DEVELOPMENT AND IMPROVING OF ULTRA-HIGH-PERFORMANCE CONCRETE IN EGYPT

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ABSTRACT

This paper introduces the development of Ultra-High-Performance Concrete (UHPC), which is one of the most advanced types of concrete. The entire method relied solely on locally available resources. All mixes were prepared without any specialized mixer, procedures, or treatments, like elevated pressure and others.

The research aimed to develop the mechanical properties, and create cost-effective UHPC using local, and available resources with respect to sustainable building concepts that achieve accepted workability, compressive strength, tensile strength, and flexure strength. In addition to studying the impact of using corrugated steel fibers with varying steel fiber contents (0.4 %, 1 % ,2 %, and 4% by volume fraction), and investigating the (ductile-brittle) behavior of concrete. The results indicated that increasing the corrugated fibers [increasing the fiber volume] will reduce the workability of UHPC, and have an Unnoticeable improvement in compressive strength, however it has significant improvement in splitting tensile, and flexure strength. Ultra-high-performance concrete (UHPC) has much higher splitting tensile strength compared to normal-strength concrete, and high-strength concrete. Previous research on UHPC has mostly examined its direct tensile strength, with inadequate attention given to its splitting tensile strength. This study will give an experimental evaluation of UHPC's splitting tensile strength.

Keyword: - *Ultra-High-Performance Concrete, UHPC, Steel Fibers, Corrugated steel fibers.*

1. INTRODUCTION

Concrete is a brittle material that has high compressive strength, but low tensile strength, thus, reinforcement of concrete is required to allow it to handle tensile stresses [1], For this reason, scientists began searching for materials and methods to improve the tensile strength properties and durability of concrete, and one of the solutions is UHPC.

Ultra-high-performance concrete (UHPC) is defined as “concrete that has a minimum specified compressive strength of 150 MPa with specified durability tensile ductility and tough-ness requirements; fibers are generally included to achieve specified requirements”, as per ACI 239R-18 [2]. Commonly, the UHPC consists of cement, silica fume, fine quartz sand, high range water reducing admixtures, steel fibers, and low water to cementitious materials ranging from 0.15 to 0.35. It is possible to employ different mixture with different constituent materials such as coarse aggregate and admixtures to improve a specific property of concrete. The mechanical properties of UHPC include compressive strength higher than 120 MPa, and splitting tensile strength greater than 3.5 MPa. Ultra-high-performance concrete durability is considerably superior to that of conventional concrete since its pores are discontinuous. That is why this type of concrete is used in different civil engineering structures such as highway infrastructure applications, and structural rehabilitation [3].

2. AIM OF THE WORK

This work aims to prepare UHPC using available resources with minimum compressive strength of 100 MPa, and add corrugated steel fibers with varying steel fiber contents (0.4 %, 1 % ,2 %, and 4% by volume fraction) and compare them with each other, and with conventional concrete to investigate the improvement of mechanical properties, moreover, investigate the (ductile-brittle) behavior of concrete using standard cubes (150 x 150 x 150) mm for compressive strength, standard cylinders (150 mm diameter – 300 mm height) for splitting tensile strength, and standard beams (150 x 150 x 700) mm for flexure strength.

3. EXPERIMENTAL STUDY

3.1 MATERIALS

3.1.1 Cementitious Materials

The cementitious material used in all concrete mixtures is Ordinary Portland Cement (OPC) with (CEM I 52.5 N). It is produced by Bani-Suef cement company, which attains the requirements of E.S.S 4756-1/2013 [4] and E. 197-1/2011 [5]. The chemical composition of cementitious materials is presented in Table 1.
In addition, micro-silica (silica fume) produced in Egypt by SIKA company for chemical materials is used to improve strength in all the cone mixtures. The properties of silica fume follow the ASTM C 1240 [6], and it is as follows: appearance is solid and grey powder, particle size is 0.2 μm, the surface area is 14 m2/g, density is 20 KN/m3, and PH is between 6 and 8.

Table -1: Chemical composition of cementitious materials

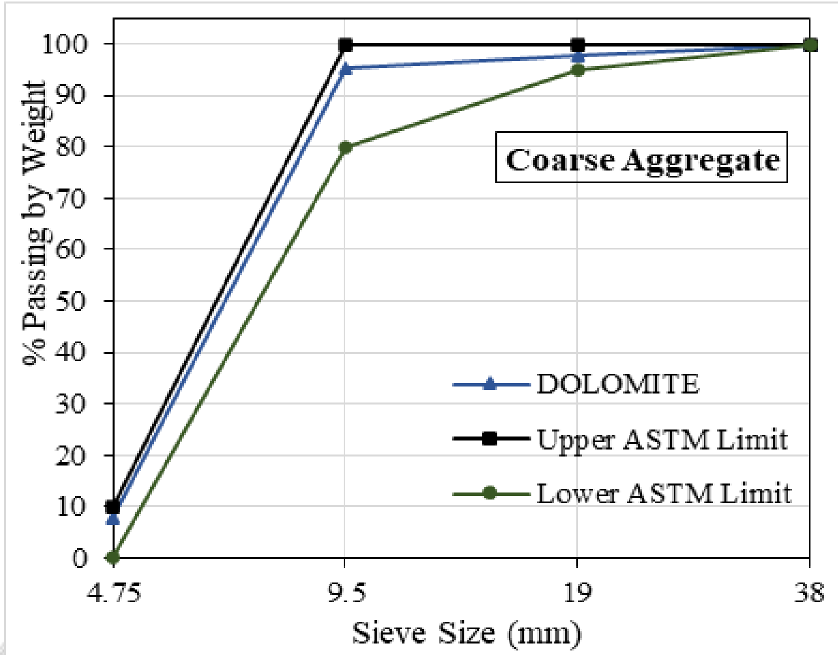
%	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	Na_2O	K_2O	SO_3	LOI, Loss of Ignition
OPC	19.8	5.5	63	1.18	3.39	0.46	0.16	3.01	5.2
SF	92	0.2	0.3	---	0.4	---	---	0.1	2

3.1.2 Aggregates

The used aggregate is a mix of coarse aggregate and fine aggregate, the crushed stone (dolomite) was used as a coarse aggregate with a specific gravity of 2.71, while natural sand was used as a fine aggregate with a specific gravity of 2.54. The physical properties of the natural sand are shown in Table 2.
The maximum coarse aggregate size was 9.5 mm. The sieve analysis results of course and fine aggregates are displayed in Fig. 1, following the American Society for Testing and Materials (ASTM). The two figures show that both coarse and fine aggregates were within the limit of sieve analysis of ASTM C 33 [7].

Table -2: Physical properties of fine aggregate (Sand)

Property	Value	Limits *
Specific gravity (SSD)	2.53	__
Unit weight (KN/m^3)	15.3	__
Fineness modulus	2.5	__
Clay and other fine materials (%)	1.5	≤ 3 %



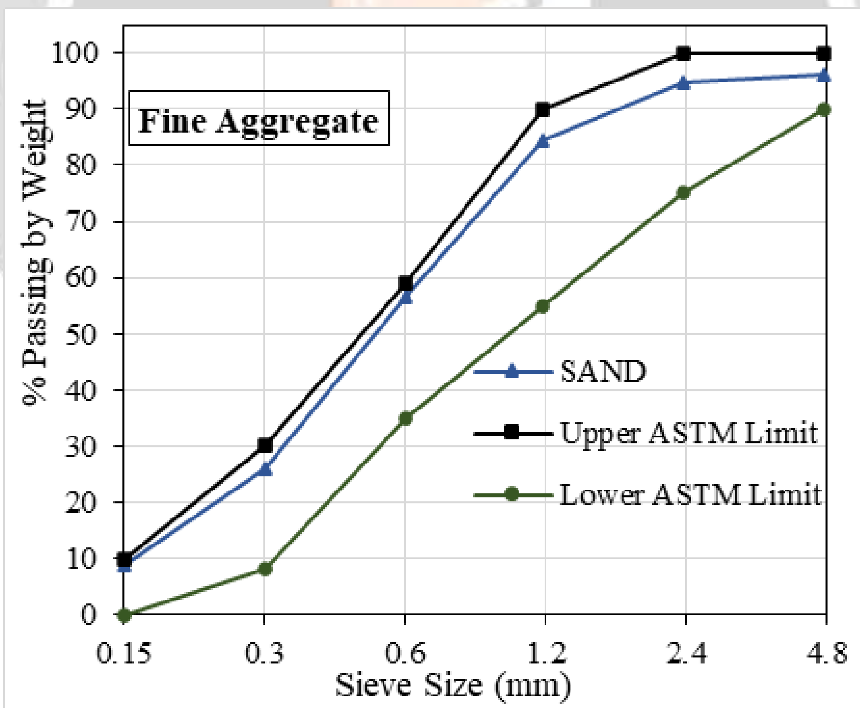


Fig- 1: Sieve analysis of coarse and fine aggregates

*(according to ASTM C 33 [7])

3.1.3 Super-plasticizer

Sikament -NN was used as a super-plasticizer that complies with ASTM C494 Type (F) [8] and BS 5075 Part 3 [9]. Sikament -NN properties are shown in Table 3.

Table -3: Properties of Superplasticizer (Sikament -NN)

Base	Naphthalene Formaldehyde Sulphonate
Appearance	Brown liquid
Density (KN/m^3)	12
Chloride content	Zero
Air entrainment	Approx. Zero
Compatibility	All types of Portland cement

3.1.4 Steel Fiber

The used steel fiber is corrugated steel fiber with length=30 ± 5 mm, Aspect ratio=40%, and tensile strength= 1100-1400 N/mm^2. The steel fiber is shown in fig.2.

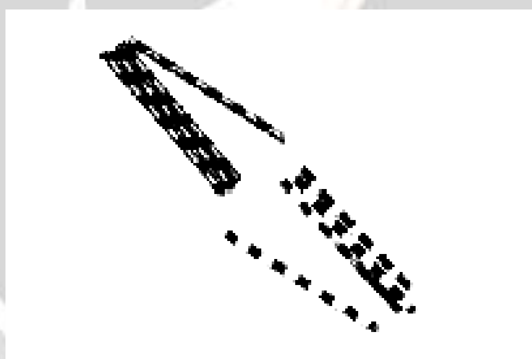


Fig- 2: Corrugated Steel Fiber

3.2 MIX DESIGN

Six trail mixes were designed to give different compressive strengths ranges from 30 MPa, 70 MPa, and 150 MPa. The first mix is for Normal Strength Concrete (NSC) and designed according to ACI 211.1-91 [10] with a unit weight of 24 KN/m^3. The second mix is for High strength Concrete (HSC) and designed according to (ACI 363R) [11] with a unit weight of 28 KN/m^3. The other four mixes are for ultra-high-performance concrete (UHPC) with different steel fiber ratios (0.4%, 1%, 2%, 4%). The material quantities for the concrete mixtures are listed in Table 4.

Table -4: Concrete Quantitates for different mixes

Mix	Mix Code	Concrete Ingredients (Kg/m^3)							
		Cement	Water	W/B	Sand	Dolomite	Silica Fume	Sikament -NN	Steel Fiber
M-C	NSC (control)	350	200	0.57	695	1142	___	___	___
M-H	HSC	550	200	0.32	560	1000	75	20	___
M-10	0.4% Steel Fiber	700	200	0.26	560	995	140	40	10
M-20	1% Steel Fiber	700	200	0.26	555	995	140	40	20
M-50	2% Steel Fiber	700	200	0.26	556	990	140	40	50
M-100	4% Steel Fiber	700	200	0.26	552	990	140	40	100

3.3 CASTING AND CURING OF TEST SPECIMENS

All the concrete mixtures in this study were mixed and casted in the Higher Technological Institute, Sixth of October Branch laboratory. For each concrete mixture, fifteen standard cubes (150 mm x 150 mm x 150 mm) were casted to determine the compressive strength at 7 days, 28 days, and 365 days.in addition to ten standard cylinders for each concrete mixture with 150 mm diameter, and 300 mm height were casted to determine splitting tensile strength at ages of 28 days, and 365 days. Furthermore, three standard concrete beams with dimensions (150*150*700) mm were casted and tested to determine flexural strength for each concrete mixture.

3.4 TESTING METHODOLOGY

This section describes all testing on fresh concrete, and hardened concrete which all tested and conducted in the Higher Technological Institute, Sixth of October Branch laboratory.

3.4.1 Determination of fresh concrete properties

The slump test is used to measure the workability and consistency of fresh concrete for the NSC (control mix) instantly after mixing, according to BS EN 12350-2:2009 [12]. Slump test is not applicable for other mixes due to the usage of superplasticizer.

3.4.2 Determination of Hardened concrete properties

3.4.2.1. Density and compressive strength tests

The density test is used to ascertain the bulk density of concrete [1]. The compressive strength test is a mechanical test for measuring the maximum compressive load that the concrete can bear before fracturing [1]. The tests were carried out on the concrete specimens (standard cubes 150 mm x 150 mm x 150 mm) according to BS EN 12390-3:2009 [13]. The specimens were submerged in water until the time of the test. The compressive strength was determined at 7 days, 28 days, and 365 days.

3.4.2.2 Splitting tensile strength tests

It was performed according to BS EN 12390-6-2009 [14] at 28 days and 365 days using standard cylinders (150 mm diameter x 300 mm height). The splitting tensile strength of concrete (f_t) was calculated using Equation 2; where P is the maximum applied load indicated by the testing machine, d is the diameter of the specimen, and L is the length of the specimen.

3.4.2.3 Flexure strength of concrete beams

The test was carried out under a controlled load of four-point loading up to failure using the compressive machine.

4. EXPERIMENTAL RESULTS AND DISCUSSION

This section comprises the fresh and mechanical concrete properties for the six concrete mixtures. It includes the slump test results, density, compressive strength, splitting tensile strength, and flexure strength. The results represent the average of measurements according to the number of specimens in each test.

4.1 COMPRESSIVE STRENGTH

The comprehensive strength (F_{cu}) results for standard cubes (150*150*150) mms are shown in table 5, and figs. 3, 4 for all the concrete mixtures. Concerning the NSC, the M-C mixture achieves a compressive strength (F_{cu}) of 32 MPa after 28 days, while HSC (M-H mixture) achieves a compressive strength (F_{cu}) of 71 MPa after 28 days. Furthermore, the four UHPC mixtures achieves convergent results close up to 150 MPa after 28 days.

Table -5: Compressive strength results, and slump, and density of concrete mixtures

Mix	Mix Code	Slump (mm)	Density (KN/m^3)	Compressive Strength (N/mm^2)		
				7-days	28- days	365 days
M-C	NSC (control)	14 mm	24	23.1	32.2	33
M-H	HSC	Not Applicable	28	31.4	71.5	74
M-10	0.4% Steel Fiber	Not Applicable	29	90.2	148.6	150.7
M-20	1% Steel Fiber	Not Applicable	31	91.4	149.3	152.1
M-50	2% Steel	Not	32	92.3	149.8	152.4

	Fiber	Applicable				
M-100	4% Steel Fiber	Not Applicable	34	92.6	150.2	153.3

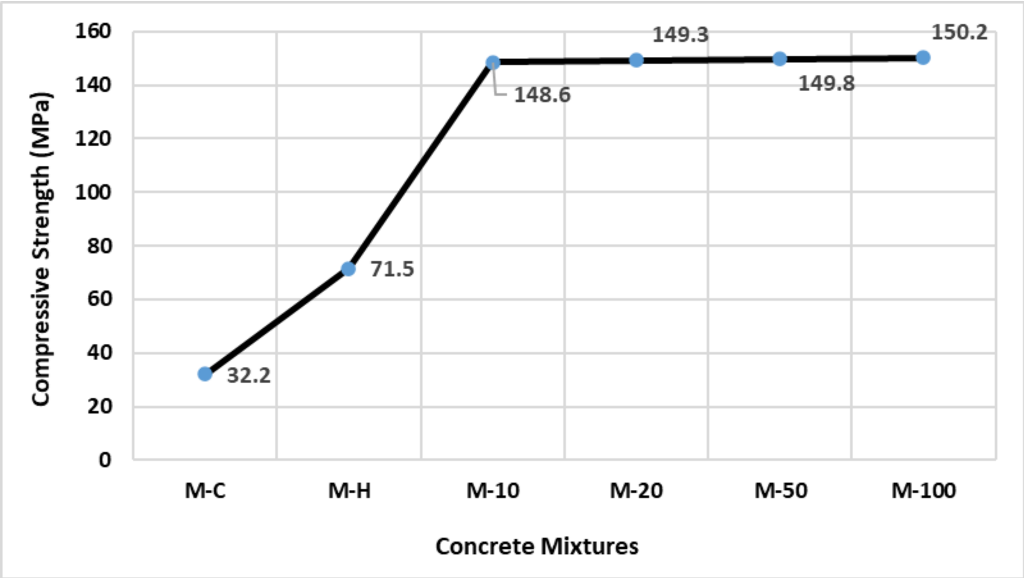


Fig- 3: Compressive strength for concrete mixtures at 28-days

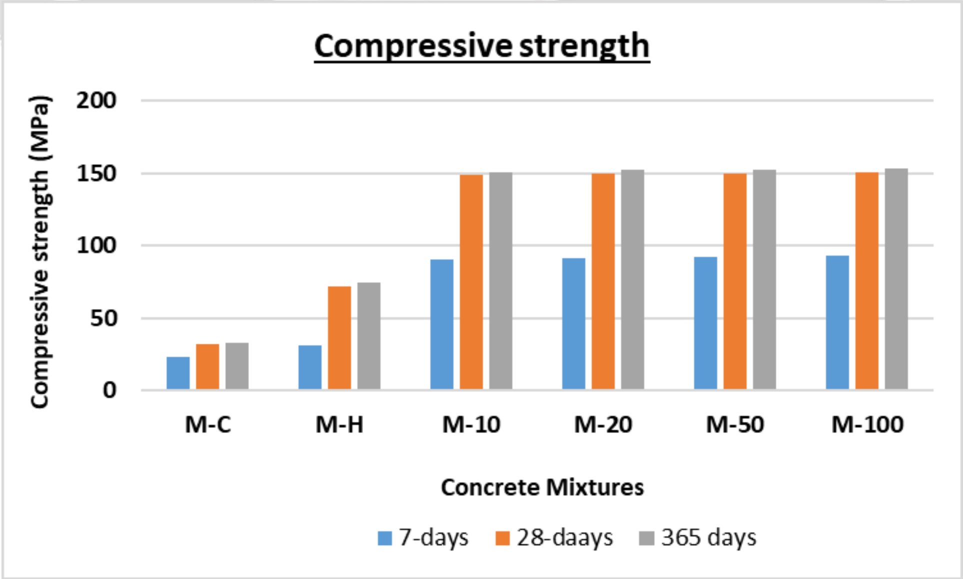


Fig- 4: Compressive strength for concrete mixtures at different ages

4.2 SPLITTING TENSILE STRENGTH

Splitting tensile strength results were conducted for standard cylinders with 150 mm diameter, and 300 mm height, as shown in table 6, and fig.5 which demonstrates improvement in splitting tensile strength for HSC than NSC, in addition, it's clear that adding steel fibers enhances the splitting tensile strength property.

Table -6: Splitting tensile strength results

Mix	Mix Code	Splitting Tensile Strength (N/mm^2)	
		28- days	365 days
M-C	NSC (control)	2.13	2.41
M-H	HSC	3.96	4.01
M-10	0.4% Steel Fiber	6.12	6.53
M-20	1% Steel Fiber	7.89	8.23
M-50	2% Steel Fiber	9.84	9.97
M-100	4% Steel Fiber	11.27	11.79

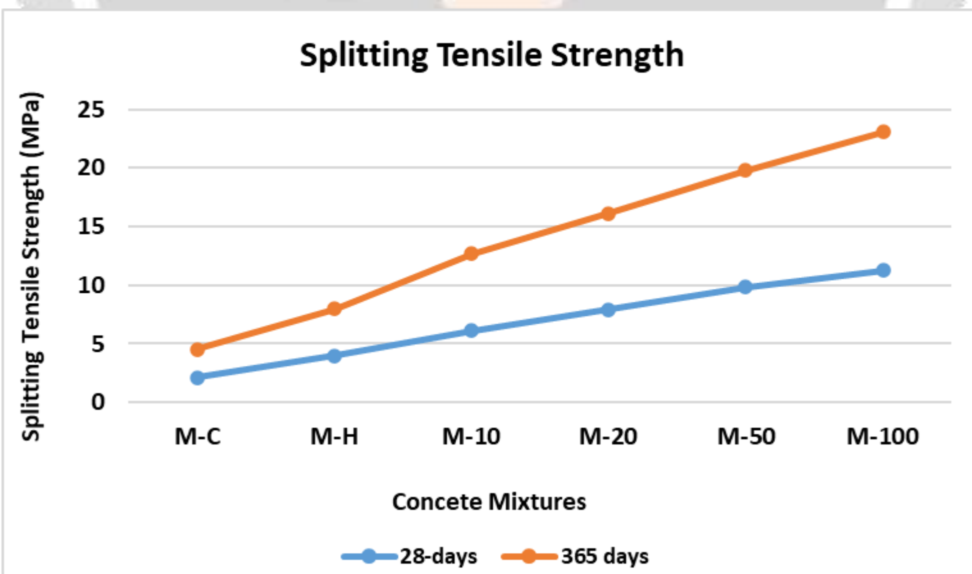


Fig- 5: Splitting Tensile strength for concrete mixtures at different ages

4.3 FLEXURE STRENGTH

Flexure strength results at 28-days were evaluated for standard beams with dimensions (150*150*700) mms using a four-point load frame as shown in Table 7. It obviously appears that the higher the percentage of steel fiber, the better the flexure strength.

Table -7: Flexure strength results

Mix	Mix Code	Flexure Strength ((N/mm^2)
M-C	NSC (control)	0.1
M-H	HSC	0.4
M-10	0.4% Steel Fiber	11.25
M-20	1% Steel Fiber	13.5
M-50	2% Steel Fiber	17.75
M-100	4% Steel Fiber	23.53

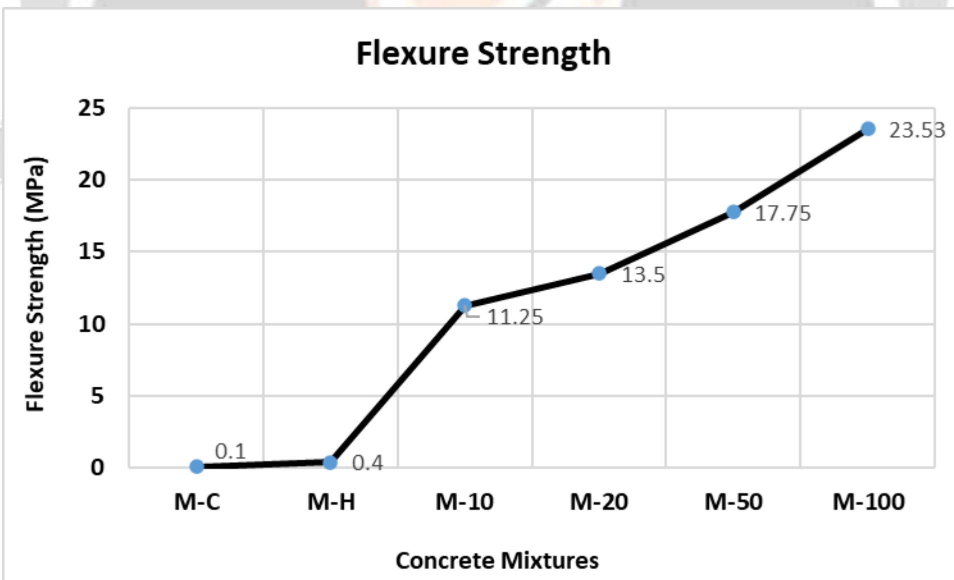


Fig- 6: Flexure strength for concrete mixtures at 28-days

6. CONCLUSION

In this research, the effect of adding different percentages of steel fibers to UHPC was studied and compared to normal-strength concrete and high-strength concrete. Compressive, splitting tensile, and flexure strengths tests were conducted, and the conclusions could be summarized in the following points:

1- Compressive strength of NSC is less than HSC by approximately 55%.

2- Splitting tensile strength of NSC is less than HSC by approximately 45%.

3- Flexure strength of NSC is less than HSC by approximately 75%.

4- Compressive strength is slightly increases with the increase of steel fiber percentage.

5- Increasing steel fiber percentage in UHPC showed significant improvement in splitting tensile strength.

6- Increasing of steel fiber percent in UHPC resulted in a considerable improvement in flexure strength.

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