work were discussed here.

CHAPTER 2: LITERATURE REVIEW

This chapter summarizes key studies and their important findings conducted by prominent researchers in the areas of UHPC, sand replacement and Jute Fiber.

Ahmad, J., Arbili, M. M., Majdi, A., Althoey, F., Deifalla, A. F., & Rahmawati, C.(2018) stated Jute fibers improved strength and durability aspect but decreased the fluidity of concrete in a similar way to synthetic fibers.

Huanghuang Huang , Xiaojian Gao , Le Teng (2016) examined Securing fiber alignment corresponding to the direction of principal tensile stress can greatly enhance the mechanical performance, especially flexural and tensile properties of UHPC.

Islam, M. S., & Ahmed, S. J said The results obtained from factorial analysis demonstrated that the fiber length and volume showed a positive influence on hardened concrete properties at early and extended curing ages, respectively.

Jian Yang , Baochun Chen , Jiazhan Su , Gang Xu , Dong Zhang , Jialiang Zhou (2018) stated Understanding the effects of various fibers on the mechanical properties of UHPC, focus on the straight steel fibers but involving also deformed steel fibers, non-steel fibers as well as hybrid fibers.

Zemei Wu , Kamal Henri Khayat , Caijun Shi (2017) said about Fiber shaping and matrix composition affect fiber pullout behavior and flexural properties of UHPC. And stated The use of steel fiber is essential to secure high strength and ductility in producing ultra-high performance concrete (UHPC).

Zemei Wu , Caijun Shi a, Wen He , Dehui Wang(2019) stated about Static and dynamic compressive properties of ultra-high performance concrete (UHPC) with hybrid steel fiber reinforcements. And their Test results indicated that UHPC with 1.5% long fiber reinforcements and 0.5% short fiber reinforcements demonstrated the best static and dynamic mechanical properties.

Huanghuang Huang , Xiaojian Gao, Kamal H. Khayat , Anshuang Su(2021) reported about Influence of fiber alignment and length on flexural properties of UHPC. And stated that Test results indicate that the longest fiber had approximately 5- and 27 time greater pullout load and pullout energy than those of the shortest fiber.

Mitsuo Ozawa , Sirjana Subedi Parajuli , Yuichi Uchida , Bo Zhou stated about Preventive effects of polypropylene and jute fibers on spalling of UHPC at high temperatures in combination with waste porous ceramic fine aggregate as an internal curing material. The key finding here is The use of ultra-high performance concrete (UHPC) with internal curing (IC) increases composite strength but increases the risk of spalling under high temperatures.

The studies reviewed focus on natural fibers like Jute Fiber, a natural, biodegradable and available material, was incorporated into UHPC mixtures. Key findings suggest natural fibers are promising alternatives for replacement of sand. The Jute Fiber is also plays a relevance in point of view of Bangladesh. It is cheap, easy to access. Inclusion of jute fibers significantly enhances the tensile and flexural strengths of UHPC while maintaining its high compressive strength.

CHAPTER 3: METHODOLOGY

3.1 General

This chapter outlines the experimental methodology of the study. It details the concrete mixture proportions, the specific cases examined, the collection and preparation of materials, the testing methods and standards for constituent materials, the preparation of testing samples, the curing methods, and the various testing procedures employed to evaluate the mechanical and durability properties of Ultra-High Performance Concrete (UHPC).Collection of Materials.

3.2 Collection of Materials

To make concrete mixtures, natural river sand was used that was collected from Durgapur. CEM Type 1 (OPC) and CEM Type II A-M as per BDS EN 197 [80%-94% clinker plus 6%-2-% mineral admixture and 5% gypsum] and silica fume were used as binding materials which were sourced from local manufacturer. The Jute Fiber used in this study was collected from a Local Market in Gazipur. As admixture, two admixtures were tried out to find the appropriate one. The admixtures were sourced from local manufacturer company.

3.3 Material Properties

The material properties were examined in the laboratory before casting according to proper specifications. The aggregates that were used in this study were tested for specific gravity, absorption capacity, gradation and unit weight. The specifications followed are stated in **Table 3.1**.

Table 3.1 Specification followed for testing material properties

Name of the Property Evaluated	Specification/Guideline Followed
Specific Gravity	ASTM C 128 (for fine aggregates) ASTM C 188 (for cement, silica fume and Jute Fiber)
Absorption Capacity	ASTM C 128
Unit Weight	ASTM C 29
Gradation	ASTM C 136

Fine Aggregates

In this study, four types of natural river sands were utilized as fine aggregates. To obtain the finest sand for concrete casting, the natural sands were sieved through 450-micron and 600-micron sieves. Based on the results of the compressive strength test, the natural river sand from Durgapur that passed through the 600-micron sieve was selected for the main concrete mixes. Figure 3.1 displays the comparison of sand gradation, while Table 3.2 presents the material properties of the sands used in this study.

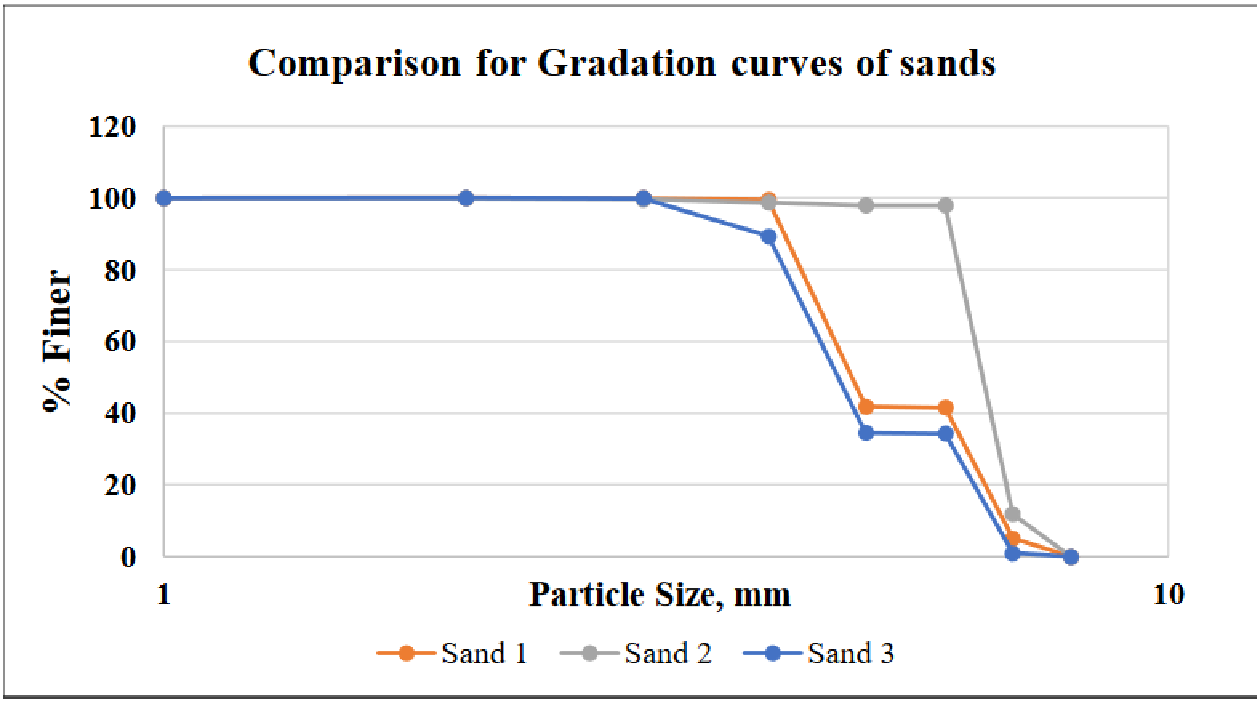

Figure 3.0.1 Comparison for Gradation curves of Sands

Table 3.2 Properties of Fine aggregate

Aggregate Type	Bulk (SSD) Specific Gravity	Absorption Capacity (%)	SSD Unit Weight (kg/m^3)
Natural River Sand 1	2.54	1.98	
Natural River Sand 2	2.58	1.98	
Natural River Sand 3	2.63	1.98	

3.3.1 Binder Material

In this study, as binding materials, CEM Type I (Ordinary Portland Cement) and CEM Type II A- M and silica fume were used. The composition of the mineral properties of cements and the specific gravity of the cementitious materials are given in **Table 3.3** and **Table 3.4** respectively.

Table 3.3 Mineral Composition of CEM Type I and CEM Type II A-M

Binder Type	Clinker	Mineral Admixture	Gypsum
CEM Type I	95-100%	0%	0-5%
CEM Type II A-M	80-94%	6-20%	0-5%

Table 3.4 Specific Gravity of Cementitious Materials

	CEM Type I	CEM Type II A-M	Silica Fume	Jute Fiber
Specific Gravity	3.15	2.90	2.25	1.3

3.3.1 Jute Fiber

For this study, Jute Fiber was used as a replacement for sand in the mixes of UHPC. Jute Fiber used in this study was collected from local market in Gazipur and before replacing with sand the specific gravity was measured which is specified in Table 3.4. To reduce the hydrophilic character of jute fiber chemical treatment of fibers is required and alkali treatment of jute fibers was carried out in this study. The cut fibers 10 mm, 15 mm were immersed in 5% (w/v) NaOH solution for 48 hours at room temperature. The treated fibers were then washed several times with water and air dried at room temperature.

Figure 3.3.2: Jute Fiber Treatment

3.3.2 Water

For mixing of concrete and curing of the concrete specimens, water was used in this study that had a unit weight of 1000 kg/m^3. The water was not polluted and free from any kinds of detrimental contaminants.

3.3.3 Admixture

In this study, two admixtures were tried in the trial mixes to find the suitable one for the control mix of UHPC. AURAMIX 500 and ARMIX Emmecrete PC 10 are the two admixtures that were used for this study. The properties of the admixtures are stated in **Table 3.5** and **Table3.6**.

Table 3.5 Properties of AURAMIX 500

Admixture Name	Chemical Type	Polycarboxylic Ether Polymer
AURAMIX 500	pH	Minimum 6.0
	Appearance	Light yellow colored liquid
	Volumetric mass at 20^0 C	1.1 ± 0.02 kg/litre
	Alkali Content	Typically less than 1.5 g Na_2O equivalent/ litre of admixture

Table 3.6 Properties of ARMIX Emmecrete PC 10

Admixture Name	Chemical Type	Polycarboxylic Ether Polymer
ARMIX Emmecrete PC 10	pH	Minimum 6.0
	Appearance	Clear to light brown liquid
	Chloride Content	Nil

3.4 Trial Mixes

The definition of Ultra-High Performance Concrete (UHPC) may be broadly defined as a cementitious, composite material that has enhanced strength, durability and tensile ductility compared to High Performance Concretes (HPC). UHPC frequently uses fibers for post-cracking ductility, have specified compressive strength of at least 120 MPa at 28 days, and are formulated with a modified multi-scale particle packing of inorganic materials of less than 0.6 mm diameter (larger sizes can be used). [Canadian Standards Association CSA A23.1/2 Annex S on Ultra-High Performance Concrete, Rexdale, ON, Canada 2018 (Draft)]. So, to achieve strength of more than 120 MPa, a total of 8 trial mixes were conducted to find the control mix. The test specimens were cubic in shape (25 mm x 25 mm x 25mm). Potable water was used for mixing the concrete mixes. CEM Type I and CEM Type II A-M were used to find the suitable one for the control mix. In the second trial, CEM Type I showed better results due to being finer than CEM Type II A-M. So later on, the trial mixes were conducted with CEM Type I. A total of 4 sands were tried to find the control mix. The Sand 1 is natural river sand passed through 450 µm sieve. Sand 2 is natural sand passed through 600 µm sieve. Sand 3 is natural river sand collected from Durgapur and passed through 2.3 mm sieve and Sand 4 is the same sand but passed through 600 µm sieve. Two superplasticizers were used in these cases and AURAMIX 500 showed better results. The compressive strength test was conducted at 7 and 28 days to find the control mix. A mixture of water curing and thermal curing was conducted. Specimens were dissolved in water for 72 hours at room temperature and then shifted to oven at 70^0 C and kept for 96 hours for thermal curing. The compressive strength enhanced when the specimens were cured through this mixed curing process. The mix design of the trial mixes is shown in **Table 3.7** and **Table 3.8**.

Table 3.7 Mixture proportions of Trials Mixes (1-4)

	Type of Content	$C_2WB_{20}SP_1$	$C_1WB_{29}SP_1$	$C_1WB_{24}SP_2$	$C_1WB_{17}SP_2$
Unit contents (kg/m^3)	CEM Type I		823	861	938
	CEM Type II A-M	923			
	Silica Fume	231	206	215	234
	Sand 1	969	905		
	Sand 2			904	986
	Sand 3				
	Sand 4				
	Water	221	291	241	186
	SP 1 (ARMIX E.PC 10)	15	12		
	SP 2 (AURAMIX 500)			36	45

Table 3.8 Mixture proportions of Trial Mixes (5-8)

	Type of Content	$C_1WB_{18}SP_2$	$C_1WB_{18}SP_2$	$C_1WB_{24}SP_2$	$C_1WB_{17}SP_2$
Unit contents (kg/m^3)	CEM Type I	921	921	861	932
	CEM Type II A-M				
	Silica Fume	231	230	215	233
	Sand 1				
	Sand 2				
	Sand 3	967		904	
	Sand 4		967		978
	Water	181	181	241	173
	SP 1 (ARMIX E.PC 10)				
	SP 2 (AURAMIX 500)	46	46	36	47

3.5 Jute Replacement Mixes

After investigating 8 trial mixes, the maximum compressive strength was found for the mix ratio of $C_1WB_{17}SP_2$. In this case, the water to binder ratio was 0.17 and the cement used was CEM Type I. AURAMIX 500 superplasticizer was used in this mix. For this case, the mixture of water curing and thermal curing was used where the cubic specimens were first cured in water for 72 hours and then shifted to oven for thermal curing under 70^0 C for 96 hours. Considering higher strength compared to all other trial mixes, $C_1WB_{17}SP_2$ was recognized as the **"control mix"** for the study. Subsequently, replacement mixes were introduced. In this study, different percentages of sand replacement were tried to examine the effect of Jute Fiber on the mechanical and durability

Properties of UHPC. In this experimental study, sand was replaced by Jute Fiber in proportions of 0.25%, 0.5%, 0.75%, and 1% by volume of the sand in the control mix. The proportions of the replacement mixes are shown in **Table 3.9**.

Table 3.9 Mixture proportions of JF replacement mixes

	Type of Content	JF_0	$JF_{0.25}$	$JF_{0.5}$	$JF_{0.75}$	JF_1
Unit contents (kg/m^3)	CEM Type I	921	872	872	872	872
	Silica Fume	231	218	218	218	218
	Sand 4	967	957	954	952	949
	JF	0	1	1	4	5
	Water	181	231	231	231	231
	SP 2 (AURAMIX 500)	46	33	33	33	33

3.6 Specimen Mold Preparation

Two varieties of samples were prepared for this research. One type was cube-shaped concrete specimens measuring 50 mm x 50 mm x 50 mm, while the other type was prism-shaped specimens measuring 25 mm x 25 mm x 285 mm. These molds are provided by the CEE Concrete Laboratory at the Islamic University of Technology. Prior to casting, the molds were made airtight by adjusting the screws provided and the inner surfaces were greased following ASTM C 31-03 guidelines. Images of the molds are depicted in the Figure.

Figure 3.0.4 Cubic Mold for UHPC Casting

Figure 3.0.5 Mold for Shrinkage testing specimens

3.7 Casting Procedure of UHPC

To cast UHPC specimens, an electrically driven mechanical mixer available in the Concrete Lab of Islamic University of Technology was used. The casting process began by placing the paddle and mixing bowl of the mixer in their fixed positions.

Initially, cement and silica fume were added to the mixing bowl and mixed at a slow speed (140 ± 5 r/min) for 90 seconds. Then, sand in saturated surface dry (SSD) condition was added and mixed at the same slow speed for another 90 seconds. Subsequently, water and superplasticizer were added and mixed at a moderate speed (285 ± 10 r/min) for 5 minutes. Finally, the mixer speed was increased to high until the mixture achieved standard workability. The entire mixing procedure typically took between 18 to 20 minutes.

After mixing, the concrete was transferred onto a non-absorbent sheet to facilitate the casting process concurrently

3.7.1 Molding of Concrete Cube Specimens

Cubic specimens were prepared according to ASTM C 109/109 M standards. Initially, a 25 mm thick layer of concrete was placed in each cube section. This layer was then tamped 16 times within approximately 10 seconds, using a non-absorbent wooden tamper, in four rounds. Each round was done at right angles to the previous one, with 8 adjacent strokes ensuring coverage of the specimen's surface. The tamping pressure was sufficient to ensure uniform mold filling. After tamping the first layer, the remaining space in the cubes was filled with the concrete mixture, and the same tamping method was repeated. The top surface of the cubes was then smoothened using the flat side of a trowel and leveled with a steel scale. The tamping sequence of the molds is illustrated in Figure 3.6.

1	2	3	4
12	11	10	9

ROUND 1 and 3

16	5
15	6
14	7
13	8

ROUND 2 and 4

Figure 3.0.6 Order of tamping of molds

3.7.2 Molding of Concrete Shrinkage Specimen

To measure the drying shrinkage of UHPC, shrinkage specimens were prepared. The control mix and the mixes with 0.25%, 0.5%, 0.75%, and 1% of sand replaced with jute fiber were tested for drying shrinkage. For each of the five cases, three prism specimens measuring 25 mm x 25 mm x 285 mm were cast, totaling 15 prisms for the study. The casting process adhered to ASTM C 490 specifications. Prior to molding, the outer joints of the molds, the contact line, and the base plate were sealed to prevent loss of mixing water from the specimens. Gauge studs were then fixed at the ends of the molds. For tamping, an initial layer of approximately 12.5 mm was cast and tamped using a non-absorbent tamper. A scale was used near the gauge stud areas to ensure an even distribution across the specimen. After tamping the first layer, the molds were filled with the remaining concrete, and the tamping method was repeated. The top layer was smoothened using the flat side of a trowel, and excess mixture was removed. Finally, a steel scale was used to level the top surface.

3.8 Curing of Specimens

The curing method followed in this study was a combination of water curing and thermal curing. After removing the cubes from the molds, the cube specimens were firstly placed in water for 72 hours in room temperature. After that, the specimens were then shifted to oven, where the cubic specimens undergo thermal curing in 70^0 C temperature for 96 hours. Then the specimens were finally removed from the oven and tested.

3.9 Conducted tests

3.9.1 Compressive Strength

Compressive strength refers to the maximum stress a concrete or mortar specimen can endure under axial loading. This parameter is essential because concrete and mortar are typically subjected to compressive stresses in most structural applications. In this study, the compressive strength of cubic concrete blocks with dimensions of 50 mm x 50 mm x 50 mm was tested in accordance with ASTM C 109 specifications..

3.9.2 Sorptivity measurement of UHPC

3.9.2.1 Sample Conditioning

The absorption of UHPC specimens was measured using the sorptivity coefficient according to ASTM C 1585-20 specifications. A specific method was employed for sample conditioning to determine the specimens' absorption. In this study, the specimens underwent a combination of water curing and thermal curing. During thermal curing, the test specimens were placed in an oven at 70°C for 96 hours to remove any free water present in the cubic specimens. After this, the test specimens were cooled and prepared for the next stage of testing.

3.9.2.2 Sample Preparation and Test Conduction

After completion of conditioning of the test samples, the 4 faces of the specimens were sealed using a duct tape keeping two sides exposed. Then, the top surface of the specimen was covered using plastic sheet and rubber band to ensure that no evaporation of water took place. Sample weight was measured in an air tight weight machine at specified time intervals described in ASTM C 1585-20 specification. The sorptivity coefficient was then determined using the following equations. The experimental setup is shown in **Figure 3.7**.

$$I = S_i + B \tag{3.1}$$

$$S_i = \frac{I}{\sqrt{t}} \tag{3.2}$$

$$I = \frac{m}{d \times A} \tag{3.3}$$

Here,

I = water absorption, mm

S_i = sorptivity coefficient, mm/$\sqrt{sec}$

t = time, sec

m= change in specimen mass in grams as a specific time, t

A = area of the exposed specimen in mm^2,

d = density of water in g/mm^3,

B = y- intercept of the best fitted line.

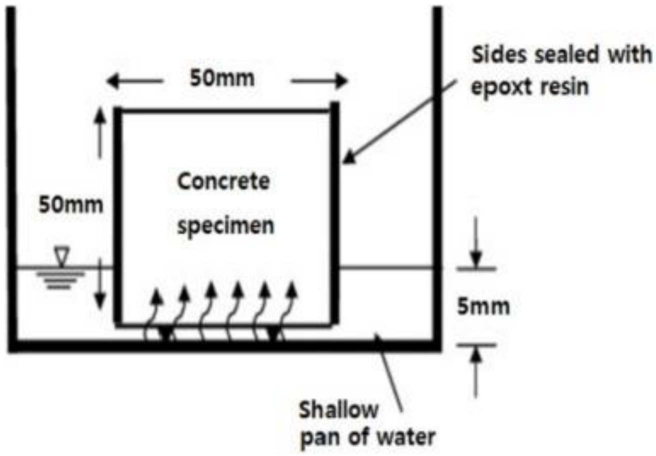

Figure 3.0.7 Setup for Soprtivity Coefficient Measurement as per ASTM 1585- 13

3.9.3 Drying Shrinkage of UHPC

The drying shrinkage for UHPC specimens were measured maintaining ASTM C 596-07 specification. For this test, prism shaped specimens were prepared with dimensions 25 mm x 25 mm x 285 mm as per ASTM C 490-07. At the end points of each prism bar, two gauge studs were fixed to measure the change in length of the specimens at pre-specified ages. The combination of water curing and thermal curing was used for the test specimens of drying shrinkage test. For each replacement cases, 3 prism specimens were prepared. The procedure of taking compactor reading of the specimens in shown in **Figure 3.8**.

Figure 3.0.8 Calibration of Compactor and taking the reading of change in length

CHAPTER 4: RESULT AND ANALYSIS

General

In this chapter, the results of the conducted tests are presented. Furthermore, the analysis of the findings of this study has also been mentioned. The analysis of the compressive strength of the trial mixes was carried out to find the control mix of the study. Afterwards, the test results and the analysis of the sand replacement mixes were also shown.

4.1 Compressive Strength Test

4.1.1 Trial Mix results and analysis

These trial mixes were designed to find an Ultra-High-Performance Concrete (UHPC) control mix that might serve as a standard for additional trials involving the partial replacement of sand with Jute Fibers. In order to identify the mixture that performs the best overall, this part analyzes the trial mixes according to the type of cement, the ratio of water to binder, and the type of sand. Figure 4.1 displays the compressive strength test results after 7 and 28 days.

4.1.1.1 Analysis of Cement Types

CEM Type II-AM was tested in C1WB29SP1 and C2WB20SP1 mixes. Comparatively speaking, the compressive strengths of these two combinations were lower. The cement's comparatively poor performance in UHPC applications, where greater early and long-term strengths are crucial, may be due to its composition, which is intended for moderate sulfate resistance. Most of the combinations used CEM Type I, which demonstrated better performance qualities. In general, mixtures containing CEM Type I exhibited superior overall characteristics and higher strength. Because of its greater early strength and endurance, CEM Type I performs better in the trial mixes and is hence more appropriate for UHPC.

4.1.1.2 Relation of W/B ratio with compressive strength of UHPC

One of the key elements in establishing the characteristics of UHPC is the water to binder (w/b) ratio. The w/b ratio range that was investigated by the trial mixes was 0.17 to 0.29. Blends with w/b ratios between 0.17 and 0.21 continuously performed better than blends with higher ratios. The concrete's mechanical qualities and durability are improved by the denser and more compact microstructure that results from the lower water content. Less pore space is produced by lower w/b ratios, which immediately improves strength and durability. Combinations having a greater w/b ratio (0.23-0.29) performed worse. The concrete matrix's pore space is increased by the increased water content, which lowers the material's density and overall strength. In UHPC applications, there is a notable trade-off between strength and durability, despite the fact that greater w/b ratios might enhance workability.

4.1.1.3 Evaluation of Sand types

Mixtures using sand that passed through a 425 µm sieve exhibited the poorest performance. The finer particles tend to increase water demand and may cause more shrinkage, which negatively affects the concrete's overall strength and durability. On the other hand, mixtures utilizing sand passed through a 600 µm sieve showed improved performance. The particle size distribution of 600 µm sand allows for denser packing and a more optimal particle arrangement, enhancing the mechanical properties of UHPC. This balance between particle size and surface area in 600 µm sand seems to create the best conditions for achieving high strength and durability. Additionally, some mixtures were tested with sand passed through a 2.3 mm sieve to evaluate the impact of coarser sand on UHPC. While the use of this coarser sand resulted in average strength, it was slightly lower than that achieved with 600 µm sand. The larger particle size can improve internal bonding and reduce shrinkage, thus enhancing the overall strength of UHPC. However, the best performance was still observed with 600 µm sand, likely due to better particle packing and reduced voids.

4.1.1.4 Assessment of admixtures and curing methods

During normal water curing, the UHPC specimens were submerged in water for 72 hours. This method was used with both ARMIX and AURAMIX admixtures. Although effective, normal water curing did not achieve the highest performance levels seen in the trial mixes. It provides sufficient moisture for hydration but may not support the rapid strength gain needed for UHPC. Subsequently, thermal curing was introduced, where the UHPC specimens were first cured in water for 72 hours, then placed in an oven at 70°C for 96 hours. This thermal curing method significantly improved the performance of the mixtures. The heat application accelerates the hydration process, resulting in faster strength gain and enhanced overall properties. Thermal curing was especially effective with the AURAMIX 500 admixture, which is designed to optimize performance under these conditions.

4.2.1.5 Conclusion

Based on the analysis, mix C1WB17SP2 was chosen as the control mix for replacing sand with Jute Fiber in UHPC. This mix, which includes CEM Type I cement, a water-to-binder ratio of 0.17, sand passing through a 600 µm sieve, and thermal curing with AURAMIX 505, achieved the highest compressive strength. It showcases the optimal balance of material properties and curing methods, making it the ideal candidate for further research on partially replacing sand with Jute Fiber. Future studies will focus on evaluating the performance of this control mix with different proportions of Jute Fiber, aiming to improve sustainability without compromising UHPC's exceptional properties.

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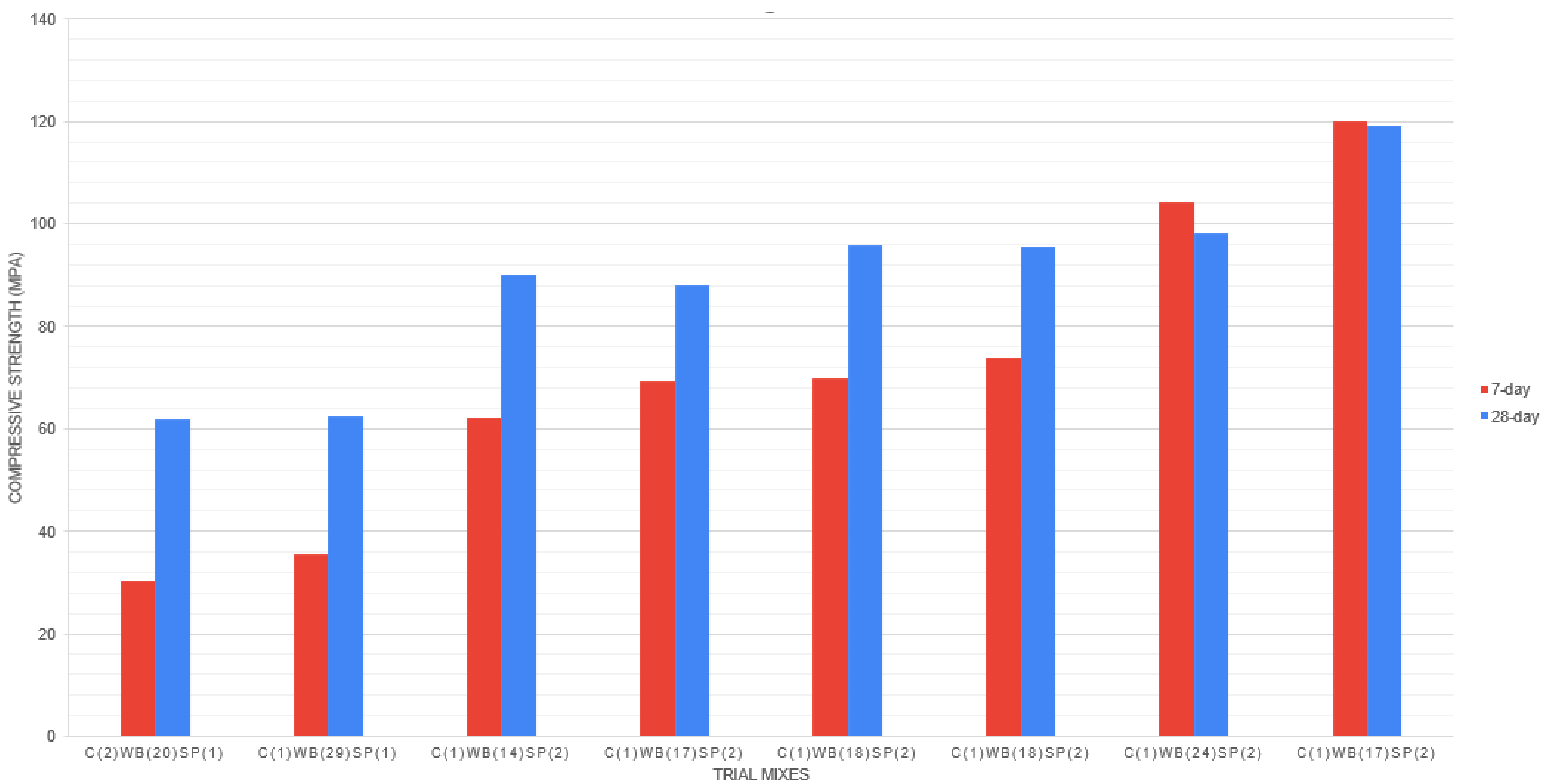


Figure 4.1 Compressive Strength Results of Trial Mixes

4.1.2 Analysis of Sand Replacement Percentages

0.25% and 0.5% Jute Fiber: Offers a balance between strength reduction and enhanced toughness. Suitable for applications where moderate fiber reinforcement is desired without compromising workability significantly.

0.75% and 1% Jute Fiber: Provides increased toughness and ductility but at the expense of substantial compressive strength. These higher percentages are suitable for specialized applications requiring superior impact resistance and energy absorption capabilities, with careful attention to mix design and casting procedures. **Figure 4.2**.

4.1.1.1 0.25% Sand Replacement

Compressive Strength: There is a slight to moderate reduction in compressive strength compared to plain UHPC. This reduction is typically due to challenges in achieving optimal bonding between fibers and the cement matrix, and potential issues with fiber distribution.

Toughness and Ductility: Improvement in toughness and ductility can be observed, which can enhance the ability of the concrete to resist cracking and absorb energy.

Workability: Minimal impact on workability compared to higher percentages. Proper mix design adjustments can maintain adequate workability.

4.1.1.2 0.5% Sand Replacement

Compressive Strength: Moderate to significant reduction in compressive strength compared to plain UHPC. Increasing the fiber content exacerbates challenges in achieving uniform distribution and strong bonding with the cement matrix.

Toughness and Ductility: Enhanced toughness and ductility compared to 0.25%, providing better resistance to cracking and improved energy absorption capacity.

Workability: Noticeable impact on workability, requiring careful attention to maintain consistency and proper compaction during casting.

4.1.1.3 0.75% Sand Replacement

Compressive Strength: Further reduction in compressive strength compared to 0.5%. The increase in fiber content continues to challenge the integrity of the cement matrix, affecting overall strength.
Toughness and Ductility: Continued improvement in toughness and ductility, which can be beneficial in applications where impact resistance and durability are critical.
Workability: Increased impact on workability compared to lower percentages. Thorough mix design adjustments are necessary to manage the mix effectively.

4.1.1.4 1% Sand Replacement

Compressive Strength: Significant reduction in compressive strength compared to lower percentages and plain UHPC. Achieving sufficient bonding and distribution becomes more difficult, leading to greater strength loss.
Toughness and Ductility: Maximum enhancement in toughness and ductility among the percentages considered. The concrete becomes more resilient to cracking and offers superior energy absorption capabilities.
Workability: Significant impact on workability, requiring meticulous adjustments and possibly specialized techniques to ensure proper compaction and placement.

4.1.1.5 Implications of Sand replacement with Jute Fiber in UHPC

The inclusion of jute fibers in Ultra-High Performance Concrete (UHPC) significantly impacts its microstructure and performance characteristics. Jute fibers, being elongated and organic, disrupt the optimal particle packing density of UHPC, leading to increased porosity and irregularities within the matrix. This disruption can slightly reduce compressive strength. However, the fibers enhance tensile strength, flexural strength, and ductility by effectively bridging micro-cracks and preventing crack propagation. The natural composition of jute fibers may also interact with the cementitious matrix, potentially altering the hydration process and affecting the formation of dense hydration products necessary for UHPC's high performance.

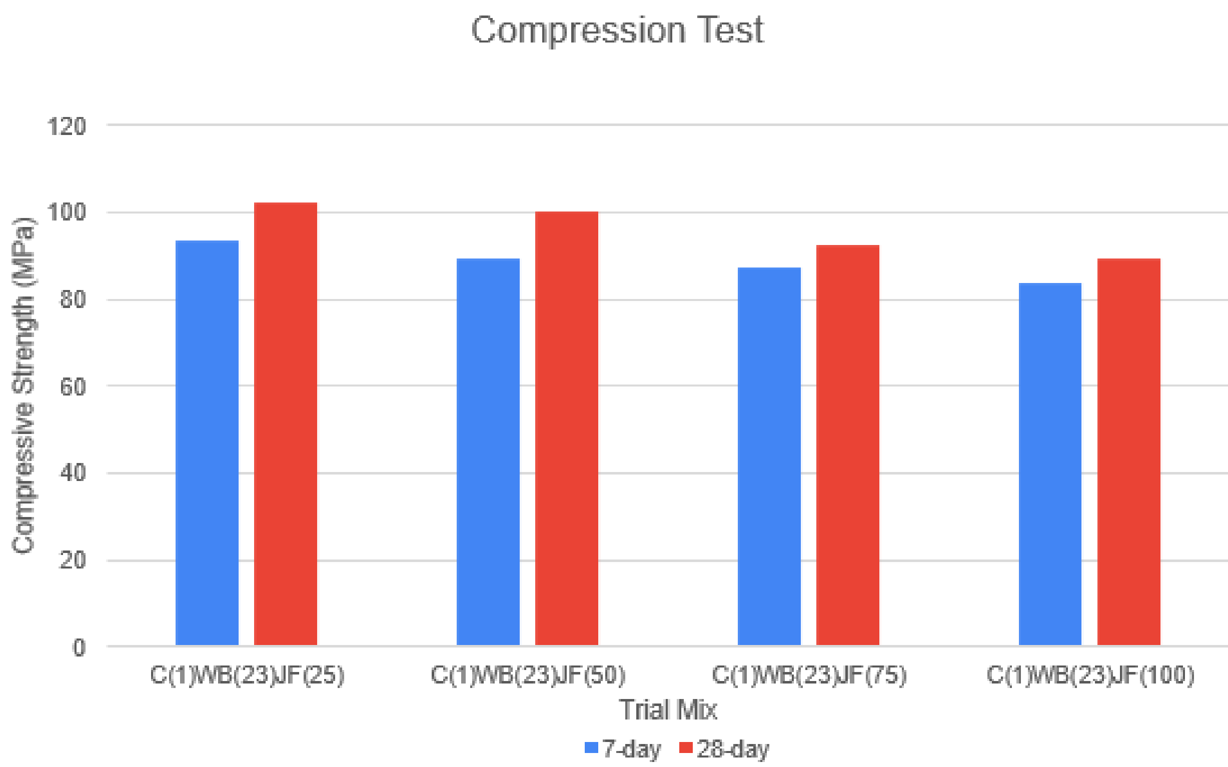


Figure 4.2 Compressive Strength Results of Trial Mixes with Jute Fiber

4.2 Sorptivity Test

Sorptivity measures the capacity of a material to absorb and transmit water through capillary action, which is a critical property for assessing the durability of concrete. In this study, the effect of partially replacing sand with Jute Fiber on sorptivity was investigated. The sorptivity coefficients for different percentages of sand replacement with Jute Fiber were compared to evaluate the impact on UHPC's capillary absorption. Four different replacement levels and the control mixture were tested: 0.25%, 0.5%, 0.75% and 1%.

4.2.1 Overview of the Sorptivity Co-efficient

4.2.1.1 Control Mix

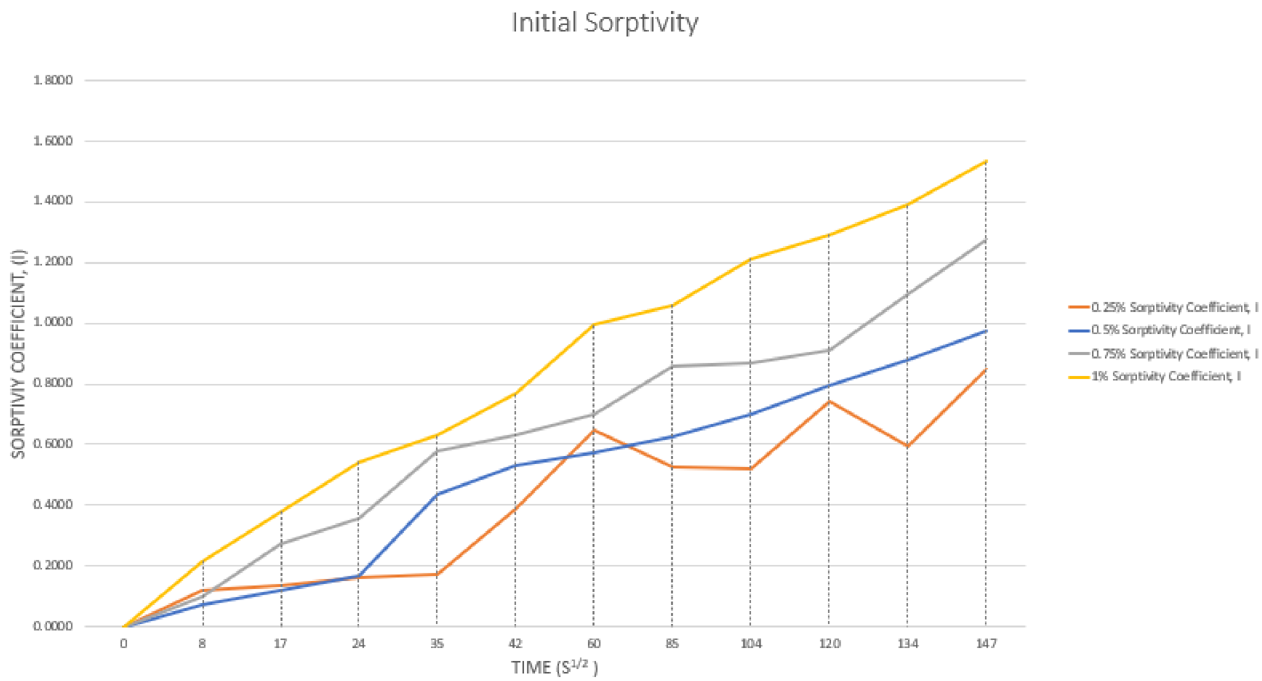
For the control mix with 0% jute fiber, the initial and secondary sorptivity coefficients provide a baseline. As jute fiber content increases, there are notable variations in these coefficients. At 0.25% fiber inclusion, there is a slight increase in both initial and secondary sorptivity, indicating an initial disruption in the capillary network due to the introduction of fibers. At 0.5% inclusion, the coefficients remain relatively stable, suggesting a minimal impact on the capillary network. At 0.75% inclusion, a slight reduction in both coefficients is observed, suggesting an optimal level where the benefits of fibers in reducing porosity begin to outweigh the initial disruption caused.

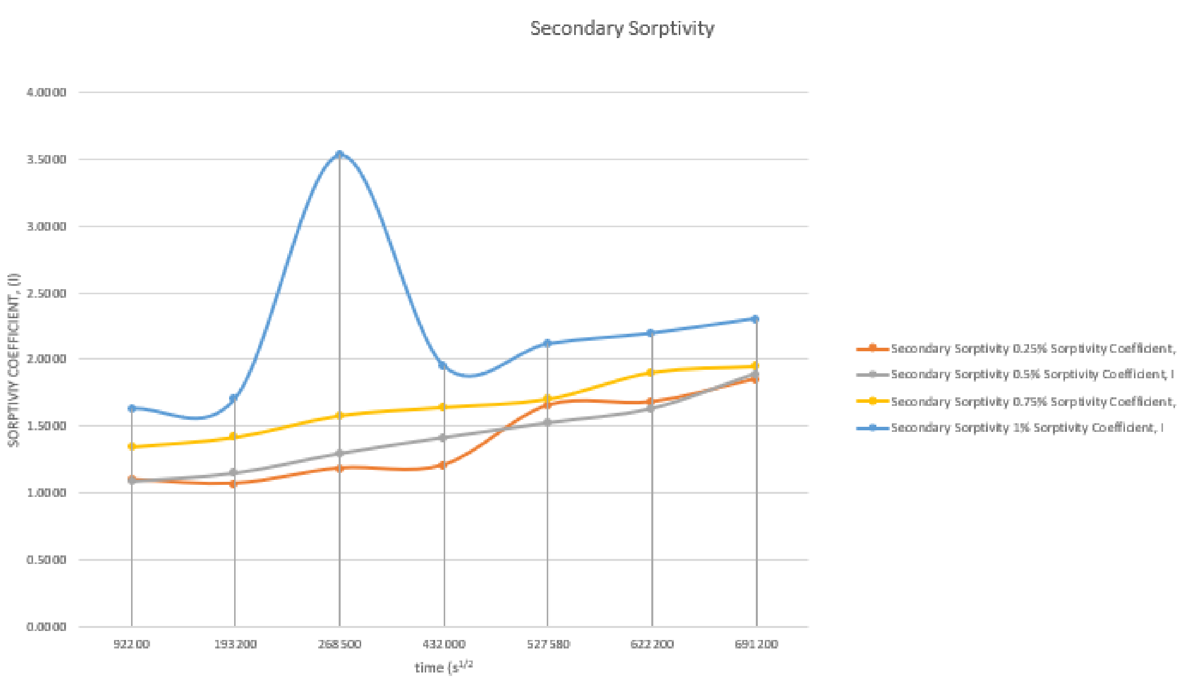
4.2.2 Analysis of Sorptivity Co-efficient Results

The variations in sorptivity coefficients can be attributed to several factors related to the inclusion of jute fibers in the UHPC matrix. Initially, the introduction of jute fibers at lower inclusion levels (0.25%) may increase porosity due to inadequate packing density and disruption of the existing pore structure, explaining the initial increase in sorptivity coefficients. However, as the inclusion level reaches 0.5%, the jute fibers seem to optimize the microstructure, reducing the overall porosity and thereby lowering the sorptivity coefficients. This indicates that there is an optimal inclusion level where the benefits of jute fibers in refining the pore structure and reducing capillary pathways are maximized.

At higher inclusion levels (0.75% and 1%), the sorptivity coefficients increase again. This can be attributed to the excessive presence of jute fibers, which may lead to a higher volume of unreacted particles and a less dense microstructure. The increased porosity at these levels facilitates greater capillary action, hence higher sorptivity. The increase in both initial and secondary sorptivity at the 1% inclusion level highlights the threshold beyond which the inclusion of jute fibers becomes detrimental to the capillary absorption properties of UHPC.

The secondary sorptivity, which reflects the longer-term water absorption capacity, shows similar trends. The optimal reduction at 0.5% inclusion indicates that jute fibers can positively impact the long-term durability of UHPC by reducing the rate at which water is absorbed over time. However, beyond this optimal point, the benefits diminish, and the sorptivity coefficients increase, suggesting compromised durability. In conclusion, the inclusion of jute fibers in UHPC can enhance the material's performance by reducing sorptivity, but only up to an optimal level. Beyond this level, the benefits diminish, and the risk of increased capillary absorption and reduced durability rises. These findings underscore the importance of precise mix design and optimization in the development of high-performance concretes incorporating natural fibers like jute. Further research is recommended to explore the long-term implications and to fine-tune the mix proportions for various practical applications.


Initial Sorptivity
1.8000
1.6000
1.4000
1.2000
1.0000
0.8000
0.6000
0.4000
0.2000
0.0000
SORPTIVIY COEFFICIENT, (I)
0
8
17
24
35
42
60
85
104
120
134
147
TIME ($S^{1/2}$)
0.25% Sorptivity Coefficient, I
0.5% Sorptivity Coefficient, I
0.75% Sorptivity Coefficient, I
1% Sorptivity Coefficient, I


Secondary Sorptivity
4.0000
3.5000
3.0000
2.5000
2.0000
1.5000
1.0000
0.5000
0.0000
SORPTIVIY COEFFICIENT, (I)
922 00
193 200
268 500
432 000
527 580
622 200
691 200
time ($s^{1/2}$
Secondary Sorptivity 0.25% Sorptivity Coefficient, I
Secondary Sorptivity 0.5% Sorptivity Coefficient, I
Secondary Sorptivity 0.75% Sorptivity Coefficient, I
Secondary Sorptivity 1% Sorptivity Coefficient, I

4.3 Drying Shrinkage for UHPC Specimen with Sand Replacement

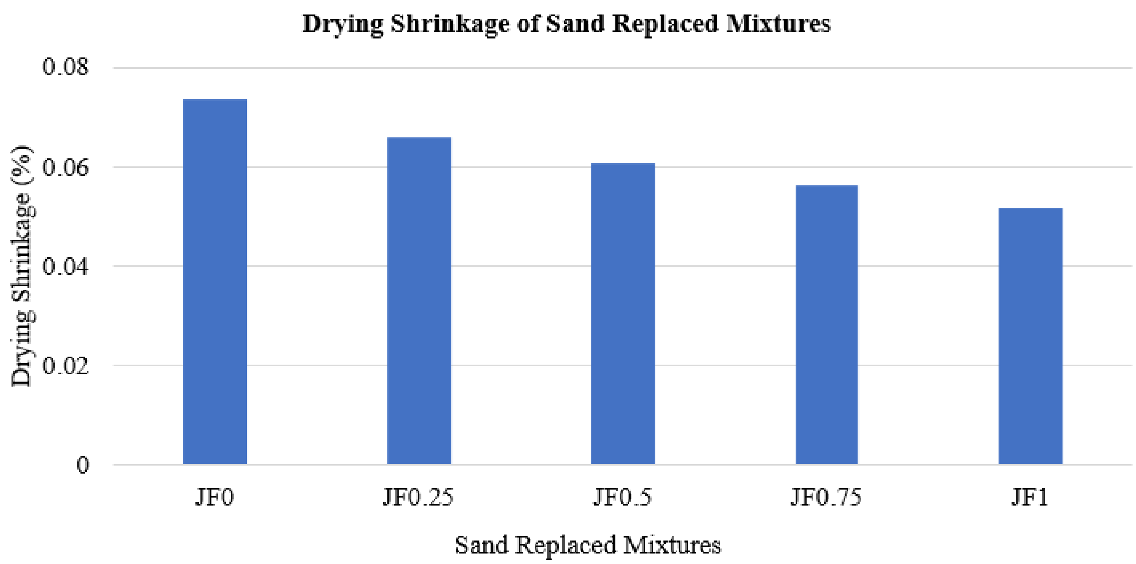
4.3.1 Overview:

The drying shrinkage of UHPC with varying percentages of jute fiber inclusion shows a noticeable trend of decreasing shrinkage. As the proportion of jute fibers increases, drying shrinkage correspondingly decreases, indicating that jute fibers positively affect the internal microstructure and moisture movement within the UHPC matrix.

Starting with the mixture containing no jute fiber inclusion, we observe the highest drying shrinkage. This baseline provides a reference point for comparing the effects of jute fiber inclusion. As jute fiber content increases to 0.25%, there is a notable decrease in drying shrinkage. This reduction can be attributed to the fibers' ability to bridge micro-cracks and reduce porosity, thereby limiting water movement and evaporation during the curing process. Further increments in jute fiber content to 0.5% and 0.75% continue this trend of decreasing drying shrinkage. The 0.5% inclusion level shows a further reduction, which can be linked to the cumulative effect of improved microstructure and the changes in the hydration products formed due to the presence of fibers. Jute fibers enhance the pore structure, making the matrix less susceptible to drying shrinkage as it loses moisture over time.

At the highest inclusion level of 1%, the drying shrinkage reaches its lowest point. This significant decrease highlights the beneficial impact of jute fiber content on the overall stability and dimensional integrity of UHPC. The high content of jute fibers leads to more effective bridging of micro-cracks and a denser cement matrix, thereby reducing moisture movement pathways and contributing to lower shrinkage rates.

Additionally, increasing the amount of jute fiber reduces the explosiveness of UHPC during failure. The confinement nature of the jute fibers helps to control and dissipate the energy release, preventing explosive spalling and enhancing the overall safety and performance of the concrete under stress.



CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Concluding Remarks

The study on the "Influence of Jute Fiber Inclusion on the Properties of Ultra-High Performance Concrete (UHPC)" has yielded significant insights into the role that natural fibers can play in enhancing the performance characteristics of UHPC. Through a comprehensive series of experiments and analyses, the following key conclusions have been drawn:

- **Mechanical Properties**: The inclusion of jute fibers in UHPC has been shown to improve several mechanical properties, including tensile strength, flexural strength, and impact resistance. The natural fibers help in bridging micro-cracks and delaying the propagation of cracks, thereby enhancing the material's toughness and ductility.
- **Compressive Strength**: While the compressive strength of UHPC generally remained high with the addition of jute fibers, there was a slight reduction compared to fiber-free UHPC. This trade-off is attributed to the slightly lower stiffness of jute fibers compared to synthetic alternatives. However, the overall performance remains within acceptable limits for most structural applications.
- **Durability**: Jute fibers have contributed positively to the durability aspects of UHPC. The fibers enhance resistance to shrinkage cracking and improve the overall integrity of the material under cyclic loading conditions. Additionally, the natural decay of jute fibers over time does not significantly impact the long-term strength and durability due to the high matrix strength of UHPC.
- **Environmental Impact**: The use of jute fibers, a renewable and biodegradable material, aligns with the goals of sustainability and reduced environmental footprint. The incorporation of natural fibers in UHPC not only enhances the mechanical properties but also supports eco-friendly construction practices.
- **Workability and Mixing**: The inclusion of jute fibers requires careful consideration of the mixing process to ensure even distribution and to avoid clumping. Adjustments in water content and superplasticizer dosage are necessary to maintain optimal workability and achieve a homogenous mix.

5.2 Recommendations

Based on the findings of this study, several recommendations are proposed for future research and practical applications:

- **Optimization of Fiber Content**: Further research is needed to determine the optimal content of jute fibers in UHPC to maximize mechanical and durability benefits while minimizing any adverse effects on workability and compressive strength.
- **Hybrid Fiber Systems**: Investigating the use of hybrid fiber systems that combine jute fibers with synthetic fibers could leverage the advantages of both types, potentially enhancing performance across a broader range of properties.
- **Long-Term Performance**: Long-term studies should be conducted to assess the durability and performance of jute fiber-reinforced UHPC under various environmental conditions, including exposure to moisture, freeze-thaw cycles, and chemical attack.
- **Manufacturing and Processing**: Improvements in the processing and treatment of jute fibers could enhance their performance in UHPC. Treatments to increase the fibers' tensile strength and durability could further improve the composite material's properties.
- **Field Applications**: Pilot projects and field applications of jute fiber-reinforced UHPC should be undertaken to validate laboratory findings and to address any practical challenges in real-world construction scenarios.
- **Sustainability Assessment**: Comprehensive life-cycle assessments should be performed to quantify the environmental benefits of using jute fibers in UHPC. This includes evaluating the carbon footprint, energy consumption, and overall sustainability impact compared to conventional UHPC.
- **Investigating ductility**: Understanding concrete's ability to deform without fracturing under tensile stress, crucial for structural performance under dynamic loading.
- **Exploring direct tensile strength**: Deeper insights into concrete behavior under direct tension, aiding in designing crack-resistant structures.
- **Examining flexural strength**: Insights into concrete's capacity to withstand bending forces, essential for applications like beams and slabs.
- **Assessing resistance to carbonation**: Shedding light on concrete's durability and long-term performance, especially in environments prone to carbon dioxide-induced degradation.

In conclusion, the inclusion of jute fibers in UHPC presents a promising approach to enhancing the material's properties while promoting sustainability. Continued research and development in this area are essential to fully realize the potential of natural fiber-reinforced UHPC in modern construction.

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