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Long Term Behavior of Ultra High-Performance Concrete

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Ultra-High-Performance Concrete (UHPC) is one of the important types of concrete technology breakthroughs in the 21st century. It achieved high results of mechanical properties, durability (resistance fire) and bonding strength. The aim of paper is to evaluate the long-time behavior of UHPC. The main variables were finesse modulus of sand, crushed quartz powder, fly ash and metakaolin and methods of curing (water& hot).The sand with different fineness modulus(3.2, 2.36 and 1.9) were used, Crushed quartz powder with ratio (10%, 20% and 30%) as a replacement of sand was used. Fly ash and metakaolin, with of (10%, 20%, 30 and 40%) and (5%, 10% and 15%) as a replacement of cement; respectively. The effect of these variables on the mechanical properties (compressive, tensile, flexural strength) at different ages. Also, the drying shrinkage strain was evaluated. The results showed that using and with fineness modulus (1.9), 20% ratio of crushed quartz powder to fine sand (CQ/S), 20% of fly ash to cement (FA/C) and 5% of metakaolin to cement (MK/C) give the best proportions of UHPC. The compressive strength for this mix was 900 kg/ cm^2.

Keywords: UHPC; cement; metakaolin.

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1. INTRODUCTION

Concrete is one of the most used building materials in the world for a long time. The first use of Portland cement was in 1824 in Joseph Aspdin of England.The concrete at this time consisted of lime, sand, water and stone [1]. It consists of cementitious materials, low water-to-binder ratio, small aggregate size, fiber and silica fume to obtain the high level of performance that is characterized by high values of compressive strength, tensile strength, durability, toughness, long-term stability, workability [2].

Ultra-high-performance concrete consists of high strength concrete with fibers;thus, it is called UHPFRC and super plasticized concrete [3]. UHPC is a composite material, which consists of Portland cement, quartz sand, silica fumes, super plasticizers, and steel fibers [4]RPC is a cement mortar mixed with short steel fibers to reinforce it and avoid any catastrophic propagation of micro cracks [5]. UHPC is a specific type of concrete, which use micro particles, steel fibers and binder phase [6].

UHPC consists of Portland cement, fine sand, quartz powder, micro silica, steel fibers, HRWRA and additional mineral admixtures such as fly ash, metakaolin, carbon nanotubes, finely ground lime-pozzolanic binder. UHPC has compressive strengths greater than 150 MPa and flexural strengths greater than 10 MPa at 28 days, 47 GPA of young's modulus, 8 MPa in tensile strength and 4 MPa in first cracking strength [7]. The key factor in producing UHPC is to improve the micro and macro properties of its mixture ingredients to ensure mechanical homogeneity, maximum particle packing density and minimum size of flaws [8,9].

UHPC is characterized by high amount of silica fume and low ratio of water to cement W/C. Generally, UHPC consists of main components such as cement, fine aggregates, water, silica fume and finally superplasticizer. reinforcement [10].

Abdel Raheem et al. [11] mentioned thatUHPC is considered a great development in concrete technology. It has many advantages that make it preferred than conventional concrete. The advantages of UHPC are as follows:Reduction in member size, reduction in form-work area and cost, longer spans,greater stiffness, UHPC achieves high compressive strength, high durability and great resistance to fire.UHPC has little disadvantages in comparison with its various advantages; the disadvantages of UHPC are as follows :UHPC has high initial cost, big amount of heat extracted from the process of hydration,the process of mixing of UHPC takes more time and more complex mixing than normal concrete.

Applications of UHPC
Sherbrooke footbridge in Canada considers the first bridge in the world. Its length is 60m with six precast segments with equal lengths [12]. Road Bridge of Shepherds Creek consists of one walkway and 4 lanes for traffic with 16 pre-tensioned precast UHPC beams, The Seoul and Sakata Miral Footbridges considers the largest bridge made of UHPC is The Sunyudo footbridge which was made with 2 steel spans and arch in the center with span 120 m with cross section shaped [13].The Portal Frame of UHPC in Malaysiawas constructed in 2008 under name Wilson Hall. Anew technology of prefabricated system of UHPC was used in this frame in the area about 2861 m^2. The following Figures show the stages of construction of the portal frame [14]. Airport of Tokyo's Haneda in Japanis considered one of largest UHPC project in Tokyo. It considers the third busiest airport in Asia and the fifth busiest in the world. It contains the area of 24000 m^2 [11].

2. EXPERIMENTAL PROGRAM

2.1 Experimental Program

The experimental program of this research was performed in the laboratory of testing materials, the Faculty of Engineering, Menoufia University, Egypt.

The aim of this research is to spotlight to evaluate the long-time behavior of UHPC. Thirteen UHPC mixes were designed according to the absolute volume method, casted and tested to determine the properties of hardened HPC concrete at long term ages. Mixtures were tested to show the effect of fine aggregate, different ratios of crushed quartz powder, fly ash and metakaolin on compressive, tensile, flexural strength and drying shrinkage at long term ages. The compressive strength and the shrinkage calculated up to 365 days.

2.2 Materials

Cement: ordinary Portland cement type(CEMI 42.5 N) produced by El-Arish Portland Cement Factory was used. 3.15 is the specific gravity of the cement used.Its chemical and physical characteristics satisfied the Egyptian Standard Specification (E.S.S. 4756-1/2013) [15].

2.2.1 Fine Aggregate

Natural siliceous sand satisfying the requirements (E.S.S. 1109/2008 and E.C.P. 203/2018) [16,17].It was clean and nearly free from impurities with a specific gravity 2.67. Three groups of natural sand are used to show the effect of different particles size of fine sand with its Fineness modulus (F.M.)of were (3.2, 2.36, 1.9).

2.2.2 Crushed Quartz Powder (QP)

Used in this research produced by "Egy Sand Company" at 50 kg bags. The utilized QP consists of very fine particles with maximum size 150µm and 2.85specific gravity.Its characteristics satisfy the requirements of [18]. Physical and mechanical properties are shown in Table (1) as provided by the manufacturer.

2.2.3 Chemical Admixtures

A high range water reducer (HRWA) as a superplasticizer was used. It is produced by Sika Company under the commercial name ViscoCrete 3425. It was used to improve the workability of concrete mixes. Its characteristics satisfy the requirements of (ASTM C494-2015 (type A and F) [19]. It is a brown liquid having a density of 1.18 kg/liter at room temperature. The amount of HRWA was 2.0 % of the blinder powder weight in all mixes.

2.2.4 Pozzolanic Admixtures

Fly Ash as a pozzolanic admixtures produced by SIKA Companywas used by (10%, 20%, 30% and 40%)of the cement weight. Its characteristics satisfy the requirements of (ASTM.C-618-2005) [20] with specific gravity 2.2 and specific surface area 20000 kg/m^2.Physical and mechanical properties are shown in Table (2) as provided by the manufacturer

2.2.5 Metakaoline

as a pozzolanic admixtures is a valuable admixture for concrete/cement applications. Metakaolineproduces a concrete mix that exhibits favorable engineering properties and was used by(5%, 10% and 15%) of cement weight. Its characteristics satisfy the requirements of (ASTM C618-15) [21] with specific gravity 2.5, specific surface area 8-15 gm/m^2 and fineness modulus 700-900 kg/m^2.Physical and mechanical properties are shown in Table (3) as provided by the manufacturer

2.2.6 Water

Which is used in the mixtures, is clean, fresh, drinkable, portable and do not have any impurities satisfying the requirements [17].

2.3 Concrete Investigation

Thirteen UHPC mixes were designed according to the absolute volume method, casted and tested to determine the properties of hardened concrete at long term ages. Mixtures were tested to show the effect of fine aggregate size and different ratios of crushed quartz powder, fly ash and metakaolin on compressive, tensile, flexural strength and drying shrinkage. The maximum nominal size of sand wasFineness modulus (F.M.) (3.2, 2.36, 1.9). The best mix was obtained at F.M. 1.9. The ratio of crushed quartz powder to sand (QP/S) were (10%, 20% and 30%). The best mix was obtained at 20% QP/S. The ratio of fly ash to cement (FA/C) was (10%, 20%, 30% and 40%). The best mix was obtained at 20% FA/C. The ratio of metakaolin to cement (MK/C) was (5%, 10% and 15%). The best mix was obtained at 5% MK/C. The ratio of superplasticizers to cement (SP/C) was 0.02% by weight. And the ratio of water to cement (W/C) was 0.20 by weight. The samples were mixed and cast in steel cubes (10×10×10 cm), cylinders (10×20 cm) and prisms (10×10×50 cm.) after oiling their surfaces according to ASTM C305 [22,23]. The concrete samples were placed on the vibration table at a low speed for complete compaction. After casting the specimens, they were covered with wet burlap in the laboratory at 24ºC and 68% relative humidity according to ASTM C192 [24]. And half of the samples are placed in the oven for 3 days at a temperature of 100°c. The proportions of the concrete mixes used are shown in Table (4).

3. ANALYSIS AND DISCUSSION OF TEST RESULTS

Figs. (1 to 29) show the results of the effect of fine aggregate size and different ratios of crushed quartz powder, fly ash and metakaolin on the properties of hardened UHPC.

Table 1. The chemical properties of the used crushed quartz powder

Component	CL_2	Na_2O	K_2O	SO_3	MgO	CaO	Fe_2O_3	AL_2O_3	SiO_2
Percentage (%)	0.05	0.05	0.22	0.33	0.21	1.02	0.35	0.83	97.0

Table 2. The chemical components of the used fly ash

Component	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	Na_2O	SO_3	K_2O
Percentage (%)	90.2	1.7	0.4	2.1	1.7	0.7	0.5	0.7

Table 3. The chemical components of metakaolin

Component	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	Na_2O	TiO_2	K_2O
Percentage (%)	40.02	34	2	0.1	0.6	0.1	1	1.7

Table 4. The proportions of the concrete mixes

Groups	**Mixes Code**	**Cement (Kg/m.)**	**Sand (Kg/m.)**	**N.M.S. of Sand**	**Q.P./ S**	**F.A./C**	**MK/C**	**W / C %**	**Ad./ C%**
N.M.S. of sand	**S1**	**580**	**870**	**1.18**	**0**	**0**	**0**	**20**	**2**
	S2	**580**	**870**	**2.36**					
	S3	**580**	**870**	**4.75**					
Q.P.	S1Q10	**550**	**830**	**1.18**	**10**				
	S1Q20	**530**	**810**		**20**				
	S1Q30	**510**	**770**		**30**				
F.A.	S1Q20F10	**470**	**780**	**1.18**	**20**	**10**			
	S1Q20F20	**415**	**775**			**20**			
	S1Q20F30	**360**	**770**			**30**			
	S1Q20F40	**310**	**760**			**40**			
M.K.	S1Q20F20M5	**475**	**750**	**1.18**	**20**	**20**	**5**		
	S1Q20F20M10	**450**	**750**				**10**		
	S1Q20F20M15	**425**	**750**				**15**		

3.1 Compressive Strength

Figs. (1to 6) show the comparison between the compressive strength for various of UHPC mixes using fine aggregate size and different ratios of crushed quartz powder, fly ash and metakaolin compared to the control mix at different ages of the test.

- **Effect of Aggregate Size**

Fig. 1 shows the effect of aggregate size on the compressive strength at different F.M.also the effect of curing was illustrated. Three F.M. of sandwere used (3.2, 2.36, 1.9)six ages the compressive strength was calculated up to 365 days (7, 28, 60, 90, 180 and 365 days).

The effect of F.M.of sand on the compressive strength was disused for the mixes at water curing for different ages as showed in Fig. 1. At F.M. of sand(1.9& 2.36) increasing in the compressive strength by (63.6% & 27.3%) respectively compared with F.M. of sand(3.2) with curing water.

From Fig. 1 when using heat as a method of curing, the compressive strength was increased more than that used water as a method of curing. 100%, 88.6% and 55.7% increasing in the compressive strength for the mixes with F.M. of sand (3.2, 2.36 and 1.9) respectively only heat as a method of curing compared with water as method of curing.

The same trend was noticed for heat curing as in water curing. Where 40% and 31% were increasing in the compressive strength for F.M. of sand(1.9 and 2.36) compared with the mixes at F.M. of sand(3.2).

The relation compressive strength and ages for mixes with different aggregate size and used heat as a method of curing was illustrated in Fig. 1.

➢ Effect of Crushed Quartz Powder

Fig. (2) shows the effect of Crushed Quartz Powder on the compressive strength at different ratio (0, 10, 20 and 30%) as a replacement of sand with six ages the compressive strength was calculated up to 365 days (7, 28, 60, 90, 180 and 365 days).Also, the effect of curing was illustrated.

The effect of *Q.P,* of on the compressive strength was disused for the mixes at water curing for different ages as showed in Fig. 2. At *Q.P,* % (10, 20, and 30%) increasing in the compressive strength by (44.4%, 75.6&29%) respectively compared with 0% *Q.P,* with curing water.

The same trend was noticed for heat curing as in water curing. Where 35.7%, 57.14% and 28.6% were increasing in the compressive strength for *Q.P,* % (10, 20, and 30%) respectively compared with the mixes at 0% *Q.P*.

From Fig. 2 when using heat as a method of curing, the compressive strength was increased more than that used water as a method of curing. 46.2%, 39.2% and 55.2% increasing in the compressive strength for the mixes with *Q.P,* % (10, 20, and 30%) respectively only heat as a method of curing compared with water as method of curing.

The relation compressive strength and ages for mixes with different Crushed Quartz Powder and used heat as a method of curing was illustrated in Fig. 2.

➢ Effect of Fly Ash

Fig. 3 shows the effect of Fly Ash on the compressive strength at different percentage of *F.A*(10%, 20%, 30% and 40%) as a replacement of cement at six ages up to 365 days (7, 28, 60, 90, 180 and 365 days). also, the effect of curing was illustrated.

The effect of *F.A.*percentage on the compressive strength was disused for the mixes at water curing for different ages as showed in Fig. 3. At *F.A*(10%, 20% and 30%) increasing in the compressive strength by (20.3%, 29.1& 20.3%) respectively compared with 0% *F.A.*But using 40% of F.A. decreasing the compressive strength by (11.4%) compared with 0% *F.A.* with curing water.

The same trend was noticed for heat curing as in water curing. Where 9.1%, 22.7% and 13.6% were increasing in the compressive strength for *F.A* (10%, 20% and 30%) respectively compared with the mixes at 0% *F.A.* But using 40% of F.A. decreasing the compressive strength by (4.5%) compared with 0% *F.A.*

From Fig. 3 when using heat as a method of curing, the compressive strength was increased more than that used water as a method of curing. 26.3%, 32.3%, 10.5% and 50% increasing in the compressive strength for the mixes with F.A.% (10, 20, 30% and 40%) respectively only heat as a method of curing compared with water as method of curing.

➢ Effect of Metakaolin

Fig. 4 shows the effect of Metakaolin on the compressive strength at different percentage of *M.K.* (5%, 10% and 15%) as a replacement of cement at six ages up to 365 days (7, 28, 60, 90, 180 and 365 days). also, the effect of curing was illustrated.

The effect of *M.K.*% on the compressive strength was disused for the mixes at water curing for different ages as showed in Fig. 3. At *M.K.*(5%) increasing in the compressive strength by (17.6%) but using (10% and 15%) of *M.K.* decreasing the compressive strength by (2%& 6.9%) respectively compared with 0% *M.K.* with curing water.

The same trend was noticed for heat curing as in water curing. Where 11.1%, was increasing in the compressive strength for *M.K.,* % (5%,) but using (10% and 15%) of *M.K.* decreasing the compressive strength by (0%& 7.4%) respectively compared with 0% *M.K*

From Fig. (4) when using heat as a method of curing, the compressive strength was increased more than that used water as a method of curing. 25%, 35% and 31.6% increasing in the compressive strength for the mixes with *M.K.,* % (5%, 10% and 15%) respectively only heat as a method of curing compared with water as method of curing.

The relation compressive strength and ages for mixes with different aggregate size and used heat as a method of curing was illustrated in Fig. 1.

From the results we can conclude that heat curing has important role which effect on the compressive strength of ULPC. And the microstructure properties as in [25].

This effects of the rate of cement hydration and pozzolanic reaction for both, Quartz powder sand, F.A. Also, the strength due to the amount of C.S.H produced and the change in crystal formation from bermorite to xonotlite as in [26].

3.2 Tensile Strength

Figs. 7 to 11 show the comparison between the tensile strength for different UHPCmixes using fine aggregate size and different ratios of crushed quartz powder, fly ash and metakaolin compared to the control mix at different ages of the test.

- **Effect of Aggregate Size**

Fig. 7 shows the effect of F.M. of sandon the tensile strength at different F.M. also the effect of curing was illustrated. Three F.M. of sandwere used (3.2, 2.36, 1.9) two ages the tensile strength was calculated (7 and 28 days).

The effect of F.M. of sandon the tensile strength was disused for the mixes at water curing for different ages as showed in Fig. 1. At 7 and 28 days the F.M. of sand(1.9& 2.36) increasing in the tensile strength by (130.3% &66.7%) and (80% & 40%) respectively compared with F.M. of sand (3.2). with curing water.

The same trend was noticed for heat curing as in water curing. Where (43.75% & 25%) and (40% & 25%) were increasing in the tensile strength for the F.M. of sand(1.9& 2.36) respectively compared with F.M. of sand(3.2) at 7 and 28 days.

From Fig. 7 when using heat as a method of curing, the tensile strength was increased more than that used water as a method of curing. 55.6%, 78.5% and 100% increasing in the tensile strength for the mixes with F.M. of sand(1.9, 2.36 and 3.2) respectively only heat as a method of curing compared with water as method of curing.

The relation tensile strength and ages for mixes with different aggregate size and used heat as a method of curing was illustrated in Fig.1.

- **Effect of Crushed Quartz Powder**

Fig. 8 shows the effect of Crushed Quartz Powder on the tensile strength at different ratio (0, 10, 20 and 30%) as a replacement of sand with two ages (7 and 28) the tensile strength was calculated. Also, the effect of curing was illustrated [27].

The effect of Q.P, of on the tensile strength was disused for the mixes at water curing for different ages as showed in Fig. 8. At Q.P, % (10, 20, and 30%) increasing in the compressive strength by (44.4%, 100&27.8%) respectively compared with 0% Q.P, with curing water.

The same trend was noticed for heat curing as in water curing. Where 35.7%, 57.14% and 28.6% were increasing in the tensile strength for Q.P, % (10, 20, and 30%) respectively compared with the mixes at 0% Q.P.

From Fig. 8 when using heat as a method of curing, the tensile strength was increased more than that used water as a method of curing. 46.2%, 22.2% and 56.5% increasing in the tensile strength for the mixes with Q.P, % (10, 20, and 30%) respectively only heat as a method of curing compared with water as method of curing.

- **Effect of Fly Ash**

Fig. 9 shows the effect of Fly Ash on the tensile strength at different percentage of F.A (10%, 20%, 30% and 40%) as a replacement of cement at two ages (7 and 28 days). also, the effect of curing was illustrated.

The effect of F.A. percentage on the tensile strength was disused for the mixes at water curing for different ages as showed in Fig. 9. At F.A (10%, 20% and 30%) increasing in the tensile strength by (11.1%, 22.2&16.7%) respectively compared with 0% F.A. But using 40% of F.A. decreasing the tensile strength by (5.6%) compared with 0% F.A. with curing water.

The same trend was noticed for heat curing as in water curing. Where 9.1%, 22.7% and 13.6% were increasing in the tensile strength for F.A (10%, 20% and 30%) respectively compared with the mixes at 0% F.A. But using 40% of F.A. decreasing the tensile strength by (4.5%) compared with 0% F.A.

From Fig. 9 when using heat as a method of curing, the tensile strength was increased more than that used water as a method of curing. 20%, 22.7%, 19% and 23.5% increasing in the tensile strength for the mixes with F.A.% (10, 20, 30% and 40%) respectively only heat as a method of curing compared with water as method of curing.

- **Effect of Metakaolin**

Fig. 10 shows the effect of Metakaolin on the tensile strength at different percentage of *M.K.* (5%, 10% and 15%) as a replacement of cement at two ages (7 and 28 days). also, the effect of curing was illustrated.

The effect of *M.K.*% on the tensile strength was disused for the mixes at water curing for different ages as showed in Fig. 10. At *M.K.* (5%) increasing in the tensile strength by (9.1%) but using (10% and 15%) of *M.K.* decreasing the tensile strength by (9.1%&13.6%) respectively compared with 0% *M.K.* with curing water.

The same trend was noticed for heat curing as in water curing. Where 11.1%, was increasing in the tensile strength for *M.K.,* % (5%,) but using (10% and 15%) of *M.K.* decreasing the tensile strength by (0%& 7.4%) respectively compared with 0% *M.K*

From Fig. 10 when using heat as a method of curing, the tensile strength was increased more than that used water as a method of curing. 25%, 35% and 31.6% increasing in the tensile strength for the mixes with *M.K.,* % (5%, 10% and 15%) respectively only heat as a method of curing compared with water as method of curing.

The relation tensile strength and ages for mixes with different Metakaolin and used heat as a method of curing was illustrated in Figs. (10& 11).

3.3 Flexural Strength

Figs. 12 to 16 show the comparison between the flexural strength for different UHPC mixes using fine aggregate size and different ratios of crushed quartz powder, fly ash and metakaolin compared to the control mix at different ages of the test.

- **Effect of Aggregate Size**

Fig. 12 shows the effect of *F.M.* of sandon the flexural strength at different *F.M.* also the effect of curing was illustrated. Three *F.M.* of sandwere used (3.2, 2.36, 1.9) two ages the Flexural strength was calculated (7 and 28 days).

The effect of *F.M.* of sandon the Flexural strength was disused for the mixes at water curing for different ages as showed in Fig. 12. At *F.M.* of sand(1.9& 2.36) increasing in the flexural strength by (60% & 20%) respectively compared with *F.M.* of sand(3.2). with curing water.

The same trend was noticed for heat curing as in water curing. Where (33.3% &22.2%)were increasing in the Flexural strength for the *F.M.* of sand(1.9& 2.36) respectively compared with *F.M.* of sand (3.2).

From Fig. 12 when using heat as a method of curing, the Flexural strength was increased more than that used water as a method of curing. 50%, 83.3% and 80% increasing in the Flexural strength for the mixes with *F.M.* of sand(1.9, 2.36 and 3.2) respectively only heat as a method of curing compared with water as method of curing.

The relation Flexural strength and ages for mixes with different aggregate size and used heat as a method of curing was illustrated in Fig. 12.

- **Effect of Crushed Quartz Powder**

Fig. 13 shows the effect of Crushed Quartz Powder on the flexural strength at different ratio (0, 10, 20 and 30%) as a replacement of sand with two ages (7 and 28) the flexural strength was calculated. Also, the effect of curing was illustrated.

The effect of *Q.P,* of on the flexural strength was disused for the mixes at water curing for different ages as showed in Fig. 2. At *Q.P,* % (10, 20, and 30%) increasing in the flexural strength by (37.5.4%, 100%& 25%) respectively compared with 0% *Q.P,* with curing water.

The same trend was noticed for heat curing as in water curing. Where 33.3%, 58.3% and 33.3% were increasing in the flexural strength for *Q.P,* % (10, 20, and 30%) respectively compared with the mixes at 0% *Q.P*.

From Fig. 13 when using heat as a method of curing, the flexural strength was increased more than that used water as a method of curing. 45.5%, 18.75% and 60% increasing in the flexural strength for the mixes with *Q.P,* % (10, 20, and 30%) respectively only heat as a method of curing compared with water as method of curing.

The relation flexural strength and ages for mixes with different Crushed Quartz Powder and used heat as a method of curing was illustrated in Fig.13.

- **Effect of Fly Ash**

Fig. 14 shows the effect of Fly Ash on the flexural strength at different percentage of F.A (10%, 20%, 30% and 40%) as a replacement of cement at two ages (7 and 28 days). also, the effect of curing was illustrated.

The effect of F.A. percentage on the flexural strength was disused for the mixes at water curing for different ages as showed in Fig. 14. At F.A (10%, 20% and 30%) increasing in the flexural strength by (6.25%, 18.75&12.5%) respectively compared with 0% F.A. But using 40% of F.A. decreasing the flexural strength by (6.25%) compared with 0% F.A. with curing water.

The same trend was noticed for heat curing as in water curing. Where 10.5%, 21% and 15.8% were increasing in the flexural strength for F.A (10%, 20% and 30%) respectively compared with the mixes at 0% F.A. But using 40% of F.A. decreasing the flexural strength by (5.26%) compared with 0% F.A.

From Fig. 14 when using heat as a method of curing, the flexural strength was increased more than that used water as a method of curing. 23.5%, 21%, 22.2% and 20% increasing in the flexural strength for the mixes with F.A.% (10, 20, 30% and 40%) respectively only heat as a method of curing compared with water as method of curing.

- **Effect of Metakaolin**

Fig. 15 shows the effect of Metakaolin on the flexural strength at different percentage of M.K. (5%, 10% and 15%) as a replacement of cement at two ages (7 and 28 days). also, the effect of curing was illustrated.

The effect of M.K.% on the flexural strength was disused for the mixes at water curing for different ages as showed in Fig. 15. At M.K. (5%) increasing in the flexural strength by (10.5%) but using (10% and 15%) of M.K. decreasing the flexural strength by (9.1%& 13.6%) respectively compared with 0% M.K. with curing water.

The same trend was noticed for heat curing as in water curing. Where 11.1%, was increasing in the flexural strength for M.K., % (5%,) but using (10% and 15%) of M.K. decreasing the flexural strength by (10.5%&15.8%) respectively compared with 0% M.K.

From Fig. 15 when using heat as a method of curing, the flexural strength was increased more than that used water as a method of curing. 23.8%, 35.3% and 37.5% increasing in the flexural strength for the mixes with M.K., % (5%, 10% and 15%) respectively only heat as a method of curing compared with water as method of curing.

The relation flexural strength and ages for mixes with different Metakaolin and used heat as a method of curing was illustrated in Figs. 15,16.

3.4 Drying Shrinkage

Figs. 17 to 21 show the comparison between the drying shrinkagefor different UHPCmixes using fine aggregate size to calculate the effect of quartz powder, fly ash and metakaolin.

- **Effect of Aggregate Size**

Fig. 17 shows the effect of F.M. of sandon the drying shrinkage at different F.M. also the effect of curing was illustrated. Three F.M. of sandwere used (3.2, 2.36, 1.9) six ages the drying shrinkage was calculated (0, 7, 28, 90, 180&365 days).

The effect of F.M. of sandon the drying shrinkage was disused for the mixes at water curing for different ages as showed in Fig. 17. At F.M. of sand(1.9& 2.36) increasing in the drying shrinkage by (61% &32%) respectively compared with F.M. of sand(3.2). with curing water.

The same trend was noticed for heat curing as in water curing. Where (42%&17%) were increasing in the drying shrinkage for the F.M. of sand(1.9& 2.36) respectively compared with F.M. of sand(3.2).

From Fig. 17 when using heat as a method of curing, the drying shrinkage was increased more than that used water as a method of curing. 28%, 29.3% and 45% increasing in the drying shrinkage for the mixes with F.M. of sand(1.9, 2.36 and 3.2) respectively only heat as a method of curing compared with water as method of curing.

The relation drying shrinkage and ages for mixes with different aggregate size and used heat as a method of curing was illustrated in Fig. 17.

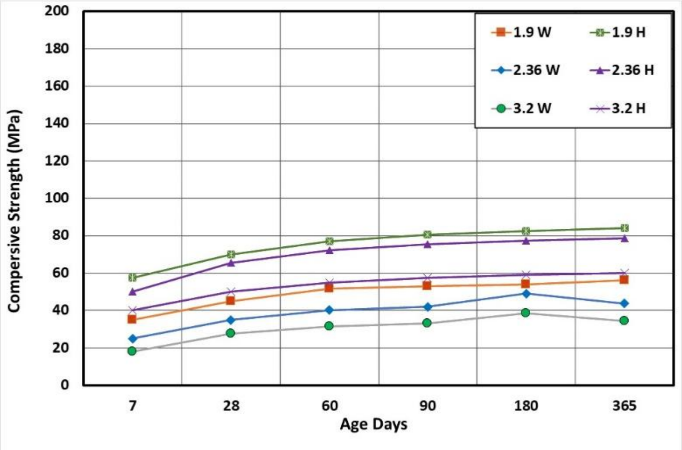


Fig. 1. Compressive strength of mixes with different aggregate size at different Curing and different ages

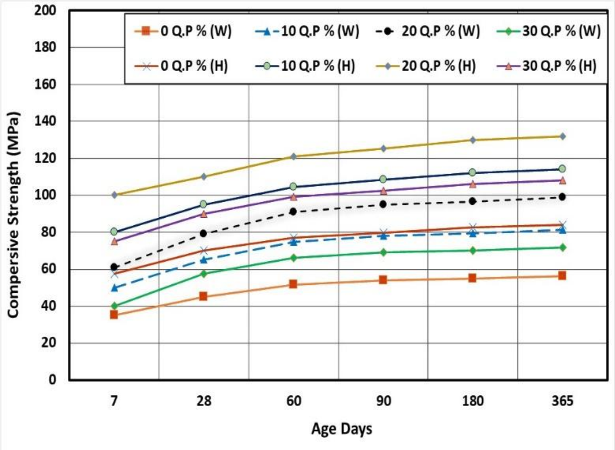


Fig. 2. Compressive strength of mixes with different Quartz Powder % at different Curing and different ages

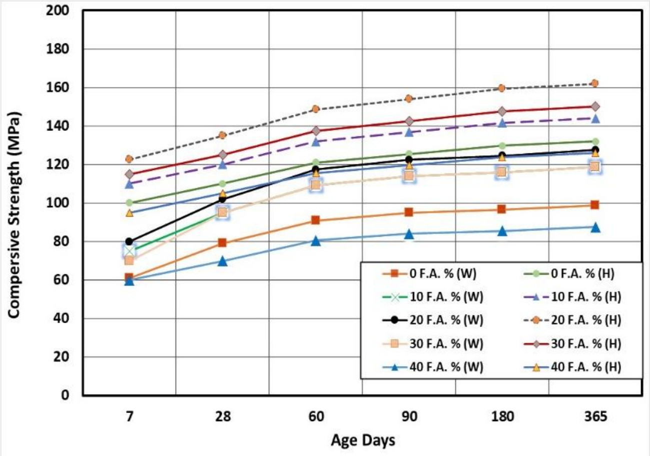


Fig. 3. Compressive strength of mixes with different Fly Ash % at Different Curing at different ages

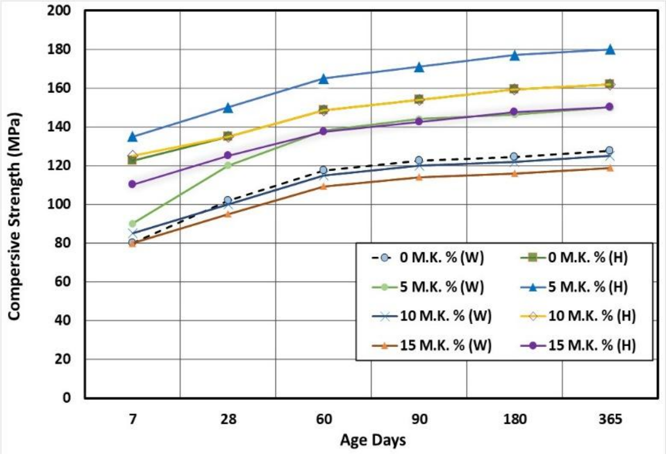


Fig. 4. Compressive strength of mixes with different Metakaolin % at DifferentCuring at different ages

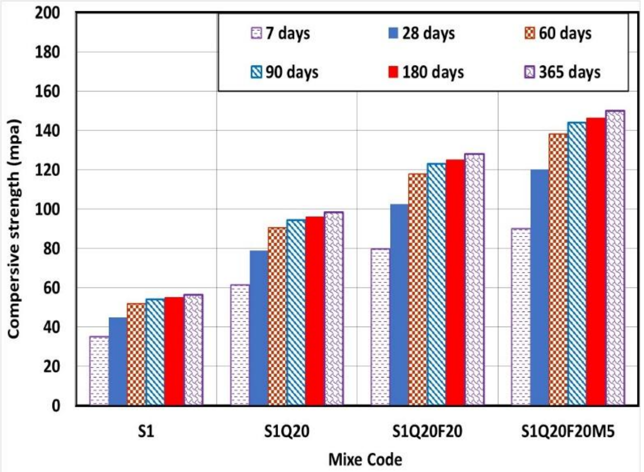


Fig.5. Compressive strength of optimum % for different variables at water Curing at different ages

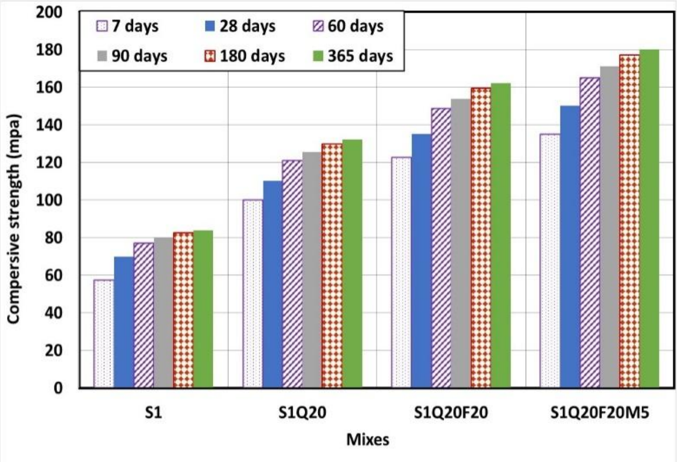


Fig.6. Compressive strength ofoptimum % for different variables at Heat Curing at different ages

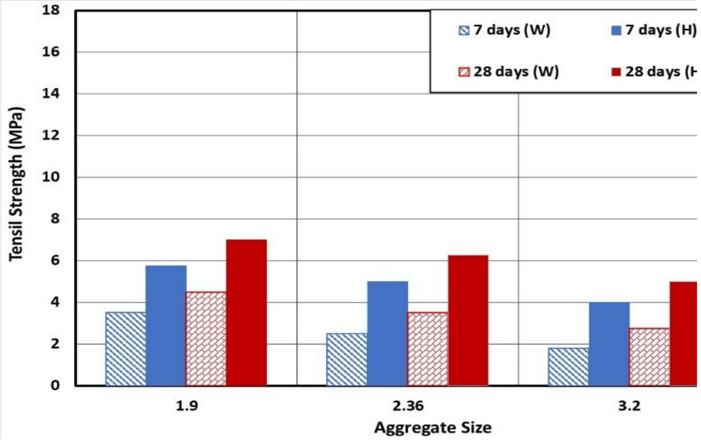


Fig. 7. Tensile Strength of Mixes with Different Aggregate Size at Different Curing and Different Ages

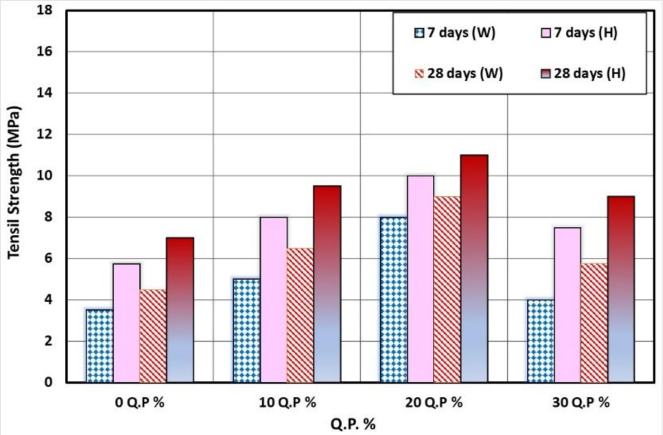


Fig. 8. Tensile Strength of Mixes with Different Quartz Powder % at Different Curing and Different Ages

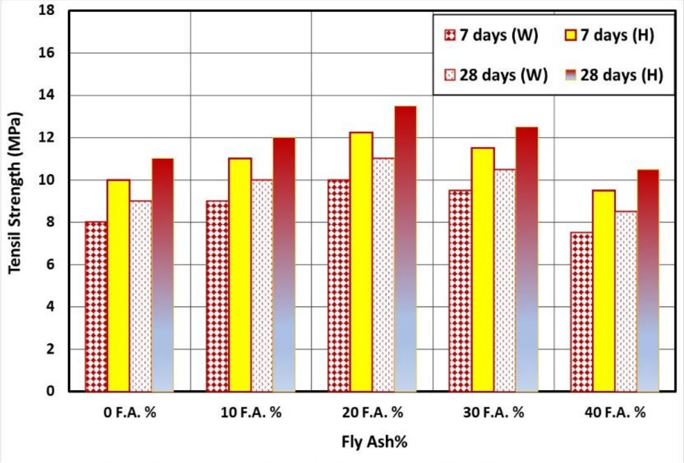


Fig. 9. Tensile Strength of Mixes with Different Fly Ash % at Different Curing and Different Ages

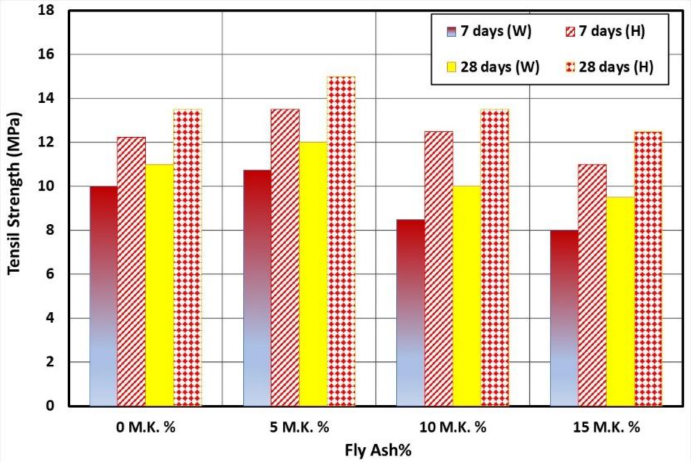


Fig. 10. Tensile Strength of Mixes with Different Metakaolin % at Different Curing and Different Ages

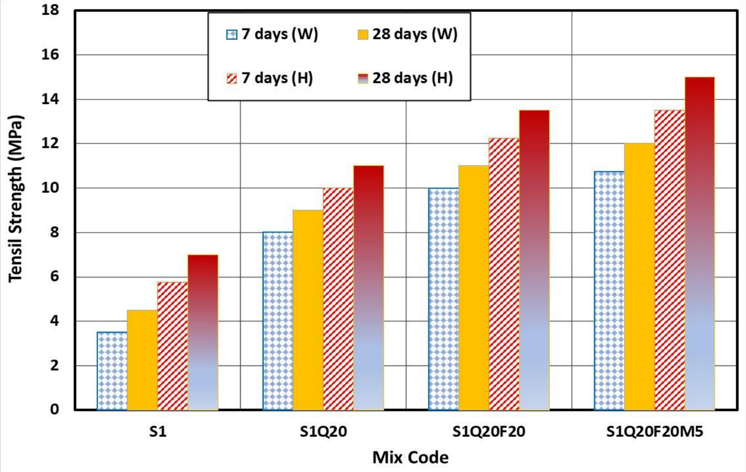
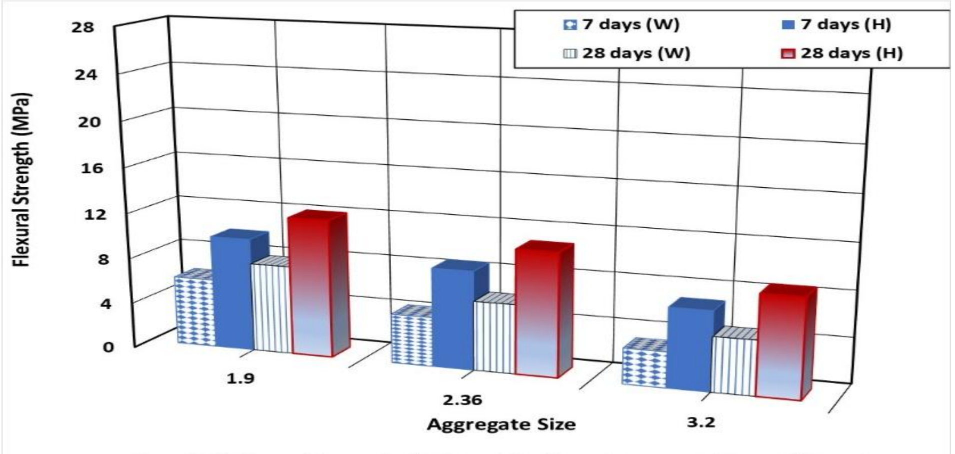


Fig. 11. Tensile Strength of Optimum Mixes with Different Variables at Different Ages



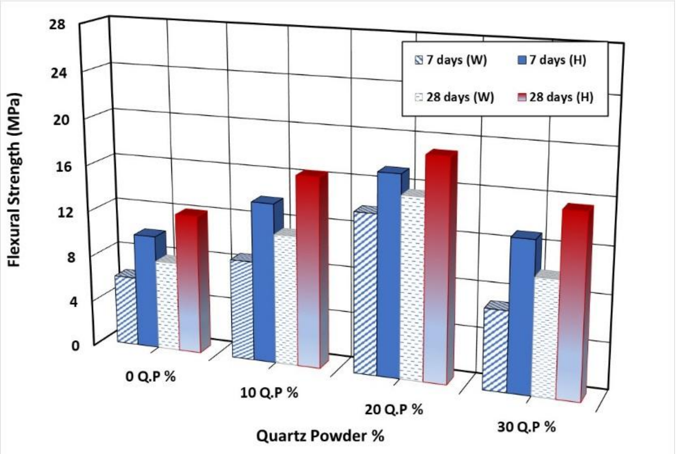
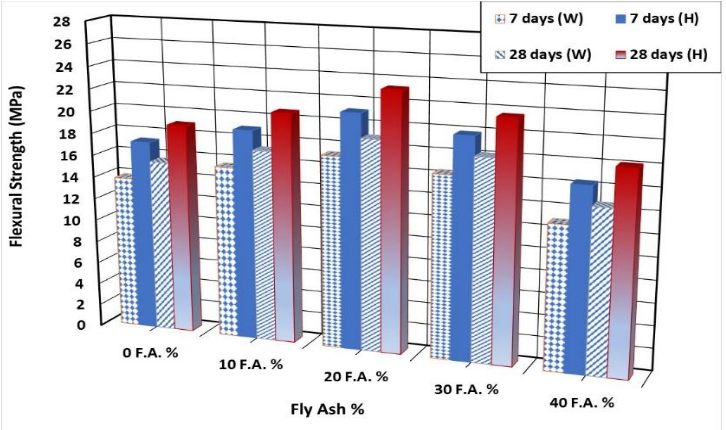


Fig. 12. Flexural Strength of Mixes with Different Aggregate Size at Different Ages with Different curing

Fig. 13. Flexural Strength of Mixes with Quartz Powder % at Different Ages with Different curing



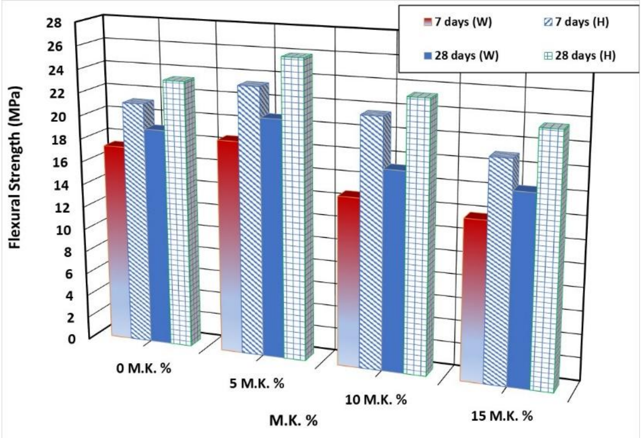


Fig. 14. Flexural Strength of Mixes with Fly Ash % at Different Ages with Different curing

Fig. 15. Flexural Strength of Mixes with Metakaolin % at Different Ages with Different curing

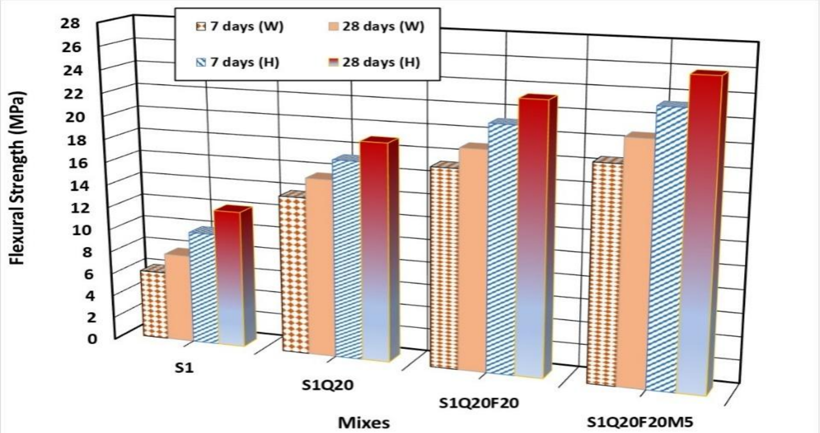


Fig. 16. Flexural Strength of Optimum Mixes with Different Variables at Different Ages with Different Curing

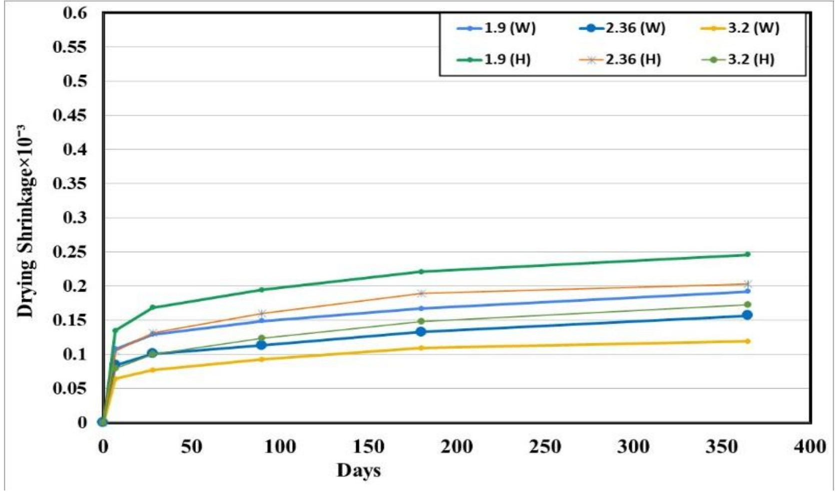


Fig. 17. Drying Shrinkage of Mixes with Different Aggregate Size at Different Agesat curing

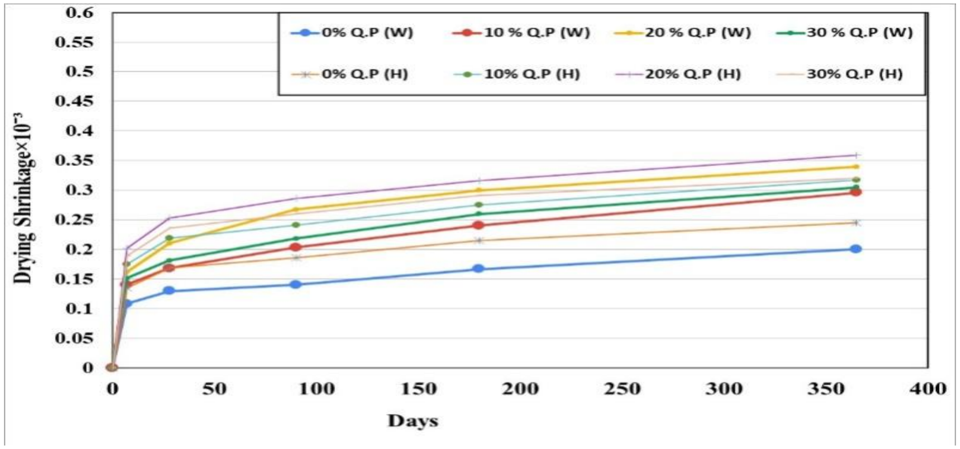


Fig. 18. Drying Shrinkage of Mixes with Different Quartz Powder%at Different Agesat curing

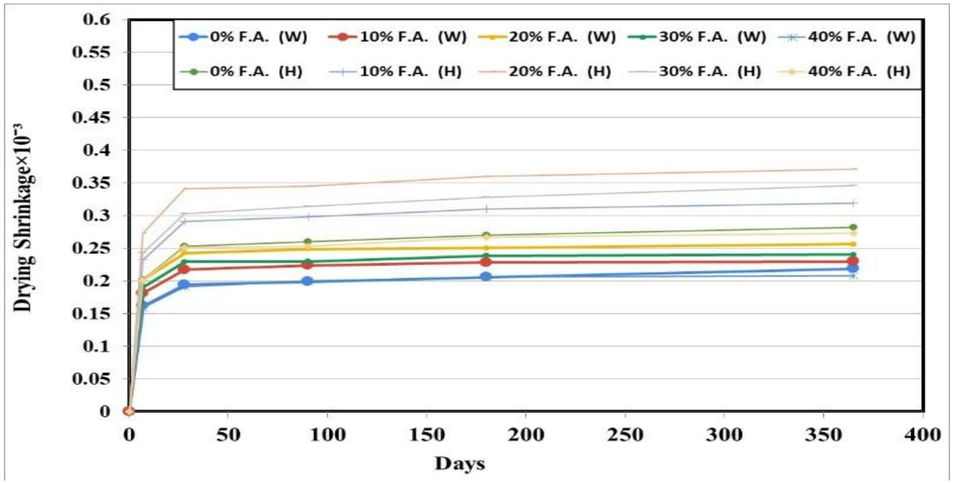


Fig. 19. Drying Shrinkage of Mixes with Different Fly Ash%at Different Agesat curing

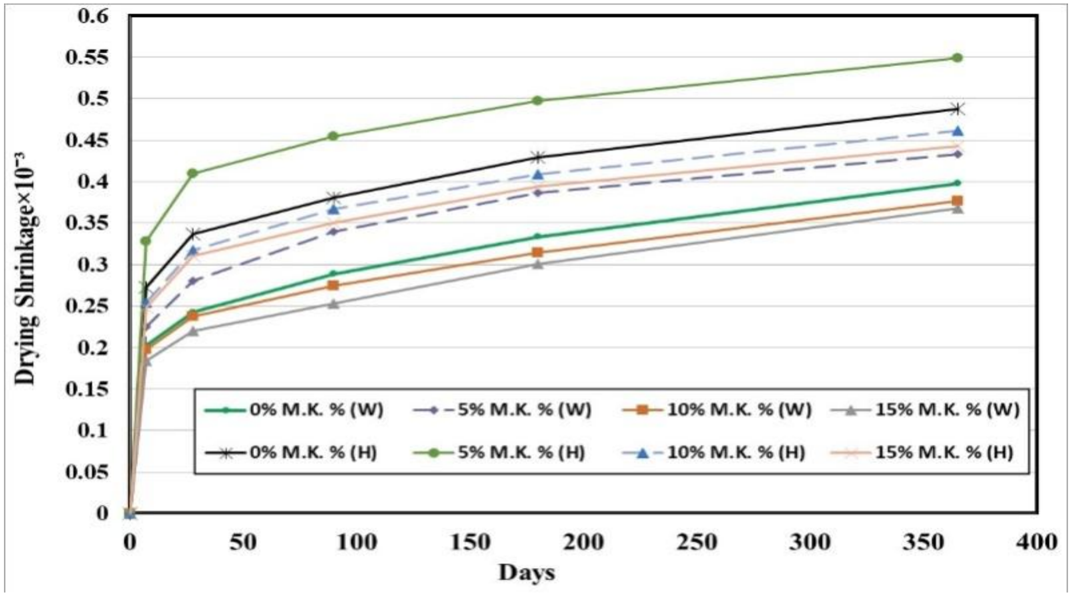


Fig. 20. Drying Shrinkage of Mixes with Different Methacholine %at Different Agesat curing

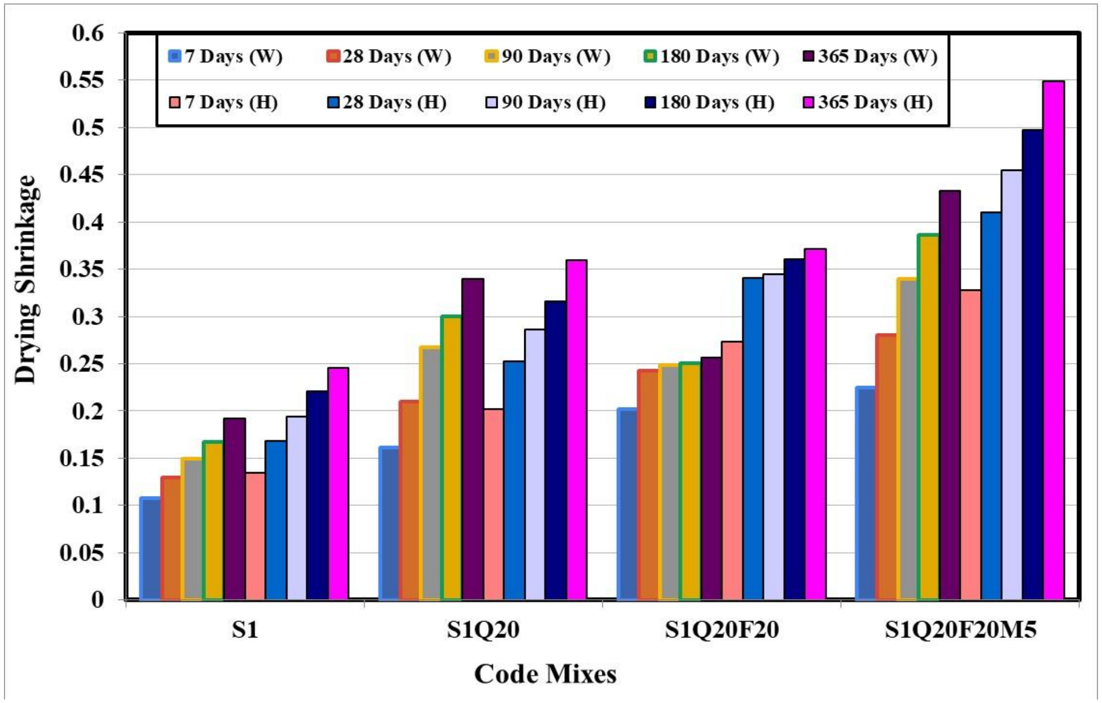


Fig. 21. Drying Shrinkage of the Optimum Mixes with Different Variables at Different Ages

- **Effect of Crushed Quartz Powder**

Fig. 18 shows the effect of Crushed Quartz Powder on the drying shrinkage at different ratio (0, 10, 20 and 30%) as a replacement of sand with two ages (7 and 28) the drying shrinkage was calculated. Also, the effect of curing was illustrated.

The effect of Q.P, of on the flexural strength was disused for the mixes at water curing for different ages as showed in Fig. 18. At Q.P, % (10, 20, and 30%) increasing in the drying shrinkage by (48%, 70%&52.3%) respectively compared with 0% Q.P, with curing water.

The same trend was noticed for heat curing as in water curing. Where 29.4%, 46.6% and 30.6% were increasing in the drying shrinkage for Q.P, % (10, 20, and 30%) respectively compared with the mixes at 0% Q.P.

From Fig. 18 when using heat as a method of curing, the drying shrinkage was increased more than that used water as a method of curing. 7.16%, 5.8% and 5% increasing in the flexural strength for the mixes with Q.P, % (10, 20, and 30%) respectively only heat as a method of curing compared with water as method of curing.

The relation drying shrinkage and ages for mixes with different Crushed Quartz Powder and used heat as a method of curing was illustrated in Fig. 18.

- **Effect of Fly Ash**

Fig. 19 shows the effect of Fly Ash on the drying shrinkage at different percentage of F.A (10%, 20%, 30% and 40%) as a replacement of cement at different ages (7 , 28, 90, 180& 365 days). also, the effect of curing was illustrated.

The effect of F.A. percentage on the drying shrinkage was disused for the mixes at water curing for different ages as showed in Fig. 19. At F.A (10%, 20% and 30%) increasing in the drying shrinkage by (5%, 17.1&9.7%) respectively compared with 0% F.A. But using 40% of F.A. decreasing the drying shrinkage by (4.8%) compared with 0% F.A. with curing water.

The same trend was noticed for heat curing as in water curing. Where 13.15%, 31.5% and 22.6% were increasing in the drying shrinkage for F.A (10%, 20% and 30%) respectively compared with the mixes at 0% F.A. But using 40% of F.A. decreasing the drying shrinkage by (3.3%) compared with 0% F.A.

From Fig. 19 when using heat as a method of curing, the drying shrinkage was increased more than that used water as a method of curing. 38.9%, 44.8%, 44% and 31% increasing in the drying shrinkage for the mixes with F.A.% (10, 20, 30% and 40%) respectively only heat as a method of curing compared with water as method of curing.

- **Effect of Metakaolin**

Fig. 20 shows the effect of Metakaolin on the drying shrinkage at different percentage of M.K. (5%, 10% and 15%) as a replacement of cement at different ages (7, 28, 90, 180& 365 days). also, the effect of curing was illustrated.

The effect of M.K.% on the drying shrinkage was disused for the mixes at water curing for different ages as showed in Fig. 20. At M.K. (5%) increasing in the drying shrinkage by (8.8%) but using (10% and 15%) of M.K. decreasing the drying shrinkage by (5.4%&7.5%) respectively compared with 0% M.K. with curing water.

The same trend was noticed for heat curing as in water curing. Where 12.5%, was increasing in the drying shrinkage for M.K., % (5%,) but using (10% and 15%) of M.K. decreasing the drying shrinkage by (5.5%&9.1%) respectively compared with 0% M.K.

From Fig. 20 when using heat as a method of curing, the drying shrinkage was increased more than that used water as a method of curing. 26.8%, 22.5% and 20.5% increasing in the drying shrinkage for the mixes with M.K., % (5%, 10% and 15%) respectively only heat as a method of curing compared with water as method of curing.

The relation drying shrinkage and ages for mixes with different Metakaolin and used heat as a method of curing was illustrated in Figs. (20,21).

4. CONCLUSIONS

1) It is available to produce UHPC by using locally available materials in Egyptian market when they carefully selected, and mixes achieved high values of mechanical properties of UHPC.
2) Compressive strength 180 MPa was achieved experimentally in mixture number

11 by using (0.15:1.18 mm) aggregate size, 20% ratio of crushed quartz powder to fine sand (CQ/S), 20% ratio of fly ash to cement (FA/C), 5% ratio of metakaolin to cement (MK/C), 900 Kg/m^{3}cement content, 20% (W/C) and 2% superplasticizers.

3) Tensile strength 15 MPa was achieved experimentally in mixture number 11 by using fixed cement content 900 Kg/m^3, (0.15:1.18 mm) aggregate size, 20% ratio of crushed quartz powder to fine sand (CQ/S), 20% ratio of fly ash to cement (FA/C), 5% ratio of metakaolin to cement (MK/C), 20% (W/C) and 2% superplasticizers.

4) Flexural strength 26 MPa was achieved experimentally in mixture number 11 by using fixed cement content 900 Kg/m^3, (0.15:1.18 mm) aggregate size, 20% ratio of crushed quartz powder to fine sand (CQ/S), 20% ratio of fly ash to cement (FA/C), 5% ratio of metakaolin to cement (MK/C), 20% (W/C) and 2% superplasticizers.

5) Drying shrinkage 0.41 MPa was achieved experimentally in mixture number 11 by using (0.15:1.18 mm) aggregate size, 20% ratio of crushed quartz powder to fine sand (CQ/S), 20% ratio of fly ash to cement (FA/C), 5% ratio of metakaolin to cement (MK/C), 900 Kg/m3 cement content, 20% (W/C) and 2% superplasticizers.

6) Aggregate size (0.15:1.18 mm) achieved the highest compressive strength, tensile strength, flexural strength and drying shrinkage among the three used sizes in this study.

7) 20% ratio of crushed quartz powder to fine sand (CQ/S), 20% ratio of fly ash to cement (FA/C) and 5% ratio of metakaolin to cement (MK/C) were achieved the highest compressive strength, tensile strength, flexural strength and drying shrinkage among the other used sizes in this study.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Mestrovic D, Cizmar D, Stanilovic V, “Reactive Powder Concrete: Material for the 21 st Century”, WIT Transactions on Engineering Sciences, 2007; 57:127-133.
2. Wan L. “Experimental and Computational Analysis of the Behavior of Ultra High-Performance Concrete, Prestressed Concrete, and Waterless Martian Concrete at Early Age and Beyond”, Doctoral dissertation, Northwestern University; 2015.
3. Yu R., Spiesz V, Brouwers H, J.H., January, “Mix Design and Properties Evaluation of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC)”, In Proceedings of the International Symposium on Interaction of the Effects of Munitions with Structures; 2013.
4. Vyas AS. Gangwar, R. Vyas, “Retrofitting of Concrete Structures Using Reactive Powder Concrete": A Review International Journal of Engineering Sciences &Research Technology, 2018;7(1):397-402.
5. Lee TH, Yang DH, Kwon MJ, Kim JHJ. Blast-Resistance of Ultra-High strength Concrete and Reactive Powder Concrete", Journal of Asian Concrete Federation, 2017;3(2):98-104.
6. Yalçinkaya Ç, Sznajder J, Beglarigale A, Sancakoglu O, Yazici H. Abrasion Resistance of Reactive Powder Concrete: the Influence of Water-to-Cement ratio and Steel Micro-Fibers", Advanced Materials Letters, 2014;5(6): 345-351.
7. Villanueva, Jesus Muro. “Mixture Proportioning and Freezing and Thawing Durability of Ultra High Performance Concrete Mixtures using Local Materials", New Mexico State University; 2015.
8. Wille K, Kim DJ, Naaman AE. “Strain-Hardening UHP-FRC with Low Fiber

Contents", Materials and Structures, 2011;44(3):583-598.

9. Shi C, Wang D, Wu L, Wu Z. The Hydration and Microstructure of Ultra-High- Strength Concrete with Cement-Silica Fume- Slag Binder", Cement and Concrete Composites, 2011;61:44-52.
10. Sbia LA. Contributions and Mechanisms of Action of Graphite Nano materials in Ultra High-Performance Concrete", Michigan State University; 2014.
11. Abdel Raheem AH, Tahwia AM, Sultan H. Ultra High Performance Fiber-Reinforced Concrete (Doctoral Dissertation, University of Mansoura); 2016.
12. Schmidt M, Fehling E, Geisenhanslüke C "Ultra High-Performance Concrete (UHPC)", In Proceedings of the International Symposium on Ultra High-Performance Concrete, Kassel, Germany. University of Kassel, Germany; 2004.
13. K. Kumaresan,(2011), "Ultra-High-Performance Concrete and Lattice Models", M.Sc., Thesis, Faculty of Virginia Polytechnic Institute and State University, USA.
14. Lei VY, Nematollahi B, Said, ABM, Gopal BA, Yee TS. Application of Ultra High Performance Fiber Reinforced Concrete-the Malaysia Perspective. International Journal of Sustainable- Construction Engineering and Technology, 2012; 3(1):26-44
15. E.S.S.4756-1/2013, "Portland Cement, Ordinary and Rapid Hardening", Ministry of Industry, Cairo, Egypt; 2013.
16. E.S.S.1109/2008, "Aggregates for Concrete", Ministry of Industry, Cairo, Egypt; 2008.
17. E.C.P.203/2018, "Egyptian Code of Practice: Design and Construction for Reinforced Concrete Structures", Research Centre for Houses Building and Physical Planning, Cairo, Egypt;' 2018.
18. ASTM.C-616. Specification for Quartz-Based Dimension Stone. American Society for Testing and Materials ASTM International, Philadelphia, USA; 2003.
19. ASTM.C-494. Chemical Admixtures for Concrete", American Society for Testing and Materials ASTM International, Philadelphia, USA; 2015.
20. ASTM.C-618, 2005,"Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete American Society for Testing and Materials ASTM International, Philadelphia, USA. (2005).
21. ASTM.C618-15. standard Specificationfor Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. ASTM International, West Conshohocken, PA, 2015;5.
22. ASTM C305. Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency. ASTM International, West Conshohocken, PA, 2014;3.
23. Chang PK, Peng YN. Influence of Mixing Techniques on Properties of High-Performance Concrete. Cement and Concrete Research, 2001;3(1):87-95.
24. ASTM C192. Standard Practice for Making Concrete and Curing Tests Specimens in the Laboratory. American Society for Testing and MaterialsStandard Practice 192, Philadelphia, Pennsylvania; 2004
25. Cwirzen A. Adv. in Cem. Res. 2007;19:1
26. Tam CM, VWY. Tam, Mag. of Con. Res. 2012;64:3
27. Helmi M, Hall MR, Rigby SP. Effect of Pressure and Heat Treatments on the Compressive Strength of Reactive Powder Concrete" MATEC Web of Conferences 2018;147: 01006 Available:https://doi.org/10.1051/matecconf/201814701006, SIBE 2017

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