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MECHANICAL PROPERTIES OF ULTRHIGH PERFORMANCE FIBER REINFORCED CONCRETE

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ABSTRACT

Ultrahigh performance fiber reinforced concrete (UHPFRC), as a new class of concrete, has attracted a lot of attention in recent years. This type of concrete with a compressive strength of more than 150 MPa, has high packing density, very low permeability, superior durability and very high abrasion and corrosion resistance. Small steel fibers, used in UHPFRC, cause the increase of flexural strength and ductility. In the present study, it has been tried to produce ultrahigh performance fiber reinforced concrete using the most suitable available materials in Egypt: such as Portland cement, silica fume, quartz powder, steel fibers, superplasticizer, fine quartz sand, and fine crushed dolomite (max nominal size 4.75 mm). For all test specimens, a w/c of 0.18 was applied. Also, the effects of adding different amounts of quartz and silica fume on main properties of UHPC have been investigated. The results show that using the available materials together with steel fibers and conducting normal treatment, UHPFRC with compressive strength up to 151 MPa and flexural strength of 33.75 MPa was produced.

KEYWORDS: UHPFRC; UHPC; RPC; Compressive Strength; Flexural Strength; Tensile strength.

INTRODUCTION

Ultra-high performance fiber reinforced concrete (UHPFRC) is a new class of concrete that has been developed in recent decades. This new class of cementitious composites with specifically tailored properties, also sometimes called reactive powder concrete (RPC), and more commonly known as ultra-high performance concrete (UHPC). When compared with high performance concrete (HPC), UHPFRC tends to exhibit superior properties such as advanced strength, durability, long-term stability, ductility, improved resistance against chemical attacks, and higher penetration resistance. UHPFRC uses a relatively high binder ratio, a water to cementitious ratio less than 0.2, and shows a compressive strength in excess of 150 MPa [1-3]. Its ductility is about 250 times higher than that of conventional concrete [4, 5].

UHPFRC is a material with a cement matrix of a characteristic compressive strength in excess of 150 MPa, a tensile strength that is more than 5 MPa with sufficient fiber content to achieve ductile behavior under tension and high binder content with special aggregates. The constituents are cement, fine sand, silica fume, quartz powder, super plasticizer, a low water-cement ratio, and inclusion of either high-strength steel fibers or non-metallic fibers [6]. The Japanese recommendations [7] impose the same limits for strength and ductility, but also specify material composition by limiting maximal aggregate size, water-cement ratio, and fiber quantity and strength. American Concrete Institute (ACI) Committee 239 [8] suggests the following definition: “Concrete, ultra-high performance concrete that has a minimum specified compressive strength of 150 MPa (22,000 psi) with specified durability, tensile ductility and toughness requirements; fibers are generally included to achieve specified requirements.”

This type of concrete was initially developed in France and it was also called reactive powder concrete (RPC) because it contains a larger quantity of silica fume. It is different from high-strength concrete not only because it does not have coarse aggregates, but also the amount of powders and fibers used. It consists of a special concrete where its microstructure is optimized by precise gradation of all particles in the mix to yield maximum density. The development of a RPC is possible by the application of a basic principles relating to the composition, mixing and post-set heat curing of the concrete [4].

- Removal of coarse aggregate to enhance the homogeneity of concrete.
- Use of silica fume for pozzolanic reaction.
- The optimal usage of superplasticizer to reduce w/c and improve workability.
- Optimization of the granular mixture for enhancement of compacted density.
- Application of pre-setting pressure for better compaction.
- Post-setting heat treatment to enhance the mechanical properties of the microstructure.
- Addition of steel fibers to achieve ductility.

However, at such a level of strength, the coarse aggregate becomes the weakest link in concrete. In order to increase the compressive strength of concrete even further, the only way is to remove coarser aggregate. This philosophy has been employed in what is today known as reactive powder concrete [9].

The absence of the coarse aggregate reduced the heterogeneity between the cement matrix and the aggregate and hence enhances the microstructure and the performance [10]. Despite that the matrix does not contain coarse aggregate, UHPC is widely recognized as concrete not as mortar.

UHPFRC is typically proportioned with Fine Sand, high content of Cement, Silica Fume, Quartz, and Super Plasticizer [11]. Fine Steel Fibers may be added to enhance ductility [12]. Accordingly, the fine Sand in RPC becomes equivalent to the coarse aggregate and the cement fills the role of fine Aggregate while the Silica Fume takes the role of Cement [13]. When used in optimum dosages, the Superplasticizer reduces the water-to- cementitious materials ratio while improving the workability of concrete. The addition of silica fume in RPC concrete serves the three-fold function enhancing the mechanical properties of the paste by filling voids (increasing density), enhancing rheology (strengthening the interfacial transition zone between cement matrix and sand), and producing secondary hydrates. The quartz powder is useful for its reactivity during heat treatment [14]. The constituents of the mixture and proportions (by fraction of cement mass) proposed by various investigators [4,15,16].

Roux et al. [17] demonstrated that the mechanical properties of RPC are obtained by lowering the water-to-cementitious materials ratio, using HRWRA's, and including silica fume. The lower water-to-cementitious materials ratio reduces the porosity of the cement paste and improves durability. The cement content has a dominant role in determining the strength of RPC. The effect of this factor was investigated by Kurdi et al.[18]. They used cement content varying from 800-1090kg/m³ and achieved a maximum compressive strength of 132 N/mm². Kurdi et al. [18] studied the effect of silica fume content. The results of their experimental study illustrated that the optimum silica fume content for RPC is about 25% of the cement weight. Collepardi et al. [10] investigated replacement of ground fine quartz sand (0.15-0.40 mm) by graded natural aggregate (max nominal size 8 mm). Studies revealed that there is no change in the compressive strength of the RPC at the same water-cement ratio. Lee and Chisholm [19] studied the effect of steel fibers on the mechanical properties of RPC. They observed that the addition of 2% straight steel fibers with aspect ratio of 65 to the RPC mix primarily improve the normally poor tensile strength of RPC. They also found that the addition of steel fibers provided a marked improvement in the measured compressive strength.

The use of UHPC allows for section dimensions to be minimized, taking advantage of the improved material properties and minimizing material usage and cost. In addition to the improved strength properties, UHPC has a very low permeability, making the material resistant to the corrosion and deterioration often associated with reinforced concrete and steel structures. This resistance directly correlates to a longer service life that can be achieved with the use of UHPC, making it an ideal material for a number of structural applications, particularly bridge structures [20].

The present study aims to investigate the feasibility of producing UHPFRC using locally available materials in the Egyptian market with no additional curing such as heat or pressure treatment required; to study the influence of the cement, silica fume, and quartz on the mechanical properties of UHPC; to obtain the mechanical properties of UHPC including, compressive strength, tensile strength, and flexural strength; to evaluate the strength of UHPC gain with age.

MATERIALS AND EXPERIMENTAL PROGRAM

The main constituents of UHPFRC are cement, water, fine aggregate, silica fume, quartz powder superplasticizer and steel fibers. The fine aggregate used was the fine quartz sand with grain size from 0.125 mm to 2 mm, a specific gravity 2.61 t/m³, and bulk density 1.820 t/m^3 and natural fine crushed dolomite graded from 2 mm to 4.75 mm (max. nominal size) with a specific gravity 2.63 t/m³ and bulk density 1.565 t/m³. Table 1 and Figure 1 show the grading of the used fine aggregate. The sand particles finer than 0.125 mm were excluded to avoid the interference with the coarse cement particles (100 um) as recommended by Kurdi et al. [18]. The cement used in all mixes was ordinary Portland cement CEM I 52.5 N, it was locally produced with specific gravity of 3.15, Blaine fineness of 3,300 cm²/gm, and 28 days compressive strength of 55.8 MPa. The percentage of chemical compound compositions of cement were; 37.16% C3S; 33.92% C2S; 7.07% C3A; and 10.822% C4AF. The chemical and physical characteristics are satisfy the Egyptian Standard Specification (ES 4756-1/2013) [21]. Silica fume locally produces used as a high active pozzolan in most of the mixes. It is a waste by-product of silicon and silicon alloys industry consisting mainly of non-combustible amorphous silica (SiO_2) particles, a specific gravity of 2.20 and a specific surface area of 170,000 cm²/gm. locally produced quartz powder with a SiO_2 content of 97%, Blaine fineness of 3,100 cm²/gm, and a specific gravity of 2.85 was used.

The high-range water-reducing (HRWR) admixtures is essential in UHPC help in increasing the workability of concrete without adding water and helping the fine particles to fill the void spaces and to decrease the amount of water in the mix. In this study a superplasticizer namely ViscoCrete 3425 locally produced was used. It is an aqueous solution of modified polycarboxylate and 1.08 specific gravity. It complies with ASTM C494-Type G and F. Steel fibers with specific gravity of 7.85 t/m^3 and 289 MPa yield stress are used to increase the tensile capacity and improve the ductility of the UHPC. The used steel fibers are chopped or cut from steel wires that locally used to tie the steel reinforcement to the stirrups. The steel wires are cut into the desired length which was 17 mm and the diameter of fibers used are 0.8 ± 0.02 mm whereas the diameter that usually used in nearly all the research in producing UHPC which was 0.2 mm. The aspect ratio of the steel fibers used was 21.25. This type of fiber is very cheap in comparison with the other types of steel fibers and is available in all markets in Egypt.

TABLE 1 Grading of the fine aggregate used

Sieve size (mm)	0.125	0.25	0.5	1.0	2.0	4.0	8.0
Passing (%)	4	14.4	27.2	42.4	64	84.8	100

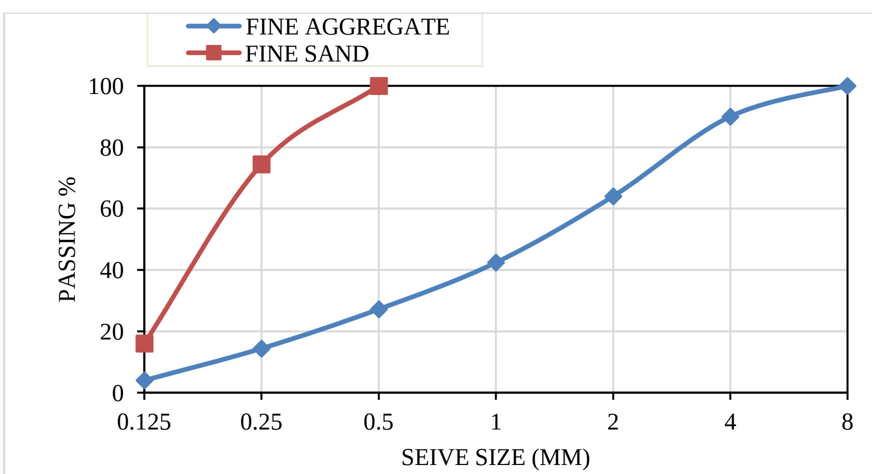

Figure 1. Particle sieve distribution of the fine aggregate used

Mixtures Properties

Mixture proportions used in this test program are summarized in Table 2. Cement content that was chosen in this research was 800, 850 and 900 kg/m³. The previous content was chosen to be within the ranging between

600 and 1000 kg/m^3 that was adopted by Yazici et al. [22]. To investigate the effect of using silica fume on the behavior of the reactive concrete, Different percentages of silica fume (0.0, 0.15, and 0.25 of cement weight) and quartz powder (0.0 and 20% of cement weight) were examined. In RPC, introduced in the nineties by Richard and Cheyrezy [4] the biggest aggregate is quartz sand up to 0.8 mm. In UHPC, the biggest aggregate is around 5 mm [23, 24]. In this research fine sand (0.125 - 2 mm) and fine crushed dolomite (2 - 4.75 mm) were used. Steel fiber content which was chosen 2% by volume in accordance to Richard and Cheyrezy [4]. The used superplasticizer content was chosen to be 4% of the cement content according to the research done by Jungwirth [25] to make the concrete more workable and to decrease the compaction effort while casting. While other researchers like Richard and Cheyrezy [4] chose the superplasticizer content to be 2% of the cement content. Yazici et al. [22] preferred to use about 6.6% of the cement content. Lee et al. [26] preferred to use one tenth of the average cement content. The water/cement ratio was taken between 0.17 and 0.19 for fibered reactive concrete according to Richard and Cheyrezy [4] and Cheyrezy et al. [27]. In this research the w/c ratio was chosen to be 0.18 for all mixes.

Table 2 Mix proportions for different UHPC mixes

Mix No.	Mix proportions (ratios by weight)							Mix proportions (kg/m³)						
	C	W	FA	SF	Q	SP	StF	C	W	FA	SF	Q	SP	StF
1	1	0.18	1.8	0	0	0.04	0.2	800	144	1440	0	0	32	157
2	1	0.18	1.6	0.15	0	0.04	0.2	800	144	1296	120	0	32	157
3	1	0.18	1.5	0.25	0	0.04	0.2	800	144	1192	200	0	32	157
4	1	0.18	1.6	0	0	0.04	0.19	850	153	1368.5	0	0	34	157
5	1	0.18	1.4	0.15	0	0.04	0.19	850	153	1215.5	127.5	0	34	157
6	1	0.18	1.3	0.25	0	0.04	0.19	850	153	1105	212.5	0	34	157
7	1	0.18	1.45	0	0	0.04	0.17	900	162	1305	0	0	36	157
8	1	0.18	1.26	0.15	0	0.04	0.17	900	162	1134	135	0	36	157
9	1	0.18	1.14	0.25	0	0.04	0.17	900	162	1026	225	0	36	157
10	1	0.18	1.62	0	0.2	0.04	0.2	800	144	1296	0	160	32	157
11	1	0.18	1.43	0.15	0.2	0.04	0.2	800	144	1144	120	160	32	157
12	1	0.18	1.31	0.25	0.2	0.04	0.2	800	144	1048	200	160	32	157
13	1	0.18	1.43	0	0.2	0.04	0.19	850	153	1215.5	0	170	34	157
14	1	0.18	1.24	0.15	0.2	0.04	0.19	850	153	1054	127.5	170	34	157
15	1	0.18	1.12	0.25	0.2	0.04	0.19	850	153	952	212.5	170	34	157
16	1	0.18	1.26	0	0.2	0.04	0.17	900	162	1134	0	180	36	157
17	1	0.18	1.08	0.15	0.2	0.04	0.17	900	162	972	135	180	36	157
18	1	0.18	0.95	0.25	0.2	0.04	0.17	900	162	855	225	180	36	157

C: cement, W: water, FA: fine aggrgatee, SF: silica fume, Q: quartz powder, SP: super-plasticizer, S_tF: steel fiber.

Mixing, Casting, and Curing Processes

The mixing process was performed using a ring concrete mixer of 15 liters. The mixture components weighted carefully then, sand, silica fume, quartz powder, and cement mixed to obtain homogenous mix. Mixing water containing half of the super-plasticizer was added and mixing continued for 2 minutes. One minute rest then the second half of super-plasticizer, diluted in an equal volume of water, was added followed by 1.5 minutes mixing at the slow speed, steel fibers added to the mix. Final mixing was applied for one-minute at a high speed (285± 10 rpm). Small size specimens were used to meet the requirement of the compression testing machine. The prepared specimens were 50x50x50 mm cubes for compression tests, 40x40x160 mm prisms for flexure tests, and cylindrical of 50 mm diameter and 100 mm height for tensile tests. The mix was cast in the moulds and mechanically compacted using vibrating table for 30 seconds. Specimens were demolded after 24 hours and cured in water bath at 21±2ºC until the age of testing.

Concrete samples

Samples were divided into three groups.

- Cubes of dimensions 50 x 50 x 50 mm for measuring the compressive strength and unit weight

- Cylinders of 50 mm diameter and 100 mm height for measuring the indirect tensile strength and,
- Prisms of 40 x 40 x 160 mm to measure the flexural strength.

Testing procedures and equipment

All tests in this research were carried out to investigate the main properties of UHPC samples as reported in this section.

- Compressive strength test: was carried out to determine the compressive strength of specimens of concrete cubes. A 2000 KN capacity compression testing machine was used. For compressive strength tests, 50x50x50 mm cubes are tested according to ASTM C109, 2008 [28].
- Tensile strength test: Indirect tension test (splitting method) was performed to determine the tensile strength of concrete mixes using cylindrical specimens of RPC according to ASTM C496, 2004 [29]. A 2000 KN capacity compression testing machine was used.
- Prism Flexural Test: This test method evaluates the flexural strength of the tested prism specimens using a flexure testing machine of 150 KN capacity according to ASTM C293, 1994 [30].
- Unit weights are measured according to ASTM C642, 2004 [31].

TEST RESULTS AND DISCUSSIONS

The properties which were taken into consideration in this research were the compressive strength, the indirect tensile strength, and the flexural strength at the age of 7, and 56 days of the RPC samples. Table 3 shows the mechanical properties of RPC mixes.

Table 3. Mechanical proportions for different UHPC

Mix No.	Cement Kg/m^3	Sf/C	Q/C	Unit weight Kg/m3	Compressive Strength (MPa)		Tensile Strength(MPa)		Flexural Strength(MPa)	
					7days	56days	7days	56days	7days	56days
1	800	0	0	2593	51	69	8.63	8.98	16.9	19.58
2		0.15	0	2584	80.3	102.8	8.87	10.57	18.13	26.75
3		0.25	0	2573	87	106.6	9.55	11.62	18.13	26.75
4	850	0	0	2587	53	70	8.83	9.46	17.67	19.88
5		0.15	0	2578	86	114.2	9.55	11.21	18.38	28.25
6		0.25	0	2570	96	132.7	9.78	11.72	19	29
7	900	0	0	2576	54	70	8. 96	9.66	17.82	20
8		0.15	0	2566	99	128.8	9.75	11.25	18.90	30.25
9		0.25	0	2558	106	150.5	9.85	12.23	20.45	31.13
10	800	0	0.2	2601	52	70	8.64	9.02	17.3	20.2
11		0.15	0.2	2592	82	104	9.55	10.79	19.25	28
12		0.25	0.2	2581	90	108	10.19	11.68	23.63	29
13	850	0	0.2	2590	54	72	8.94	9.52	17.8	21.4
14		0.15	0.2	2581	92.2	121.2	10.43	11.48	23.38	29.75
15		0.25	0.2	2574	104	142.6	10.62	11.89	27.3	30.25
16	900	0	0.2	2587	56	73	9.23	9.86	18.3	23.23
17		0.15	0.2	2577	101	139.4	10.45	12.23	24.25	33.75
18		0.25	0.2	2565	108.4	151.2	11.04	13.59	31.88	33.75

Compressive Strength Test Results and Discussion

Table 3 and Figures 2 and 3 shows that there is a great positive effect of increasing silica fume content on the compressive strength of UHPC at 7 and 56 days tests of samples regardless cement content. Mixes without quarts cotent, increasing silica fume content improves the compressive strength at the age of 7 days by about 57-83% and 70-96% for 15% and 25% silica fume content respectively for different cement contents

compared to samples without silica fume content. After 56 days, the compressive strength increased by about 48-84% and 54-115% for 15% and 25% silica fume content respectively for different cement contents compared to samples without silica fume content. When mixes content 20% quarts of cement weight, increasing silica fume content improves the compressive strength at the age of 7 days by about 57-80% and 73-93% for 15% and 25% silica fume content respectively for different cement contents compared to samples without silica fume content. After 56 days, the compressive strength increased by about 48-91% and 54-107% for 15% and 25% silica fume content respectively for different cement contents compared to samples without silica fume content.The main reason for the increase in the compressive strength is due to the physical effect of the finer silica fume grains that allows denser packing within the cement particles and improves the concrete microstructure which leads to increase in the reactive concrete compressive strength. The previous results were coincident with the results of Richard and Cheyrezy and Shihada and Arafa [4, 32].
Increasing the cement content increases the compressive strength of UHPC samples at age of 7 and 56 days for samples despite the silica fume content. For mixes without quartz content, increasing cement content improves the compressive strength at 7 days tests by about 3.9-10.3% and 5.9-23% for 850 kg/m^3 and 900 kg/m^3 compared to cement content of 800 kg/m^3. Results of 56 days tests show that compressive strength increased by about 1.4-24.5% and 1.4-41% for 850 kg/m^3 and 900 kg/m^3 compared to cement content of 800 kg/m^3 for different values of silica fume content. When mixes content 20% quarts of cement weight, increasing cement content improves the compressive strength at 7 days tests by about 3.8-15.6% and 7.7-23% for 850 kg/m^3 and 900 kg/m^3 compared to cement content of 800 kg/m^3. Results of 56 days tests show that compressive strength increased by about 2.9-32% and 4.3-40% for 850 kg/m^3 and 900 kg/m^3 compared to cement content of 800 kg/m^3 for different values of silica fume content. The reason for the increase in the compressive strength is very clear because the cement is the main bonding material and any increase in its content leads to an increase in the compressive strength. The changing in cement content affected the compressive strength but with less effect than the effect of the changing in silica fume content.

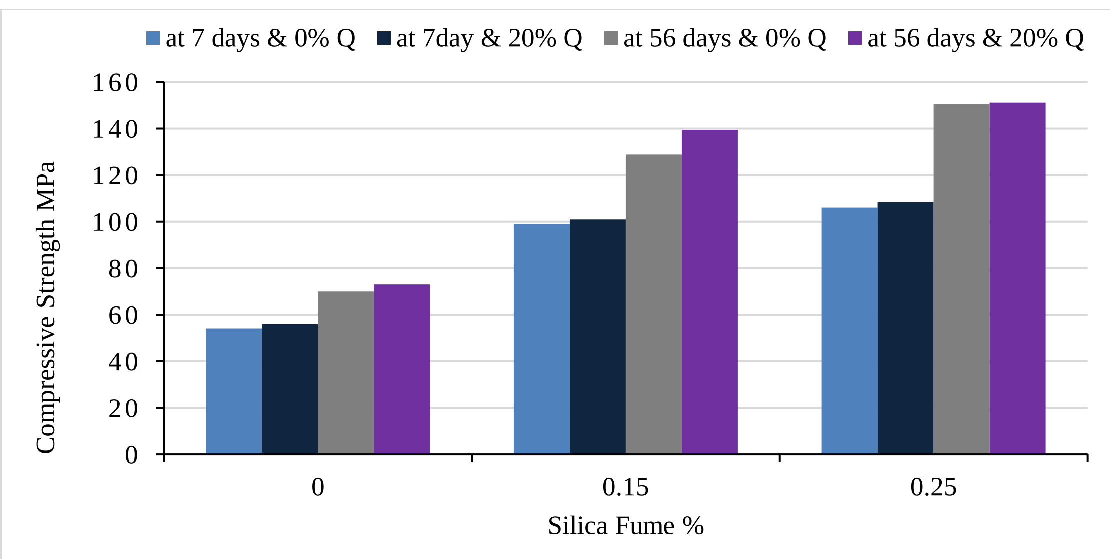

Figure 2. Compressive strength for samples of 900 kg/m^3 cement content.

The age effect on the compressive strength of the UHPC is shown in Figure 2. It is shown that the increase of the 56 days compressive strength with respect to 7 days compressive strength is affected by the cement and silica fume content. When the cement and silica fume content increase the enhancement of the compressive strength is increased and that is shown in the percentage of the compressive strength increasing which was about 28% for samples without silica fume, quartz powder and 800 kg/m^3 cement content and was about 35% at 25% silica fume and 900 kg/m^3 cement content and about 27% for samples without silica fume and 800 kg/m^3 cement content and was about 39.5% at 25% silica fume, 20% quartz powder and 900 kg/m^3 cement content.The previous results agree with conclusions of the research carried out by Habel et al. [33].

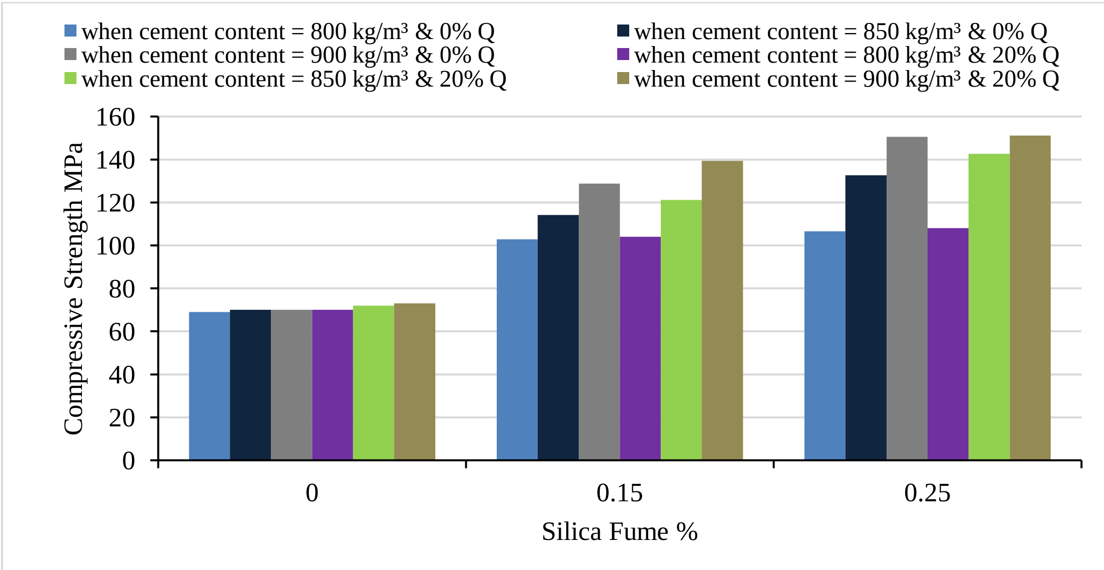

***Figure 3. Compressive strength for samples at 56 days*.**

Tensile Strength Test Results and Discussion

The indirect tensile strength test results are shown in Table 3 and figures 4 and 5. The increasing in the silica fume content has affect positively the indirect tensile strength at 7 and 56 days reactive concrete age for samples without considering the cement content. For mixes without quarts, and at 7 days UHPC samples age the indirect tensile strength was increased by about 2.7-8.8% for 15% silica fume content and 10.5-13.2% for 25% silica fume content with respect to the indirect tensile strength of samples without silica fume content. After 56 days, indirect tensile strength increasing by about 16.5-18.5% for 15% silica fume content and 24-29.4% for 25% silica fume content samples with respect to the indirect tensile strength of samples without silica fume content. When mixes content 20% quarts of cement weight, the increasing in the silica fume content has affect positively the indirect tensile strength at 7 and 56 days reactive concrete age for samples without considering the cement content. At 7 days UHPC samples age the indirect tensile strength was increased by about 9.8-10.8% for 15% silica fume content and 18-20% for 25% silica fume content with respect to the indirect tensile strength of samples without silica fume content. After 56 days, indirect tensile strength increasing by about 19.6-24% for 15% silica fume content and 25-37% for 25% silica fume content samples with respect to the indirect tensile strength of samples without silica fume content. The previous results shows that by increasing the silica fume content, the ductility of the reactive concrete increase and that tends to improve in the tensile strength of the reactive concrete. The previous results are coincides with results of Habel et al. [33] who report that there is a beneficial effect of the silica fume reaction on the tensile strength.

The increasing in the cement content has a positive effect on the tensile strength at 7 and 56 days reactive powder concrete samples age for samples without considering the silica fume content. For mixes without quarts, and at 7 days UHPC samples age the indirect tensile strength was increased by about 2.3-7.7% for 850 kg/m^3 and 3.1-10% for 900 kg/m^3 cement content samples with respect to the indirect tensile strength of samples with 800 kg/m^3 cement content. The indirect tensile strength at the age of 56 days for the UHPC samples was increased by about 0.8-6% for 850 kg/m^3 and 5.2-7.6% for 900 kg/m^3 cement content samples with respect to the indirect tensile strength of samples with 800 kg/m^3 cement content. When mixes content 20% quarts of cement weight, and at 7 days UHPC samples age the indirect tensile strength was increased by about 3.4-9.2% for 850 kg/m^3 and 6.8-9.4% for 900 kg/m^3 cement content samples with respect to the indirect tensile strength of samples with 800 kg/m^3 cement content. The indirect tensile strength at the age of

56 days for the UHPC samples was increased by about 1.8-6.4% for 850 kg/m^3 and 9.3-16.4% for 900 kg/m^3 cement content samples with respect to the indirect tensile strength of samples with 800 kg/m^3 cement content. The increasing in the indirect tensile strength was related to the increasing in the compressive strength.

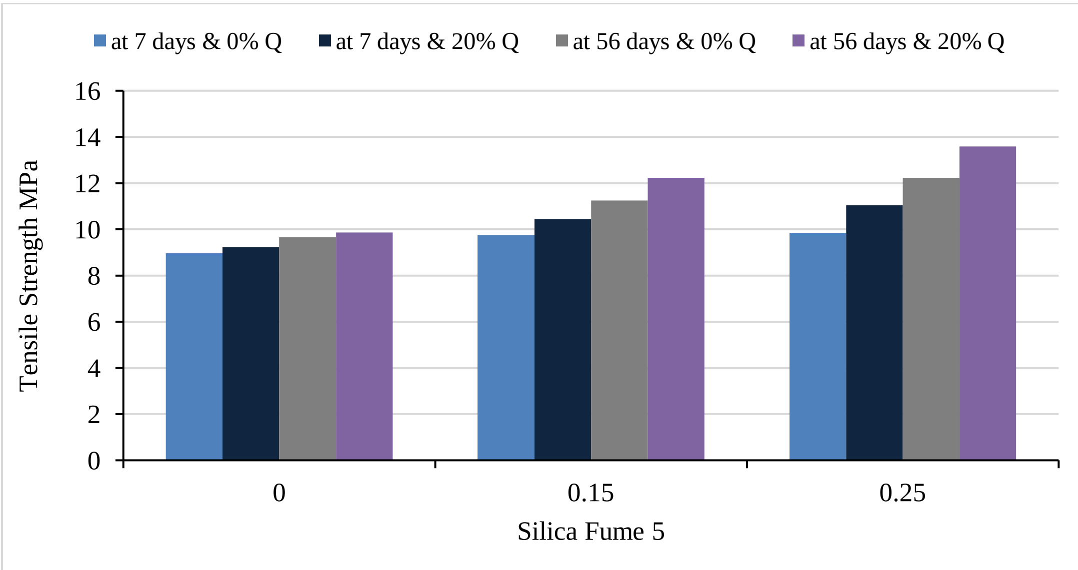

Figure 4. Tensile strength for samples of 900 kg/m^3 cement content.

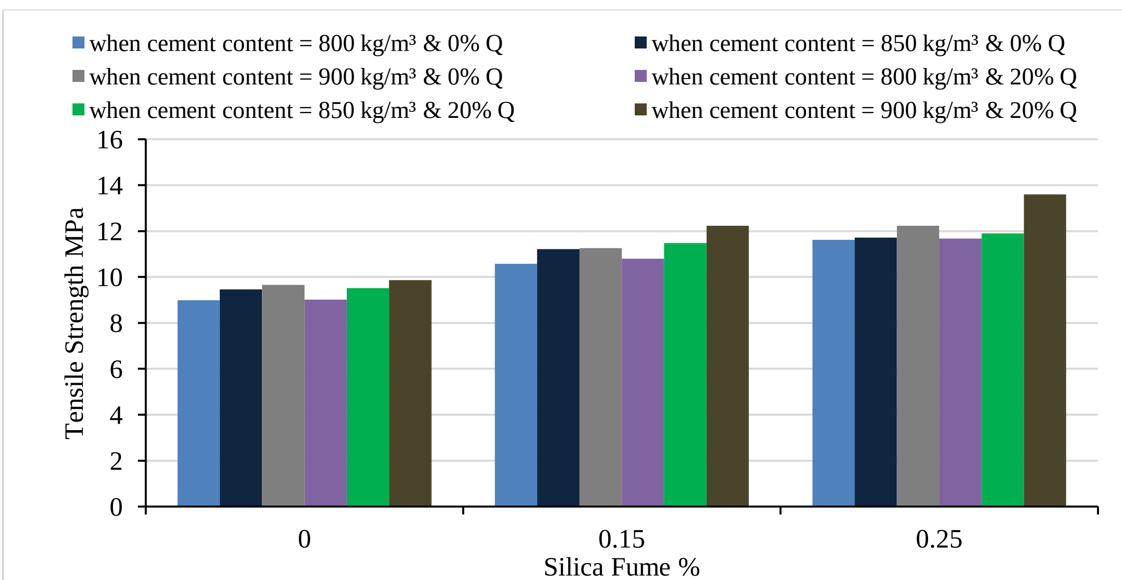

Figure 5. Indirect tensile strength for samples at 56 days.

Results indicated from indirect tensile strength test executed on 7 and 56 days RPC age shows that the increasing of 56 days indirect tensile strength with respect to 7 days indirect tensile strength was affected by the cement and silica fume content. When the cement and silica fume content increase the increasing in the indirect tensile strength was decreased and that was shown in the percentage of the indirect tensile strength increasing which was about 40.5% for samples without silica fume, quartz powder and 800 kg/m^3 cement content and was about 24% at 25% silica fume and 900 kg/m^3 cement content and about 44% for samples without silica fume, 20% quartz powder and 800 kg/m^3 cement content and was about 23% at 25% silica fume and 900 kg/m^3 cement content.

Flexural Strength Test results and Discussion

The flexural strength test results are shown in Table 3 and Figures 6 and 7. The flexural strength test results show that the increasing in silica fume content has a valuable positive effect of on the flexural strength of the UHPC at 7 days age for samples without considering the cement content. For mixes without quartz powder and at 7 days UHPC samples age the flexural strength was increased by about 4-7.3% for 15% silica fume content and 7.3-14.8% for 25% silica fume content samples with respect to the flexural strength of samples without silica fume content. After 56 days, flexural strength increasing by about 36-51% for 15% silica fume content and 36.6-56% for 25% silica fume content samples with respect to the flexural strength of samples without silica fume content. When mixes content 20% quartz of cement weight, The flexural strength test results show that the increasing in silica fume content has a valuable positive effect of on the flexural strength of the UHPC at 7 days age for samples without considering the cement content. At 7 days UHPC samples age the flexural strength was increased by about 11-33% for 15% silica fume content and 36-74% for 25% silica fume content samples with respect to the flexural strength of samples without silica fume content. After 56 days, flexural strength increasing by about 38-45% for 15% silica fume content and 41-45% for 25% silica fume content samples with respect to the flexural strength of samples without silica fume content. The previous results are another evidence for the positive effect of adding silica fume on the ductility of the reactive concrete which leads to better behavior in bending.

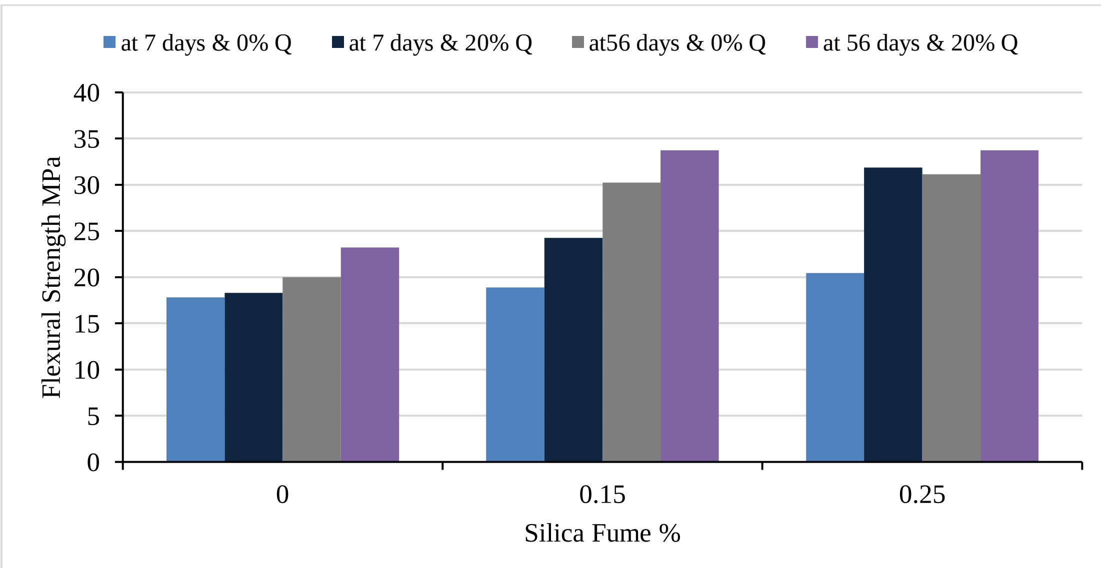

Figure 6. Flexural strength for samples of 900 kg/m3 cement content.

The increasing in the cement content increases the flexural strength at 7 and 56 days UHPC samples age for UHPC samples without considering the silica fume content. For mixes without quartz content and at 7 days UHPC samples age the flexural strength was increased by about 1.4-4.8% for 850 kg/m^3 cement content and by about 4.2-12.8% for 900 kg/m^3 cement content samples with respect to the flexural strength of samples with 800 kg/m^3 cement content. The flexural strength at the age of 56 days for the UHPC samples was increased by about 1.5-8.4% for 850 kg/m^3 cement content and 2.1-16.4% for 900 kg/m^3 cement content samples with respect to the flexural strength of samples with 800 kg/m^3 cement content. When mixes content 20% quartz of cement weight and at 7 days UHPC samples age the flexural strength was increased by about 2.9-21.5% for 850 kg/m^3 cement content and by about 5.8-34.9% for 900 kg/m^3 cement content samples with respect to the flexural strength of samples with 800 kg/m^3 cement content. The flexural strength at the age of 56 days for the UHPC samples was increased by about 4.3-6.3% for 850 kg/m^3 cement content and about 15-

20.5% for 900 kg/m^3 cement content samples with respect to the flexural strength of samples with 800 kg/m^3 cement content.

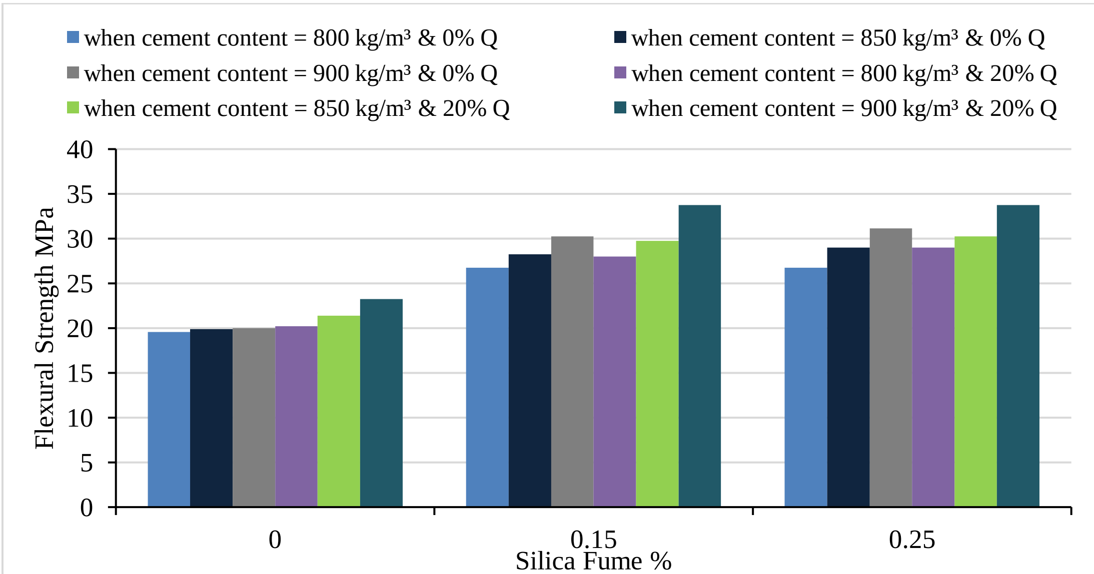

Figure 7. Flexural strength for samples at 56 days.

Density Results

The density of concrete decreases as the silica fumes content increases, as shown in Table 3 and Figures 8. The decrease in density for the 15% silica fume mix is about 0.4% smaller than the 0% silica fume mix. Based on the results shown in Figure 8, one can easily conclude that densities of concrete specimens increase with increasing the percent of ultrafine. The quartz powder acts as a filler between the aggregate and cement grains. This means that the smaller particles of fine aggregate are able to provide a denser concrete matrix.

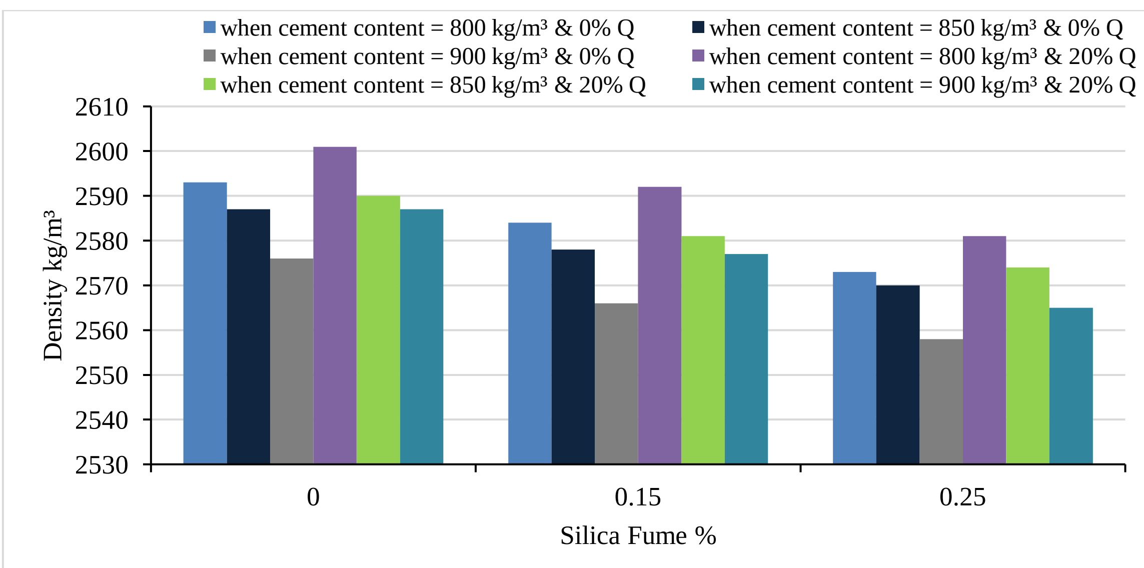

Figure 8. Effect of silica fume and cement content on UHPFRC density

CONCLUSIONS

Based on the results obtained from the current research, the following main conclusions can be summarized:

- It is possible to produce UHPFRC in Egypt by using materials which are available at the local markets, if they are carefully selected, and will achieve a minimum compressive strength of 151 MPa at the age of 56 days.
- A compressive strength of 151 MPa, indirect tensile strength of 13.59 MPa, and flexural strength of 33.75 MPa were approached for samples of 900 kg/m^3 cement content, 25% silica fume/cement, and 20% quartz/cement (mix no. 18).
- Increasing silica fume contents improves the compressive strength, tensile strength and flexural strength values at different UHPC ages.
- Increasing cement contents enhance the compressive strength, tensile strength and flexural strength values at different UHPC ages.
- Increasing quartz contents improves the compressive strength, tensile strength and flexural strength values at different UHPC ages.
- The densities of concrete decreases as silica fume content increases, while keeping other contents constant.
- densities of concrete specimens increase with increasing the percent of ultrafine.

Finally, it can produce an economic UHPC using locally available materials in Egypt, in order to manufacturing a pre-cast ultrahigh strength concrete with ultra-mechanical properties.

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