The Flexural Behavior of UHP Prestresses Concrete Beams

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Abstract: **The Ultra high performance concrete (UHPC) is a new type of concrete that has developed in recent years, and the emerge of ultra-high performance concrete became popular in the construction industry. The properties of materials used in UHPC depends on the desired characteristics of this material. However, UHPC is also a good mechanical properties, such as high compressive strength, sufficient tensile strength, tensile toughness and durability.**

The purpose of this study is to evaluate flexural behavior of UHPC of pre-stressed beams. The experimental work is carried out on four pre-stressed concrete beams, on which the compressive strength values ranged from 40MPa to 160MPa. The reinforcement ratio was (0.00465), effective depth to width (d/b) (1.536) and reinforced tendon for beams with $\bar{f}_c$ (40MPa to 160MPa) is investigated.

Test results have indicated, in pre-stressed concrete beams, with unbounded tendons that the strains in the tendons are incompatible with those in the adjacent concrete. It is considered that the ultimate loading capacity stage in a simple beam occurs when the concrete fiber strain in compressive region, in a critical section, and reaches ultimate level. An increase in compressive strength for pre-stressed beams, from (40to 160) MPa, leads to an increase in the ultimate load by about 46.25%.

The load deflection curves of UHPC beams are similar to those made from normal strength concrete beams. The load-deflection, responses of all the beams, appears to be linear up to the yield load. Failure mode types are tensile failure. Tensile failure of UHPC generally occurs when the steel fiber reinforcement begins to deboned form and to pull out of the UHPC beams, due to fibers are randomly distributed and oriented in the UHPC matrix.

I-Ultra-high performance concrete

Concrete has been one of the most widely used building materials because of its compressive strength and its ability to easily form and place, on needed based. Today, high-performance concrete and ultra-high performance concrete, with embedded steel reinforcement, replace normal strength concrete in several structural applications.

High performance concrete (HPC) meets special combinations, of performance and uniformity requirements, which cannot always be achieved routinely using conventional constituent materials and normal mixing, placing, and curing practices.

Ultra-high performance concrete (UHPC) is made of carefully from, selected high quality ingredients and optimized mixture design; that are batched, mixed, placed and cured for highest standards. Normal and special materials are used to make these specially designed concrete mixtures that must meet a combination of performance requirements[1,2] .

Ultra-high performance concretes (UHPC) used for construction structures has steadily increased over the past years, which leads to designing smaller sections. This in turn reduces the dead weights, allowing longer span and more usable area of building. Reduction in mass is also important for economical design of earthquake resistant structures.

II-Materials

The preparation of Ultra high performance concrete requires high quality materials and chemical admixtures. The following is a brief description for the materials used throughout the study.

A-Cement:

The cement used in the tests was ordinary Portland cement.

B-Silica fume:

Densified silica fume, gray color .

C-Fine Aggregate (Sand):-

Locally available fine aggregate was used, and crushed fine aggregate was used after washing and grading.

D-Coarse Aggregate (Gravel):

Coarse aggregate used was crushed aggregated gravel, a maximum size of 9.5mm was used after washing.

E-Water:

Ordinary drinking water was used for mixing, washing and curing for all types of concretes.

F-Steel fiber:

The hooked type steel fibers, manufactured in Germany, were used with f_y=1250MPa, E=210Gpa, 30mm length and

(0.6x0.6) mm cross-sectional dimensions given aspect ratio *l/d* equal to 50, for reinforcing concrete beams of compressive strength (90,120and 150 MPa).

G-Tendon:

The tendon is the basic element of a post-tensioning system. A tendon comprises one or more strands, constrained at both ends by a compact, efficient and easily installed. The strands used for post tensioning-tendons are comprised of 7-wires. Low relaxation steel is made of high tensile strength steel wire. A strand is comprised of 7 individual wires, with six wires wound helically to a long pitch around a center wire, seven-wire strand conforming to the requirements of ASTM A 416 "Standard Specification for Steel Strand, Uncoated Seven Wire Strand for Pre-stressed Concrete". ASTM A 416[3] provides minimum requirements for mechanical properties (yield, breaking strength, elongation) and maximum allowable dimensional tolerances. The strand used in the present work is Grade 1860(270) as shown in Table (1).

Table (1) Strand Properties

Strand Properties	Results	ASTM A416 [3]
Diameter	15.2mm	15.2mm (0.6")
Area	140.77mm^2	140mm2 (min)
Min. load at 1% Extension	1725MP	1675.7MPa (min)
Yield Strength	1903MP	
Breaking load	265kN	260.7kN (min)
Elongation	5%	
Elastic modulus	199.4GPa	

H-Ducts:

Post-tensioned tendons are encapsulated within the deck in a duct which is usually manufactured in corrugated steel (sometimes galvanized), the Galvanized Metal Corrugated Duct was used throughout the work, with inner diameter of 32mm and thickness of 0.6mm.

I-End Anchorage:

All anchorages are designed to the same principles, varying only in the size and the number of strands. End anchorage facilitates the introduction of a post tensioning force in the tendon with the tensioning operations carried out by hydraulic jacks.

J- Reinforcing Steel:

Deformed steel bars of 8mm diameter were used. The vertical stirrups were 8mm in diameter deformed steel bars. The physical properties of the steel reinforcement are summarized in Table (2).

Table (2) Physical properties of steel reinforcement.

Size mm	Measured Dia. mm	Area mm^2	Yield Steength fy MPa	Ultimate Strength fu MPa	Elongation %
8	8.003	50.30	480	646	17.2

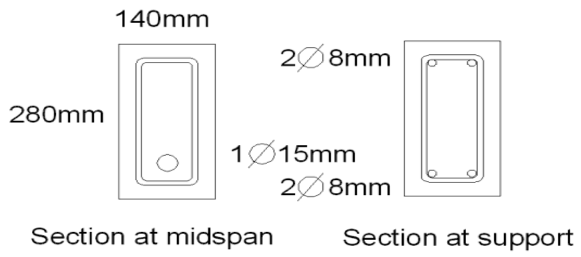

Fig.(1a) Detail of the Pre-stressed Tested Specimens

III-Specimens Identification

A total of four prestresses concrete beams were tested, with different *fc'*. Detail properties of the tested specimens are shown in Table (3) and detail of beam shown in Fig. (1).

All beams were designed for shear to prevent shear failure. The stirrups were managed every 100mm C / C spacing along the beam, while end of the beams, used 50mm C / C stirrups to prevent sudden shear failure, and end anchorage for pre-stressed specimens.

Table (3) Properties of tested beams

Note: 1- All the tested beams had total length of 2700mm and clear span of

Specimen No.	b mm	h mm	d mm	As mm^2	ρ	d / b	fc'
1	140	280	215	140	0.00465	1.536	150
2	140	280	215	140	0.00465	1.536	120
3	140	280	215	140	0.00465	1.536	90
4	140	280	215	140	0.00465	1.536	60

2400mm. 2*- For this group, ρ calculate in the base of area of one prestressed tendon.

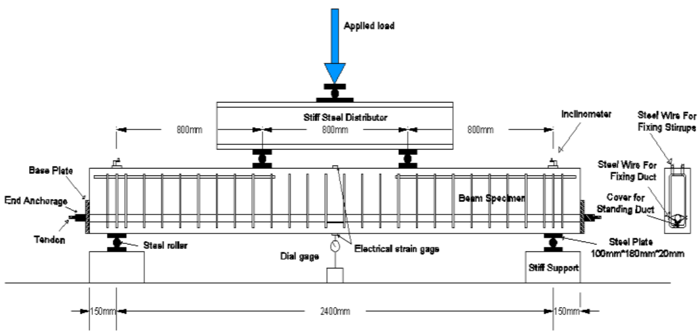

Fig.(1b) Detail of the Pre-stressed Tested Specimens

IV-Concrete Properties

A-Compressive Strength:

For UHPC compressive strength determination, (100*100*100) mm cubes were used. The maximum capacity of testing machine was limited to (2000 kN); for comparison of results, the same size was used for HSC. (100*100*100) mm cubes ASTM C109, [4] and a portion of prisms ASTM C349 [5].

B-Splitting Tensile Strength:

The splitting tensile strength was obtained by testing 150x300 mm cylindrical specimens according to ASTM C496[6] standards. Three cylinder specimens were tested for each group of different compressive strength of beam specimen.

C-Flexural Strength:

Tests were performed for the five concrete types (HSC-1, HSC-2, HSC-3,UHPC-1 and UHPC-2) with prisms 75x75x380 mm, and loaded in third point according to ASTM C1018 [7], the point load was located in 100 mm from the supports.

D- Modulus of Elasticity:

Modulus of Elasticity was determined using (150*300) mm cylinders and apparatus defined in ASTM C469 [8].A dial gauge of 0.001mm accuracy was used for Determining axial compression strength for concrete.

V-UHPC Properties and Composition

A-Compressive Strength (f_c):

Cubes (100 * 100 *100mm) were used for finding compressive strength of control mixes, the compressive tests were completed according to ASTM C109[4] (standard test method for cubes). All tests were performed on the corresponding day that is listed in the table (4), for the control mixes different curing regime were used (for high strength control mixes normal curing was used, while for UHPC steam-treated regime was used). The rate of increasing of compressive strength with time at early age in HSC is more than UHPC as shown in Table (4). While UHPC rapidly gains strength over the first few days, Fig.(2).

B- Splitting Tensile Strength (f_{ct}):

The tensile strength of UHPC was measured by ASTM C496[6](Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens). This test, referred to as split-cylinder test, indirectly measures the tensile strength of concrete. Table (5) shows the result of splitting tensile strength of control mixes, and it can be noted that UHPC have a splitting tensile strength twice that of HSC ,and the table shows that commonly, the value of splitting tensile strength of about (6-8) %of its compressive strength.

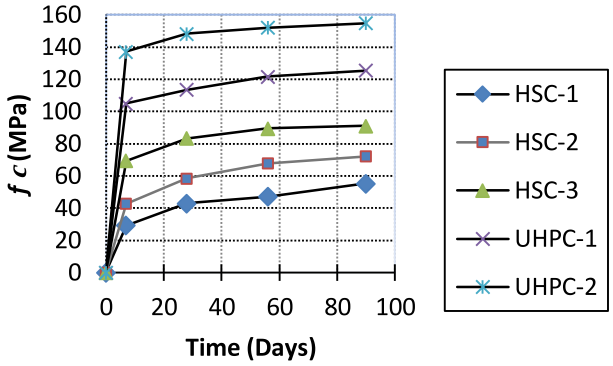

Fig. (2) Compressive Strength of Control Mixes.

Table (4) Compressive Strength of Control Mixes (MPa)

Mix	fc' (Days)			
	7	28	56	90
HSC-1	29.3	42.9	47.1	55.3
HSC-2	42.7	58.4	67.7	72.1
HSC-3	69.3	83.3	89.4	91.1
UHPC-1	105	113.4	121.7	125.4
UHPC-2	137.1	148.3	152.1	154.9

Table (5) Splitting Tensile Strength of Control Mixes (56 days)

Mix Type	fc' (MPa)	fct (MPa)	fct / fc' (%)	fct / √fc'
HSC-1	40.0*	3.195	7.99	0.505
HSC-2	57.6*	4.835	8.39	0.637
HSC-3	76.0*	6.270	8.25	0.719
UHPC-1	125.4**	8.352	6.66	0.746
UHPC-2	154.9**	10.799	6.97	0.678

*f'_c=0.85 f_{cu}[12] for f_{cu}< 120 MPa.

**f'_c=1.0f_{cu}[12]for $f_{cu} \geq$ 120 MPa.

C-Flexural Strength (Modulus of Rupture) (f_r):

The flexural strength results of control mixes are shown in Table (6), 75x75x300 mm prisms tested in third point loading and it can be noted that flexural strength of UHPC is (3-5) times higher than that of HSC. Flexural strength of UHPC is about (10-13) % of its compressive strength, while flexural strength of HSC is about (9-11) % of its compressive strength.

Table (6) Flexural Strength of Control Mixes (56 days)

Mix Type	$P_{max.}$ (kN)	fc' (MPa)	fr (MPa)	fr / fc' (%)	fr / √fc'
HSC-1	5.965	40	4.24	10.6	0.670
HSC-2	8.014	57.6	5.7	9.90	0.751
HSC-3	12.243	76	8.7	11.45	0.998
UHPC-1	17.015	125.4	12.1	9.65	1.081
UHPC-2	27.984	154.9	19.9	12.85	1.599

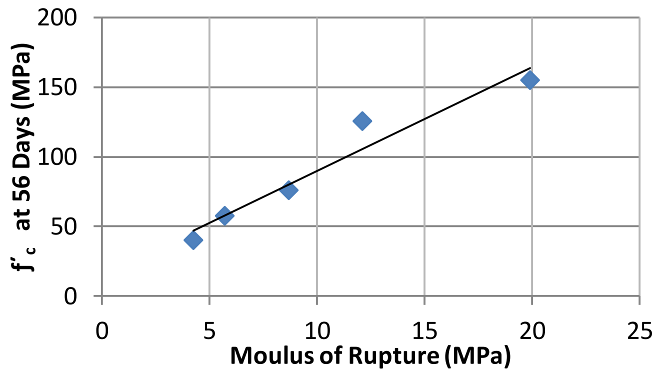

Fig. (3) Relationship between Modulus of Rupture and Compressive Strength

D-Modulus of Elasticity (E_c):

Modulus of elasticity is obtained according to ASTM C469 [8] (based on 0.000050 axial strain and 40% of ultimate load), the results are given in Table (7).

Table (7) Modulus of Elasticity of Control Mixes (56 days)

Results	Experimental results	
Parameter	fc' Mpa	ASTM C469 E (Gpa)
HSC - 1	40.0	28.1
HSC - 2	57.6	30.2
HSC - 3	76	34.7
UHPC - 1	125.4	44.3
UHPC - 2	154.9	48.3

IV- Test Results and Discussions

The flexural behavior of four beam tests are evaluated, these four reinforced concrete beams tested under four point loadings. The parameters take into account the concrete compressive strength (f_c).

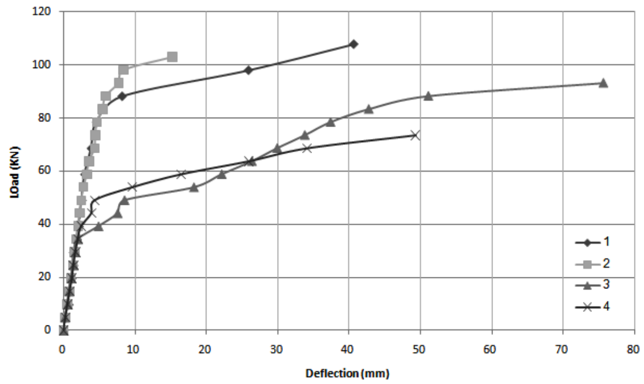

Fig. (4) load deflection curve for post-tensioning beams.

A- Tested Specimens:

A total of four post-tensioned prestressed beams were unbounded tendons, which included deflection, rotation and mid span strain of concrete beams, under four point loading, for different compressive strength of concrete. In prestressed concrete beams with unbounded tendons, the strains in the tendons are incompatible with those in the adjacent concrete, and so the assumption of plane sections fails. It is considered that the ultimate loading capacity stage in a simple beam occurs when the concrete fiber strain in compressive region in a critical section reaches ultimate level. total of 4 specimens were used to evaluate the bending response of HSC and UHPC. The specimens were tested for 40 to 150 MPa concrete compressive strength, the type is post tensioned prestressed beam. Table (8) shows the details of the tested beams.

Table (8) Details of the Tested Beams at age of 56 Days.

Concrete Type	f_{cu}	fc'	f_r	P_{cr}	P_f	Mode of Failure
UHPC - 2	159.3	159.3	18.4	54.0	114.78	Comp.
UHPC - 1	121.2	121.2	13.0	54.0	107.91	Comp.
HSC - 3	86.1	73.2	8.4	44.2	98.1	Comp.
HSC - 2	47.7	40.6	4.4	34.3	78.48	Comp.

*f'_c=0.85 f_{cu}[12] for f_{cu}< 120 MPa.

**f'_c=1.0f_{cu}[12]for $f_{cu} \geq$ 120 MPa

B-Effect of Compressive Strength:

The load deflection curves shown in Fig. (4) For prestressed beams with compressive strength of 1, 2, 3 and 4, are (159.3, 121.2, 73.2 and 40.6) MPa respectively. For prestressed beams changing f'c (40.9 to 159.3) MPa, the central deflection decreases by 50.7%.

C-Load-Deflection Response:

Load deflection curve for post-tensioning beams is similar to HSC & UHPC, normally increasing compressive strength of concrete has small effects on load deflection curve, while it can be seen that effects of compressive strength of concrete of post-tensioning beams does not appear clearly, because the beam is fully un bounded prestresses (not grouting of duct) and during loading appear one crack in the mid span bottom of the beam, increasing width of crack sometimes the load decreasing for short time due to crashing of top concrete .

Two electric strain gauges were attached top and bottom mid span of the beam for reading compressive and tensile strain of concrete during loading of beams, but due to crashing of concrete at top of beams and increasing crack width of bottom of beams during loading some data were lost and not correct.

D- Crack Patterns and Modes of Failure:

Modes of failure of the tested beams were different depending on the concrete compressive strength, amount of main reinforcement and cross-section size of the beams. Failure modes of the tested beams are identified as follows:

1- The cracking loads of a specimen were noted during the test, when the first vertical cracks were observed. Some of the specimens had hairline cracks on the surface before testing, possibly due to drying shrinkage.

2- The first cracking could not be recognized until they propagated to the surface of the beam. Also, the crack might be so small that it takes some time to be visible. Therefore, the recorded crashing load is usually slightly overestimated.

3- Compression failure: in this type of failure, the concrete was crushed, while the main reinforcement was within elastic range. All Specimens have this type of failure.

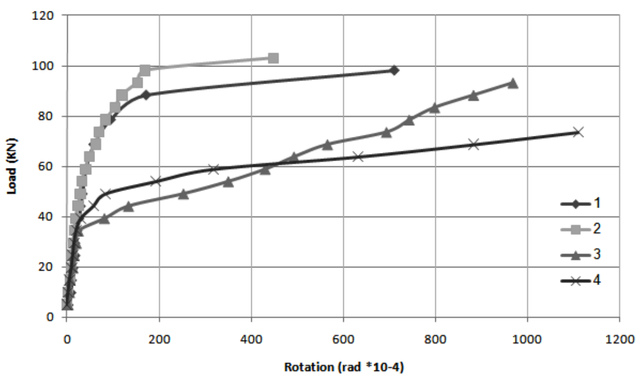

Fig. (5) load –rotation curve for post-tensioning beams.

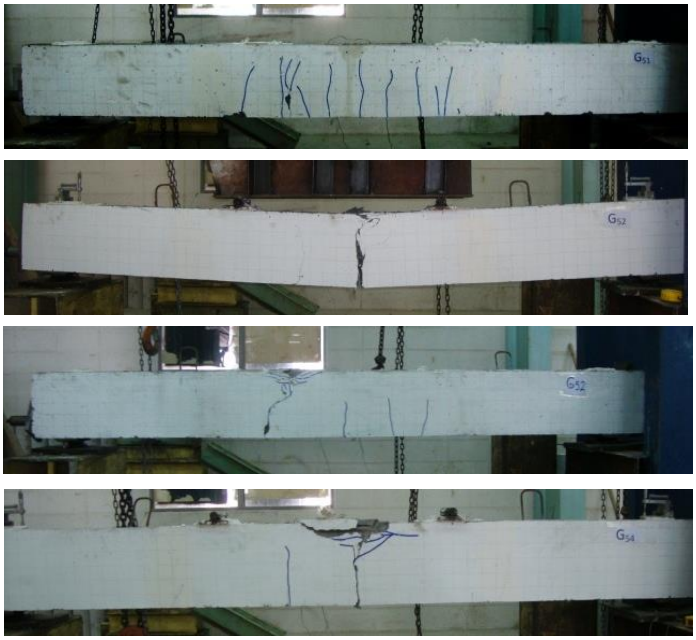

Fig. (6) Crack Pattern of Tested Specimens.

Table (9) Cracking, Yield and Failure Loads Results of the tested beams.

Concrete Type	fc' (MPa)	Load at First Crack (kN)	Load at Failure (kN)	Mode of Failure
UHPC - 2	159.3	54.0	114.78	Comp.
UHPC - 1	121.2	54.0	107.91	Comp.
HSC - 3	86.1	44.2	98.1	Comp.
HSC - 2	47.7	34.3	78.48	Comp.

IIV- Conclusion and recommendation

A-Conclusion:

From the tests performed on properties of UHPC, tests on reinforced concrete beam specimens, the following conclusions can be drawn:

1. UHPC has an extraordinary mechanical property, compared with HSC, in which increase in: compressive strength up to (287%), and causes increase in splitting tensile strength by (238%), in flexural strength by (369%), and in modulus of elasticity by (68%), respectively.

2. An increase in compressive strength from (41 to 154) MPa, leads to an increase in the yield load by about 13.64%, while the ultimate load was increased by 26.05 %.

3. An increase in compressive strength for prestressed beams from (41 to 159) MPa, leads to an increase in the ultimate load by about 46.25%.

B-Recommendations:

UHPC is considered as a new material for use in structural applications; and a little has been written about it; therefore, the following researches are suggested;

1. Additional testing on UHPC beams should be performed with variation in the following parameters: compressive stre**ngt**h higher ranges, tensile strength, fiber volume and types, reinforcement type, loading rate, variation distance between two point load and support conditions.
2. The same work is suggested (behavior of UHPC reinforced concrete beams), to investigate the effect of the load rate and effect of reversed (cyclic) loading.
3. The same work recommended with testing full scale beam specimens to get more practical results, and larger sections and spans.
4. Testing UHPC beam specimens using pretensioned and bonded post-tensioned tendon as the flexural reinforcements.
5. Flexural behavior of concrete beam reinforced with glass fiber reinforced polymer.
6. Applying the numerical model (Finite element method) for predicting strength and behavior of UHPC reinforced concrete beams.
7. Testing UHPC beam specimens using Ultra High Performance Self Compacting Concrete.

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