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PROPERTIES OF ULTRA-HIGH PERFORMANCE FIBER CONCRETE (UHPFC) UNDER DIFFERENT CURING REGIMES

Lawend K. Askar
Highways and Bridges Engineering,
Duhok Polytechnic Uuniversity, Kurdistan Region - Iraq

Bassam A. Tayeh
Civil Engineering Department, Islamic University of Gaza, Gaza, Palestine
Buildings Technology Engineering Department, University College of Applied Sciences, Gaza, Palestine

B. H. Abu Bakar
School of Civil Engineering, Engineering Campus,
Universiti Sains Malaysia, Penang Malaysia

A.M. Zeyad
Department of Civil Engineering, Jazan University, Saudi Arabia

ABSTRACT

Ultra-High Performance Fiber Concrete (UHPFC) is one of the breakthroughs in the 21st century in the field of concrete technology where this composite material providing an important improvement in strength, workability, ductility and durability when compared with normal concrete. This paper discusses the influence of different curing conditions on the mechanical properties of UHPFC and the bonding between UHPFC and bar of 12 mm in diameter. An experimental program was performed to study the mechanical properties of UHPFC which were cured under six different curing conditions. Test results indicated that steam and boil curing methods showed a promising performance particularly at early age of curing compared to other type of curing. The results of pull out test showed that the failure was in bar (bar rapture failure) in all type of curing regimes.

Key words: UHPFC, Curing Regimes, Compressive Strength, Flexure Strength, Ultrasonic Pulse Velocity (UPV), Pull Out, Steam Curing.

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1. INTRODUCTION

Concrete has occupied an important place among construction materials and is widely used in all types of civil engineering structures ranging from small buildings to huge ones. Advances in the science of concrete materials have led to the development of new class of cementations composites; namely, UHPFC [1, 2]. The mechanical and durability of UHPFC made it an ideal alternative material for use in developing new solutions to pressing concerns about highway infrastructure deterioration, repair, and replacement; in particular, when UHPFC became commercially available worldwide therefore many more are actively considering the use of UHPFC [3, 4]. It is defined that "curing is the name given to procedures used for enhance the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete"[5, 6]. Barring of any of the moist curing parameters such as humidity or temperature adversely affects the compressive strength of the Portland cement concrete. Although curing is an important aspect in the production of good concrete, the timing and duration of curing is more important [7]. Curing leads to better strength development because allows more water to be made available for the hydration reaction of the concrete's cement paste. It is also to improve the ultimate compressive strength improves resistance to abrasion and reduces surface dusting [8].

Bond resistance is made up of chemical adhesion, friction and mechanical interlock between the bar and surrounding concrete. In the plain bars, only the first two of these components contribute to the bond strength. In the deformed bars, the surface protrusions or ribs interlocking with and bearing against the concrete key formed between the ribs contribute more positively to bond strength, and is the major reason for their superior bond effectiveness [9].

The objective of this study is to determine the mechanical properties of Ultra-High Performance Fiber Concrete due to different curing condition and, to identify appropriate curing condition of UHPFC and to study the bonding between UHPFC and Bar of 12mm in diameter.

2. EXPERIMENTAL DETAILS

2.1. UHPFC mix

A typical UHPFC mix contains cement, sand, silica fume, steel fiber, superplasticizer, and water in the ranges shown in Table 1. Mix compositions of materials which was used in this experiment reported in terms of weight per unit volume. The function of these fibers within UHPFC is to enhance tensile strength of concrete. Superplasticizers (high range water reducers) was used as chemical admixtures which can maintain the workability required. This mix was obtained by using DOE program.

Table 1 UHPFC mix proportion of materials

Material	Amount (Kg/m3)	Percent by weight
Portland cement	825	33.60
Fine Sand	1140	46.43
Silica Fume	181	7.37
Superplasticizer	45	1.83
Steel Fibers	90	3.66
Water	174	7.08
Water/binder ratio	174/1006	0.17

2.2. Preparation of concrete mixture and samples

A mechanical mixer with capacity of 0.25 m^3 operated by electrical power was used in preparing samples. The procedure of mixing was as follows; prepare the required sand in terms of weighing and sieving, silica fume and cement placed in the mixer in a sequence manner, in other words, sand is first put in the mixer followed by the silica fume and finally the cement. Then, the dry materials were well-mixed to obtain a uniformed mixture and before adding water, superplasticizer was added to a mixture. Finally, steel fiber was added to the mixture; afterwards, the whole ingredients of the mixture were mixed to obtain a homogenous mixture with reduction in binder ratio equal to 0.17.

In preparation of specimens, there were 72 cubes (100mm x 100mm x 100mm), 72 beams (280mm x 70mm x 70mm), 48 cylinders (50mmx100mm) and 18 cylinders (100mm x200mm) including controlled specimens. The moulds were cleaned and the internal surface was oiled to prevent the adhesion of concrete after hardening. UHPFC casting was carried out in three layers. Each layer was compacted by using a vibrating table until no air bubbles emerged from the surface of the concrete. Then, the concrete was levelled off smoothly to the top of moulds. Moreover, the specimens were covered with polyethylene sheet in the laboratory for about 24 hrs and the specimens were then remolded carefully and cured by different methods.

2.3. Curing regimes

After the casting process was completed, the concrete should be prevented from premature drying, and avoid the varying in temperature. These precautions are necessary in order to protect the concrete from a negative impact on methods of curing. In this study, six curing methods were used as follows:

- Spraying specimens with water (fog room).
- Immersing specimens in water.
- Normal curing.
- Boiling Water curing method.
- Steam cured after one day casting.
- Steam cured after two days casting.

In fog room curing method, the specimens were tested after 3, 7, 14 and 28 days. However, concrete should first be kept in the cube for 24 hours before curing. UHPFC specimens were placed in the fog room along the process of curing. The specimens in the immersing water method placed in the lab for 24 hours to complete process of hardening. The specimens were demolding carefully. The specimens were immersing in water until the finishing operation complete within ages.

The third method was normal curing method, after complete the 24 hours. UHPFC specimens were placed in ambient weather with temperature nearly to, 28 ºC. This type of curing has four ages for specimens; 3 days, 7days, 14days, and the final age were 28 days.

Another method of curing was referred to as boiling water curing method; the specimens were moist-cured in the laboratory for 23 hours. After elapsing the 23 hours, the specimens were lowered into the boiling curing tank for 3.5 hours with a 100 ºC temperature. The total time for cooling the specimens was 28.5 hours, then immersed in water until completing the ages test for specimens.

In Steam cured, casting specimens were Left for one day after casting without curing, apply curing treatment includes steaming the UHPFC at 90 ºC for 60 hours (Including 6 hour ramp up and 6 hour ramp down times). All specimens were removed after the 60 hour cure process after this stage [10, 11].

The last method of curing is Steam cured after two days, it is very similar to the process conducted in one-day steam cured; however, the delay with this method is extended into two days instead of one which is the only difference with the pre-mentioned one-day approach.

2.4. Compressive Strength Test

A machine with a capacity of 1000 KN was utilized and the load was applied at a rate of 0.3 KN/sec. The specimens of concrete were (100 x 100 x 100) mm cubs that have three cubes per age. A total of three specimens were tested in compression at 3, 7, 14 and 28 days of curing. The maximum Compressive strengths recorded from each of these tests were averaged for each testing day.

2.5. Flexure Strength

Flexure strength represent one of the most important mechanical properties of concrete. The machine for testing flexure strength has four rollers :the distance between two above rollers was third of the depth specimen, the distance between the two bottom rollers was three times of depth specimen according to [12]. The dimension of the specimens was (70x70x280) mm . The two Prism specimens are tested for each age with following periods 3, 7, 14, and28 days of curing.

2.6. Static modulus of elasticity

The modulus of elasticity was tested on diameter 50 mm and height 100mm cylindrical specimens. The test of modulus of elasticity was according to (ASTM C 469-94, 2004). The apparatus used to testing modulus of elasticity was with capacity of 1000 kN. The load was applied at a rate of 0.241 MPa/sec. The modulus of elasticity provides stress-strain relationship or forces-deformation relationship. Three cylinder specimens were tested for each age with following periods 3, 7, 14, and 28 days of curing.

2.7. Ultrasonic pulse velocity (UPV)

The ultrasonic pulse velocity test was carried out according to ASTM C 597 – 97, 2004. Testing Instruments were used for measuring UPV.

The test operation is waving velocity which dependent on the elastic properties and density of material. Best results are therefore obtained when the receiving transducer is placed on the opposite face of the concrete member. This is so called Direct Transmission. Ultrasonic pulse velocity measurements are influenced by surface condition, moisture content, temperature of concrete, path length, shape and size of member. Petroleum jelly was used between the surfaces of the specimens and the contact faces of the transducers to ensure good contact. Then the average results were taken. The UPV was calculated according to the equation below:

V=L/T (1)

Where,

V: The pulse velocity (mm/second).

L: Length between the two surfaces of the sample on test direction (mm).

T: Transit time (sec).

Table 2 Limit of pulse velocity (IS 13311, 1992)

Concrete Type	UPV (m/sec)
Excellent	Above 4500
Good	3500 to 4500
Medium	3000 to 3500
Doubtful	Below 3000

2.8. Pull Out Test

A hollow hydraulic machine with a maximum loading capacity of 30 ton was used to perform current bond tests. The load was applied with a rate of 2 kN/sec and distributed over a specimen surface by a square steel plate of 20 cm size with a hole at the centre. A bar was inserted into a fresh concrete, the pullout strength is determined by measuring the maximum force required to pull the insert bar from the concrete mass [13]. The utilized specimens were of cylindrical shape with the following dimensions; 20 mm x10 mm. All the specimens were tested at the age of 7 days.

3. RESULT AND DISCUSSION

3.1. Compressive strength

The results of compressive strength tests for all specimens and at all conditions are demonstrated in Table 3. Each value represents the average of three specimens.

Table 3 Compressive Strength Test

Curing Condition	Compressive Strength (MPa)			
	3 days	**7 days**	**14 days**	**28 days**
Steam Curing one day delay	164.45	169.59	171.86	173.6
Steam Curing two days delay		166.35	168.58	170.54
boiling Curing	163.63	167.74	170.39	172.48
Fog room Curing	119.31	137.62	150.49	158.28
Water Curing	119.86	139.74	152.36	159.86
Normal Curing	117.17	132.93	144.67	152.63

The results in Table3 indicates that all types of curing methods the compressive strength is proportionally increase with curing ages. In steam curing method, UHPFC has a relatively higher compressive strength with 28 days [14]. The compressive strength on the 28th day for UHPFC is 173.60 MPa. In terms of strength development, it is shown that UHPFC has a gradually increased strength development. In other words, the UHPFC strength increased regularly day by day until the 28th day. Steam curing two-day delay and boiling curing obtained a compressive strength of 170.54 MPa and 172.84 MPa respectively by the 28th day. The result shows that steam curing and boil curing methods increase the compressive strength in the first age of curing. Steam curing and boil curing is a methods used to accelerate the rate of strength development of concrete. In the case of curing of concrete by fog are the same conditions surrounding the concrete as in the case of curing by water curing method and the results obtained were very little different from those obtained with a fog method. The compressive strength at the 28th day the fog room curing and immersion water curing are 161.28 MPa and 162.86 MPa respectively. In Normal curing the compressive strength in 28 days was 155.63 MPa this value is lowest result in different curing regimes in 28 days. Increased strength development in normal curing method slower than fog, water, steam, and boil curing method due to that slower hydration process occurs because of the lack of water.

3.2. Flexure Strength

The effect of different curing methods on the flexure strength of UHPFC could be notice in Table 4.

Table 4 Flexure Strength Test

Curing Condtion	Flexure Strength (Mpa)			
	3 days	7 days	14 days	28 days
Steam Curing one day delay	25.72	26.43	27.32	27.92
Steam Curing two days delay		25.64	26.32	26.86
boiling Curing	25.27	25.83	26.76	27.42
Fog room Curing	16.68	18.75	20.34	21.64
Water Curing	16.95	19.31	21.16	22.21
Normal Curing	15.93	17.62	18.71	19.69

Flexural testing was conducted at 28 days on prisms that underwent six curing regimes. A total of 72 prisms were test. The flexure strength on the 28th day for UHPFC is 27.92 MPa in the case of steam curing one day delay [15]. Steam curing tow day delay and boil curing obtained flexure strength of 26.68 MPa and 27.42MPa respectively by the 28th day. In the case of curing of concrete by fog are the same conditions surrounding the concrete as in the case of curing by water curing method and the results obtained were very little different from those obtained with a fog method. The flexure strength at the 28th day the fog room curing and immersion water curing are 21.64 MPa and 22.21 MPa respectively. In Normal curing the flexure strength in 28 days was 19.69 MPa this value is lowest result in flexure strength under different curing regimes in 28 days. This result indicates that the UHPFC mechanical properties gradually increased until the 28th day. Also the first three methods used to accelerate the rate of flexure strength of UHPFC in the first age of curing. However, increased flexural strength in natural weather curing method slower than other methods due to slower hydration process occurs.

3.3. Modulus of Elasticity

The results of modulus of elasticity tests for Ultra-High Performance Fiber concrete specimens at all conditions are illustrated in Table 5. Each value represents the average of three specimens.

Table 5 Modulus of elasticity at 3, 7, 14, and 28 days of curing.

curing Method	Modulus Of Elasticity			
	3 days	7 days	14 days	28 days
Steam Curing one day delay	49.17	49.91	50.24	50.52
Steam Curing two days delay		49.46	49.82	50.13
boiling Curing	49.5	49.74	49.97	50.17
Fog room Curing	42.32	44.59	46.43	47.52
Water Curing	43.67	45.17	46.66	47.55
Normal Curing	41.56	44.37	46.02	46.9

The results indicated that in all curing regimes, the modulus of elasticity increases steadily until the 28th day. In other words, the results indicated that all specimens of curing regimes exhibited a gradual increase in modulus of elasticity with development of curing ages. At 3 days of curing the highest value of modulus of elasticity for steam curing one day delay and the lowest value of modulus of elasticity for normal curing are 49.47 GPa and 41.56 GPa, respectively. The boil curing has nearly the value for steam curing the modulus of elasticity at 3 days of curing is 49.35 GPa. This indicates that the steam and boil curing accelerate modulus of elasticity at the first age of curing. At 28 days curing the highest value of the modulus of elasticity is 50.52 GPa for steam curing one day delay.

In curing of UHPFC by steam two days delay the modulus of elasticity at the 28th day is 50.13 GPa. This is almost equivalent to modulus of elasticity cured in boil at the age of 28 days. In fog room method the modulus of elasticity at 28 days is 47.52 GPa. In water curing method the modulus of elasticity at 28 days is 47.55 GPa. The final result at 28 days and the lowest magnitude for normal curing is 46.9 GPa. it is observed that the highest results were obtained in steam curing methods and boil curing method at 28 days curing.

It is important to know that the results indicate that steam curing one day delay has the highest value in modulus of elasticity, in addition the steam and boil curing increase the modulus of elasticity at the first age of curing which means steam and boil curing can be used to accelerate the modulus of elasticity at first age of curing. Lower compressive strength values for UHPFC subjected to normal curing shows that slower hydration process occurs in the UHPFC sample compared to the other curing methods.

It can be said from the results, the reason for this increase in modulus of elasticity may be the same reason as for the increase of compressive strength and flexural strength, which is discussed in section 4.4 and 4.5. However, the results of modulus of elasticity test indicated that the six curing methods have continuous increase in modulus of elasticity with development of curing ages.

The results indicated the differences of modulus of elasticity with different curing regimes**.**

3.4. Ultrasonic Pulse Velocity test (UPV)

The results of the ultrasonic pulse velocity test for Ultra-High Performance Fiber concrete specimens and at all conditions are illustrated in Table 6. It can be observed the effect of six curing methods on the ultrasonic pulse velocity. Each value represents the average of three specimens.

Table 6 Ultrasonic Pulse Velocity at 3,7,14, and 28 days for UHPFC

Curing Method	Age (days)	Pulse Velocity (m/sec)	Concrete Quality
Steam curing after one day delay	3 days	8340	Excellent
	7 days	8580	Excellent
	14 days	8890	Excellent
	28 days	9180	Excellent
Steam curing after two days delay	3 days		
	7 days	8400	Excellent
	14 days	8640	Excellent
	28 days	8810	Excellent
Boil curing	3 days	8310	Excellent
	7 days	8490	Excellent
	14 days	8680	Excellent
	28 days	8930	Excellent
Fog curing	3 days	7270	Excellent
	7 days	7720	Excellent
	14 days	8050	Excellent
	28 days	8270	Excellent
Water curing	3 days	7290	Excellent
	7 days	7760	Excellent
	14 days	8080	Excellent
	28days	8830	Excellent
Normal curing	3 days	7150	Excellent
	7 days	7470	Excellent
	14 days	7760	Excellent
	28 days	8010	Excellent

Different results are shown in Table 6; the results for this experiment are excellent quality regardless of their curing method. The ultrasonic pulse velocity of the concrete ranged from 7150 to 9180 m/s, which indicates good physical conditions of the concrete. It agree with [16]. In steam curing one day delay, the UHPFC sample has the highest velocity value throughout the 28 days. The ultrasonic pulse velocity of the UHPFC increased with increasing age for all curing methods. Boil curing provided higher ultrasonic pulse velocity than steam curing two days delays, but lower than that of steam curing one day delay. The highest velocity can be seen for fog cures and water curing samples when comparing with the samples that cured in normal curing. On other hand, in fog curing and water curing method, up sample show higher velocity than the normal samples. The velocity also increases gradually for both samples from the beginning of the experiment until 28 days. Normal curing provided the lowest level of ultrasonic pulse velocity. The reasons are probably the same, as discussed in case of compressive strength. However, the reduction in ultrasonic pulse velocity caused by normal curing was relatively low. This is perhaps due to the micro-filling effect of micro-silica that reduced the porosity. The degree of saturation of the concrete affects the pulse velocity. The pulse velocity of saturated concrete may be up to 5 % higher than in dry concrete. In addition, the pulse velocity in saturated concrete is less sensitive to changes in its relative quality.

3.5. Pull Out Test

The results of pull-out tests for all the specimens and at all conditions are demonstrated in Table 7. Each value represents an average of three specimens.

Table 7 Pull Out Test Results

Curing used	Load (KN)	Failure mode
Fog room	48.72	Bar Rapture Failure
Immersing specimens in water.	48.44	Bar Rapture Failure
Normal curing.	49.5	Bar Rapture Failure
Boiling water curing.	50.11	Bar Rapture Failure
Steam cured after one day casting.	50.59	Bar Rapture Failure
Steam cured after two days casting.	50.84	Bar Rapture Failure

The results in Table 7 indicate that with all types of curing methods, the reinforcing steel bars is in rapture failure. In steam curing method, the maximum load on the 7th day for UHPFC in Steam curing one day delay is 50.59 KN. In Steam curing two-day delay a maximum force was 50.84 to cause rapture failure in bar in 7 days. The Maximum load at the 7th day for the fog room curing, immersion water curing, and normal curing are 48.72, 48.44 MPa, and 49.55 respectively. The presence of silica fume in UHPFC significantly enhances the adhesion strength between UHPFC and reinforcing steel bars [17-20]

4. CONCLUSION

As a result, steam and boiling methods proportionally increases the mechanical properties of UHPFC, in the first ages of curing. This means that both curing methods accelerating the rate of compressive strength and flexure strength of UHPFC, it was noticed that curing was accelerated by retaining heat of hydration or by the addition of heat via steam or boil method. Increase of temperature method effect on the microstructure and mechanical properties of UHPFC at an early age of curing. Mechanical properties in fog curing method is slightly different from the water curing method while the normal curing method gave the lowest values in mechanical properties because dry curing resulted in a lower mechanical properties compared to other curing methods.

As a result, in pull out test can note that in all type of curing regimes the result is closely same which the failure happen in bar of 12 mm diameter (bar rapture failure) this indicate that the UHPFC has excellent bonding due to silica fume and steel fiber that used with UHPFC mix.

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