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Effect of Concrete Type on the Structural Behavior of Hybrid Reinforced Concrete Coupled Beams

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ABSTRACT : *An experimental work was performed to evaluate the structural response of hybrid reinforced concrete coupled beams, this type of beams are characterized by light weight and long spans in multi storey precast buildings. The experimental plan consists of casting and testing of six specimens; having dimensions 1100 mm for length, 400 mm for height and 100 mm for width. One of these specimens was casted as a solid beam to make a comparison between specimens. The study parameters include a change in concrete type at top and bottom chord and concrete type at ribs. Three types of concrete were used in this investigation; normal strength concrete, high strength concrete and reactive powder concrete. The main aim of this study is to examine the beams behavior for each hybrid section category. The test results indicated that using reactive powder concrete and high strength concrete improved the ultimate load carrying capacity of specimen to 130.8%. Also, first crack load was increased to 134.7% when using reactive powder concrete at bottom chord and ribs, and high strength concrete at top chord with higher reinforcement ratio at top and bottom chords. The stiffness of coupled beam increased to 90.36% and energy absorption to 321.91% compared with solid specimen, and then caused high reduction in the deflections and strains through loading life. All beams failed by shear due to crack initiation at supports and extending diagonally through ribs.*

KEYWORDS *coupled beam, hybrid section, fibrous high strength cponcrte, rib, top chord, bottom chord.*

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I. INTRODUCTION

The use of lightweight structures in recent years is one of the most important topics that have won a large part of the tendency of designers and researchers in concrete structures. So that the use of these structures does not affect the capacity and behavior of structural members, and at the same time that there is the possibility of obtaining large spans, that facilitate using the building. The use of coupled beams is a good solution to reduce the weight of overall structure, especially if hybrid sections are used, as it is possible in these cases to achieve lightweight structure with large spans. Coupling beams connected to structural walls can supply energy dispersal and stiffness. In numerous cases, limits of geometry result in deep coupling beams regarding their clear span, ACI318-19 (2019).

Coupling beams linked to building structures can provide the dispersal energy and stiffness. In several situations, geometry restrictions lead to extensive coupling beams with relation to their span. Deep coupling beams can be controlled by shear, and under earthquake loads, they can be responsible for stiffness and strength damage. Reinforced concrete coupled walls are cantilevered shear walls performed with regular openings joined by coupling beams and are used in high-rise structures for many years, that resisting both lateral(wind or seismic forces) and gravity loads. Coupling beam conduct affects the strength of the coupling walls, so many researchers studied the behavior of these beams. Some methods are suggested for increasing the strength of shear walls in past decades. Common methods are based on strengthening the coupling beams confining enhances the strength of the materials by using high quality concrete Lequesneet.al.(2010), Galano and Vignoli(2000) .

Lequesneet.al.(2010) summarized a series of experiments conducted on High-Performance Fiber Reinforced Concrete (HPFRC) strain hardening beams, with span length to depth ratios (Ln / h) of 1.75 and 2.75. Test results have shown that implementing HPFRC enhances the detailing necessary to ensure a stable response of coupling beams that undergo earthquake-induced displacement variations. The results of five precast coupling beam tests are reported, three with Ln/h=1.75 and two with Ln/h=2.75. The precast HPFRC coupling beams were inserted into the structural walls without interlocking with transverse reinforcement. Testing results verified that HPFRC can effectively confined diagonal reinforcement and maintained stable hysteresis behavior. HPFRC was designed to dramatically increase shear strength, and succeeded in a flexure governed failure mode with slight hardness deterioration and efficient energy dissipation. A modified coupling beam layout philosophy is described in order to ensure ductile flexural behavior.

Galano and Vignoli(2000) proposed an experimental study into the earthquake excitation of reinforced concrete coupling beams. The main variables of the experiments were the reinforcement configuration and the loading history. Test findings found that beams with diagonal or rhombic reinforcement configurations performed stronger than beams with longitudinal steel bars configurations. These findings were provided by the specific resisting truss mechanisms that were formed in the coupling beams after the first cracking. The variations in energy dissipation between diagonal and rhombic shapes were marginal.

Canbolat, et. al. (2005) experiments, an alternate method using high-performance fiber reinforced cement composites (HPFRCCs) in coupling beams with standard reinforcement detail of the design specifications of the ACI Building Code was explored. In the case of reinforced concrete (RC) coupling beams in earthquake-resistant structures, substantial reinforcement detail is needed to ensure reliable seismic behavior, cause overcrowding and installation difficulties. This construction choice has led to a significant saving of time and workmanship at the job site and has given excellent material quality assurance. Large-scale test results demonstrated the exceptional damage tolerance and retention capability of the HPFRCC coupling beams. Reported that high displacement capacity was obtained by diagonal reinforcement. Due to the confining offered by the HPFRCC material, transverse reinforcement across the diagonal bars was successfully removed.

Hybrid reinforced concrete beams are well-known beams that are composed of two various materials; these materials are compatible in a number of properties such as coefficient of thermal expansion, and may complement each other in other properties. Hybrid beams are obtainable in various types by utilizing various types of polymers or fibers in part or in the whole depth in order to guarantee their structural behavior improved Al-Shadidi (2006).

The design criteria and philosophy in using hybrid elements or composite building members, is that such use should be sparing to include only the structural members that are subjected to high external loads and/or sever environmental conditions. That is because hybrid materials adopted in enhancing performance are usually costly; examples involve HSC, HPC and UHPC. Such hybrid elements can also be used under high concentrated loadings and they are distinguished for their low dead weight Habel, K. (2004).

Adding new concrete layers to old ones is one of the typical mechanisms employed in maintaining and strengthening buildings. Based on the study of Bernard et al. (1998), they appraised structural members with hybrid concrete, as those members with both old (basic) and new (additional) layers of concrete.

Such needed effective characteristics are accomplished by using layers of concrete with different properties of strength capacity; specifically, using high strength concrete in the needed places only. Consequently, ending up with what is so called "hybrid" section. For I-shaped concrete sections under shear stress, the web part has the essential role in resisting such stresses; and hence the web should be strengthened by, for instance, using steel fibers to obtain higher shear strength. On the other hand, to increase the flexural strength in the tension zone and in order to restrict or reduce cracking and deformations, steel fiber reinforced concrete is usually used surrounding the longitudinal steel bars Swamy, R. N., and Al-Taan, S. (1981), Padmarajaiah, S. K., and Ramaswamy, A. (2002). Moreover, to increase flexural strength in the compression zone, high strength concrete is recommended in that region Lin, T. Y., and Burns, N. H. (1981).

Rationalizing an investment in a facility's infrastructure can be a difficult prospect for any plant engineer or technician, often requiring extensive justification. Investments that are deemed “low-risk” by upper management and have a fast return on investment (ROI) are typically the easiest to substantiate. One such investment that will pay considerable dividends over the course of its operating life is a comprehensive power monitoring system. Even though increased energy prices have become a larger influence on the balance sheet, many facilities do not take advantage of opportunities to better manage these expenses. Those without monitoring systems likely have no understanding of their energy usage; those with them may not be using their systems to the fullest potential.

Because the quality of energy supplied can adversely affect its operation, oftentimes leading to loss or degradation of equipment, product, revenue, and reputation, plant managers must weigh the advantages of implementing a monitoring program.

The second section of this paper shows three methods for monitoring systems of solar plants. The third section discusses communication and monitoring system for wind turbines, and finally the conclusion is discussed in the fourth section.

II. STUDY OBJECTIVES

The behavior of hybrid reinforced concrete coupled beams is demonstrated. The paper has several variables:-

- Concrete types of top and bottom chord.
- Concrete types of ribs.

The behavior discussed in this paper will include studying the load versus deflection behavior, ultimate load capacity, first crack load, stiffness of specimens, load versus strain relationships, energy absorption and failure pattern of tested beams.

III. EXPERIMENTAL WORKS

The experimental works of this study is based on five specimens; it studied the effect of using reactive powder concrete and high strength concrete at bottom and top chords. Details of these five specimens are shown in Table 1.

Five simply supported beams having 100 mm thickness, 400mm total depth and 1000 mm the c/c span between supports. Two point loads were applied at mid span; the distance between point loads were 400mm, see fig. 1 and fig.2. The specifications and details of these beams are listed below:

1. Beam RN: Solid beam casted with normal strength concrete.
2. Beam RR: Coupled beam casted with reactive powder concrete.
3. Beam B1: Coupled beam casted with reactive powder concrete at bottom chord, normal strength concrete at top chord and normal strength concrete at ribs.
4. Beam B2: Coupled beam casted with fibrous high strength concrete (HSC 50MPa with steel fiber 2%) at bottom chord, normal strength concrete at top chord and normal strength concrete at ribs.
5. Beam B3: Coupled beam casted with normal strength concrete at bottom chord, high strength concrete at top chord, and normal strength concrete at ribs.

Table 1: Details of the Tested Beams

Specimens	**Bottom chord**		**Top Chord**		**Ribs**	
	Concrete Type	**Reinforcement**	**Concrete Type**	**Reinforcement**	**Concrete type**	**Reinforcement**
Beam RN	NSC	4Φ8 mm	NSC	4Φ8 mm	-	-
Beam RR	RPC	4Φ8 mm	RPC	4Φ8 mm	RPC	4Φ8 mm
Beam B1	RPC	4Φ8 mm	NSC	4Φ8 mm	NSC	4Φ8 mm
Beam B2	FHSC	4Φ8 mm	NSC	4Φ8 mm	NSC	4Φ8 mm
Beam B3	NSC	4Φ8 mm	HSC (50 MPa)	4Φ8 mm	NSC	4Φ8 mm
Beam B4	RPC	4Φ8 mm	HSC (70 MPa)	4Φ8 mm	NSC	4Φ8 mm

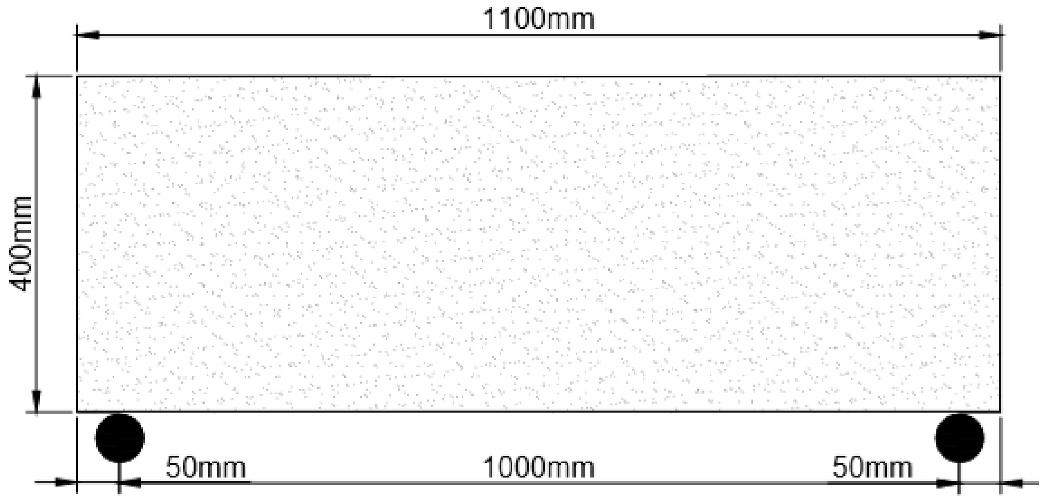

Fig. 1. Details of reference specimen RN (all dimensions in mm)

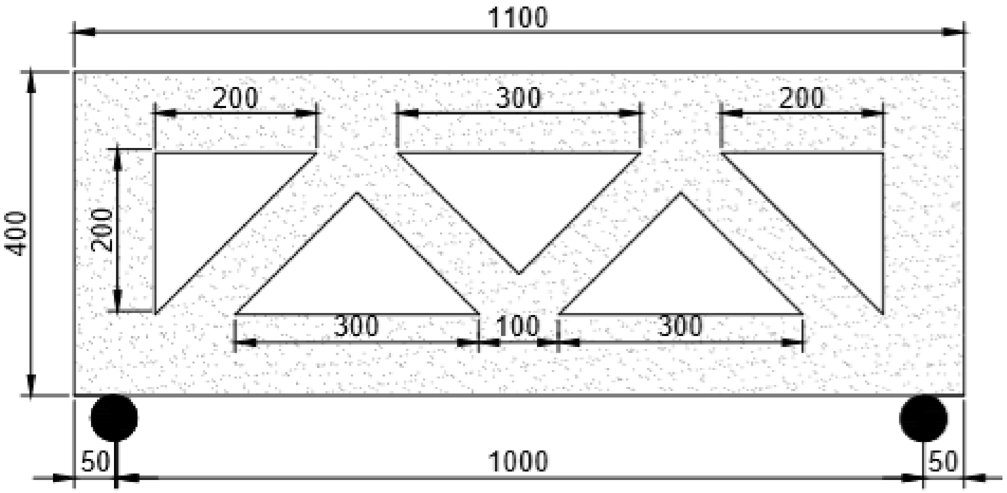

Fig. 2. Details of coupled beams (all dimensions in mm)

IV. MATERIALS

Three concrete mixes were used in this research; normal strength concrete (NSC), reactive powder concrete (RPC) and high strength concrete (HSC). Materials description and specifications are shown below:

Cement

The cement kind employed in concrete manufacturing during this study's experimental work was ordinary Portland cement (Type I) for ordinary concrete strength, high concrete strength, and reactive powder concrete. The cement pack was kept in a position of dry environment so that atmospheric conditions did not affect it badly. The chemical structure of cement and its physical characteristics are shown in Tables 2 and 3 respectively. There is a conformance with the Iraqi standards specification No.5 (1984), according to the test results. The study was performed at the National Laboratory and Research Center for Construction (NCCLR), Baghdad, Iraq.

Table 2: Chemical Composition of Cement

Compound composition	Chemical composition	Percentage by weight	Limit of IOSNo.5/ 1984
Lime	CaO	62.11	------
Silica	SiO_2	21.37	------
Alumina	AL_2O_3	5.2	------
Iron Oxide	Fe_2O_3	4.42	------
Magnesia	MgO	1.73	<5
Sulfate	SO3	2.62	<2.8
Loss on Ignition	L.O.I	2.76	<4

Lime Saturation Factor	L.S.F	0.94	0.66-1.02
Insoluble residue	I.R	0.71	<1.5
Main Compounds (Bougue'sequations)			
Tricalcium aluminates	C3A	6.31	------
Tricalcium silicate	C3S	41.64	------
Dicalcium silicate	C2S	30.1	------
Tricalciumalumona ferrite	C4AF	13.43	------

Table 3: Physical Properties of Cement

Physical Properties	Test Result	Limit of IOS No.5/ 1984
Finess using Blaine air permeability apparatus (cm^2/g)	4420	> 2300
Soundness using autoclave method	0.21%	<0.8%
Setting time using Vicat's instrument		
Initial (min)	190 min	> 45 min
Final(hrs)	5 hr	< 10 hr
Compressive strength for cement paste at		
3 days (MPa)	23	>15
7 days (MPa)	30	> 23

Fine Aggregate

The maximum size and fineness modulus of Natural sand were (5 mm) and (2.35) respectively. The test results are in match with Iraqi standard No.45 (1984). Both Tables 4 and 5 show the sand gradients and specifications. The tests were carried out in the laboratory of constructional materials belonging to the Engineering Faculty of Al-Mustansiriyah University.

Table 4: Sand Sieving Analysis

No.	Sieve size(mm)	Cumulative passing (%)	Limits of Iraqi specification No.45/1984 zone 2
1	10	100	100
2	4.75	95.50	90-100
3	2.36	87.70	75-100
4	1.18	74.60	55-90
5	0.6	52.60	35-59
6	0.3	12.40	8-30
7	0.15	2.30	0-10

Table 5: Chemical and Physical Properties of Fine Aggregate

Physical properties	Test result	Limit of Iraqi specification No.45/1984
Specific gravity	2.5	-
Apparent Specific gravity	2.68	-
Sulfate content(SO3)	0.4 %	≤ 0.5%
Absorption ratio	0.78 %	-
Passing 0.075 mm (%)	0.4 %	≤ 5%
Clay (%)	0.04 %	≤ 1%
Organic (%)	0.466 %	≤ 0.5%

Extra Fine Aggregate (Silica Sand)

Extra fine sand was used for manufacturing of reactive powder concrete, it have a particles with maximum size (600µm). The properties of extra fine aggregate conformed the IQS No.45 (1984). The grading and physical properties of extra fine aggregate are shown in Tables 6 and 7 respectively.

Table 6: Grading of Fine sand

No.	Sieve size(mm)	Cumulative passing (%)	Limits of Iraqi specification No.45/1984 zone 4
1	10	100	100
2	4.75	100	95-100
3	2.36	100	95-100
4	1.18	100	90-100
5	0.6	100	80-100
6	0.3	47	15-50
7	0.15	6	0-15

Table 7: Physical Properties of Fine sand

Physical properties	Test results	Limits of Iraqi specification No. 45/1984
Specific gravity	2.63	-
Amount of sulfate %	0.21%	≤ 0.50%

Coarse Aggregate (Gravel)

For the NSC and HSC mixes, crushed aggregate with a peak particle size less than 14 mm was used as coarse aggregate. In order to enhance RPC's homogeneity, it was produced without coarse aggregates. The grading of the gravel used is consistent with the Iraqi Standard Specification No.45 (1984) as shown in Table 8.

Table 8: Grading of Coarse Aggregate

No.	Sieve Size (mm)	Cumulative passing (%)	Limits of Iraqi specification No.45/1984
1	20	100	100
2	14	100	90-100
3	10	79	50-85
4	5	2	0-10
5	2.36	---	---

Silica Fume

Silica fume is an extra fine powder, a partial replacement of cement by silica fume gives an enhancement in the properties of concrete; the replacement ratio ranged between 15% to 25% by cement, it about 22.4% of cement weight, the silica fume is a product of manufacturing Ferro-silicon metal or silicon, using silica fume in this study in production of RPC as a good option to achieve good concrete properties. Table 9 explained the main chemical properties of silica fume, which satisfied the American Standards ASTM C1240 (2004).

Table 9: Main Components of Silica Fume

Compound Composition	Chemical Composition	Results %	Specifications Limits (ASTM C1240)
Silica	SiO_2	92.1	85 (min)
Alumina	Al_2O_3	0.5	---
Iron oxide	Fe_2O_3	1.4	---
Lime	CaO	0.5	---
Magnesia	MgO	0.3	---
Potassium oxide	K_2O	0.7	---
Sodium oxide	Na_2O	0.3	---
Sulphate	SO_3	0.1	---
Loss on ignition	L.O.I	2.8	6 (max)

Admixtures (Superplasticizer)

High range water reducing agents (HRWRA), also called superplasticizeris usually employed to produce reactive powder concrete mixes and high concrete strength mixes, as used in this study. Glenium 51 has been adopted as one of the modern polymer-based superplasticizers, that is employed to produce RPC. Glenium 51 is usually used with recommended dosage 1 liter per each 100 kg quantity of cementitious components. Table 10 demonstrates the key characteristics of Glenium 51 that was employed to enhance mix flow ability. Glenium 51 ASTM C494-ClassF(2017) is free from chlorides; it could be adequately used with all types of Portland cements mixes that obey a known documented worldwide standard.

Table 10: Specifications of Superplasticizer

Commercial name	Glenium 51
Form	Viscous liquid
Appearance/Color	Light brownish liquid
Labeling	No hazard label required
Relative density	1.08 – 1.15 gm/cm^3@ 25°C
Viscosity	128 +/- 30 cps @ 20°C
pH value	6.6
Chloride ion content%	Free
Transport	Not classified as dangerous

Steel Fibers

The steel fibers have typically been used in the combination of reactive powder concrete and high-strength fibrous concrete; the use of steel fibers in concrete helps to improve concrete's tensile strength. Table 11 shows the characteristics of steel fibers which the company (SIKA) has proven.

Table 11: Characteristics of Used Steel Fibers

Type of steel	Hooked-Ends steel fibers
Relative Density	7850 kg/m^3
Yield strength	1100 MPa
Modulus of Elasticity	210 000 MPa
Average length (L)	35 mm
Nominal diameter (d)	0.55 mm

8. Water

Clean tap water was used for both mixing and curing, Table 12 presents the test results of used water.

Table 12: Water Properties

Test Type	**Test Results**
PH	6.65
TDS	45.7(mg/l)
Ec	74.7(Ms)
Turbidity	0.43(NTV)

Reinforcing Steel Bars

Deformed steel bars have a nominal diameter of 8 mm was used as flexural main longitudinal reinforcement bars in the top chord, ribs and bottom chord of beams. Deformed steel bars with a diameter of 5 mm were used as shear reinforcement (stirrups), as shown below in fig. 3 and fig. 4. Steel bars with diameters 8mm and 5mm each having length 500mm were tested under tensile force, the test results are shown in Table 13.

Table 13: Specifications of Steel Bars

NominalDiameter (mm)	**Actual Diameter (mm)**	**Yield Stress (f_y) (MPa)**	**Ultimate Strength (F_u) (MPa)**
5	4.89	352	445
8	8.1	475	532.05

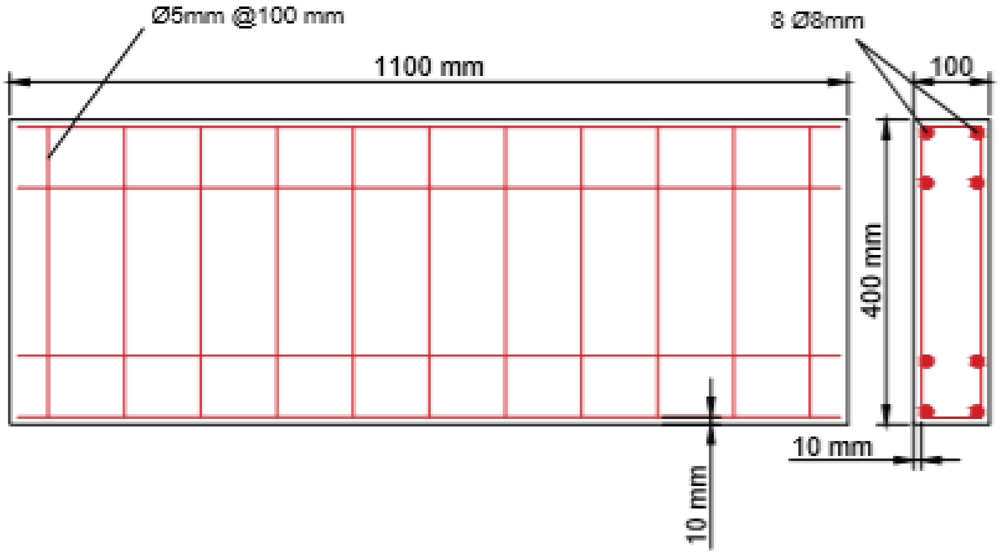

Fig.3. Reinforcement details of reference specimen RN (all dimensions in mm)

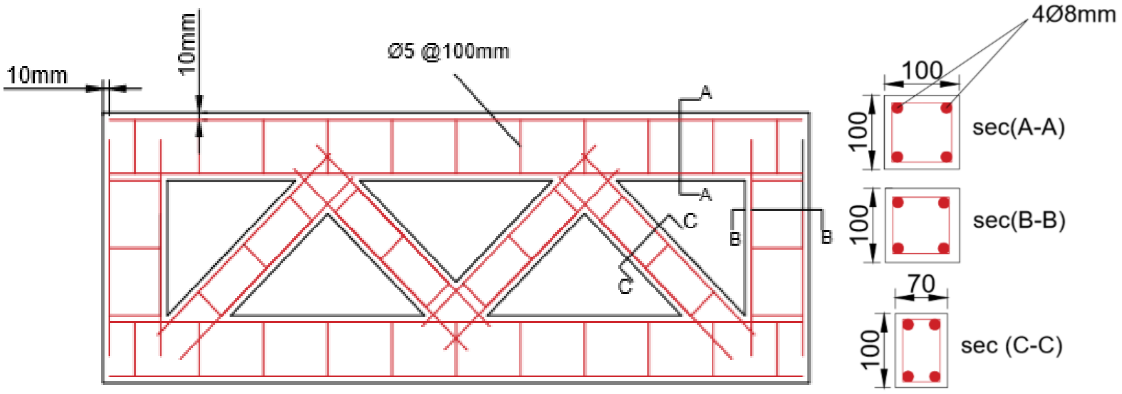

Fig. 4. Reinforcement details of coupled beams (all dimensions in mm)

V. RESULTS AND DISCUSSIONS

Ultimate Load Carrying Capacity

In this comparison, the effect of different types of concrete and reinforcement ratio on ultimate load carrying capacity are considered, as shown below in Table 14, the difference in ultimate load with respect to reference specimen are also discussed in this section.

Table 14: Ultimate Load of Tested Specimens

Specimens	Ultimate Load (kN)	% of Improvement
Beam RN	162.5	R*
Beam RR	375.0	130.8
Beam B1	215.0	32.3
Beam B2	247.5	52.3
Beam B3	167.5	3.1

*** Reference specimen.**

The specimen (B1) achieved an increase in ultimate load about (32.3%) over the reference specimen (RN), specimen (B1) are poured with reactive powder concrete at bottom chord, and specimen (RN) is solid beam poured with normal strength concrete. When using fibrous high strength concrete (FHSC 50 MPa) at bottom chord, the ultimate capacity was increased about 52.3% over than the reference specimen (RN), as shown in Table 14. The specimen (B2) achieved higher increase in ultimate load than specimen (B1), this increase in ultimate load is may be attributed to increase the steel fibers ratio to 2% in specimen (B2), while specimen (B1) having (1%) steel fibers ratio. In bottom zone of the coupled beam, the increase in tensile strength is more effective than increase in the compressive strength of concrete on improvement the load carrying capacity of the coupled beams.

The reactive powder concrete specimen (RR) recorded high improvement in ultimate capacity of the coupled beams; it was recorded 130.8 % an increase in ultimate capacity over the reference specimen (RN). This indicates that, when using concrete with superior properties, the carrying capacity increased for coupled beam in comparison with solid beam. The benefit is that can reduce the overall weight of the structure with larger spans. On the other hand, there is good improvement because of lack the joints between bottom chord and ribs in fully reactive powder concrete specimen.

When using high strength concrete (HSC 50 MPa) at top of the coupled beam (B3), in addition to normal strength concrete at bottom chord and ribs, there are a slight increase in ultimate strength about 3.1%, in comparison with reference specimen (RN), the slight increase in strength of coupled beam is may be due to the low tensile strength of normal strength concrete at bottom chord, where the cracks propagation and extension are increased rapidly in width and length, and the high strength concrete at top chord contributes to some extent to reach the strength of this beam in comparison with reference beam.

First Crack Load

The test results of first crack load of tested beams are shown in Table 15. The first crack load is an important factor to determine the stage of reaching the concrete to its tensile strength. The first crack load means that the applied stresses exceed the concrete tensile strength.

Table 15: First Crack Load of Tested specimens

Specimens	First Crack Load (P_{cr})kN	% of Improvement
Beam RN	122.5	R*
Beam RR	287.5	134.7
Beam B1	85.0	30.6*
Beam B2	110.0	10.2*
Beam B3	72.5	40.8*

***Decreasing in first crack load.**

Normal strength concrete solid beam (RN) recorded first crack load of 122.5 kN, reactive powder concrete coupled beam (RR)attained first crack at 287.5 kN, this increase produced from the high tensile strength of reactive powder concrete. In hybrid concrete coupled beam, in general, a decrease in first crack load was appeared, the decrease in first crack load (Pcr) belong to reduction in section geometry of coupled beam, such that the first crack load of specimen (B1) (reactive powder concrete at bottom chord and normal strength concrete at ribs and top chord) recorded first crack load at 85 kN.

When using high strength concrete with steel fiber at bottom chord (FHSC) in specimen (B2), there is an increase in first crack load to 110kN. Using high strength concrete (HSC) at top chord, the first crack load was decreased in comparison with specimens B1 and B2, that have reactive powder concrete (RPC) and fibrous high strength concrete (FHSC 50MPa) at bottom chord, this result is expected due to low tensile strength of normal strength concrete (NSC) at bottom chord of specimen B3, where the first crack appeared at the bottom chord.

Stiffness

Stiffness may give an indication on the deformations degradation of specimens under loading, it can be calculated by dividing ultimate load by ultimate deflection[100]. The stiffness values are shown below in Table 16.

Table 16: Stiffness of Tested Beams

Specimens	Ultimate Load P_u (kN)	Deflection (mm)	Stiffness (kN/mm)
Beam RN	162.5	2.10	77.38
Beam RR	375.0	4.15	90.36
Beam B1	215.0	2.71	79.34
Beam B2	247.5	3.07	80.62
Beam B3	167.5	2.77	60.47

In general, there is an increase in coupled beams stiffness in comparison with solid beam. As shown in Table 16, the stiffness of reference specimen (RN) is 77.38 kN/mm. Specimen (RR) that poured with reactive powder concrete, achieved stiffness about (90.36kN/mm), its stiffness higher than that reference specimen (RN) by about 16.77 %. The beam B1 recorded increase in stiffness about 2.53 % over the reference specimen (RN). Beam B2 that poured with fibrous high strength concrete(FHSC 50MPa) at bottom chord recorded (80.62 kN/mm) stiffness, it’s higher than the stiffness of reference specimen (RN) by about 4.19%. Beam B3recorded a decrease in stiffness, this beam having normal strength concrete in bottom chord. So, the cracks extension easier through the section than other specimens having reactive powder concrete and fibrous high strength concrete at bottom chord, the deformation of this specimen higher than other specimens.

Load-Deflection behavior

The load-deflection curves of tested specimens are shown in fig.5 below. The load-deflection curves are passing through three main stages; the first stage indicates the elastic response of the specimen, the second stage indicates the elastic-plastic response of the specimen, and the third stage or failure stage indicates the plastic behavior of specimen. The first stage starts at beginning of loading until appearing of first crack, the deflection increments at this stage are lower than later stages, the specimen in elastic stage characterized by good response to loading, due to small deflections. After first crack load (Pcr), the second stage is started at first crack and finished at first yielding of reinforcing steel bars, approximately linear relationship can be seen in this stage; larger displacement can be seen than the first stage, as a result of appearing the cracks and increasing in its width and height, the reduction in stiffness of specimen are higher than that of the previous stage. The third stage of load-deflection curves are indicated in curved shape, this stage called (failure stage), the cracks are increased in width and height, and the large part of stiffness is lost in this stage; large deflections were distinguished until failure of specimen. When review the load-deflection curves, it can be concluded that the deflections of reactive powder concrete specimen are lower than other specimens at the same loading level. While the higher deflection was detected in specimen B3, that having normal strength concrete at bottom chord.

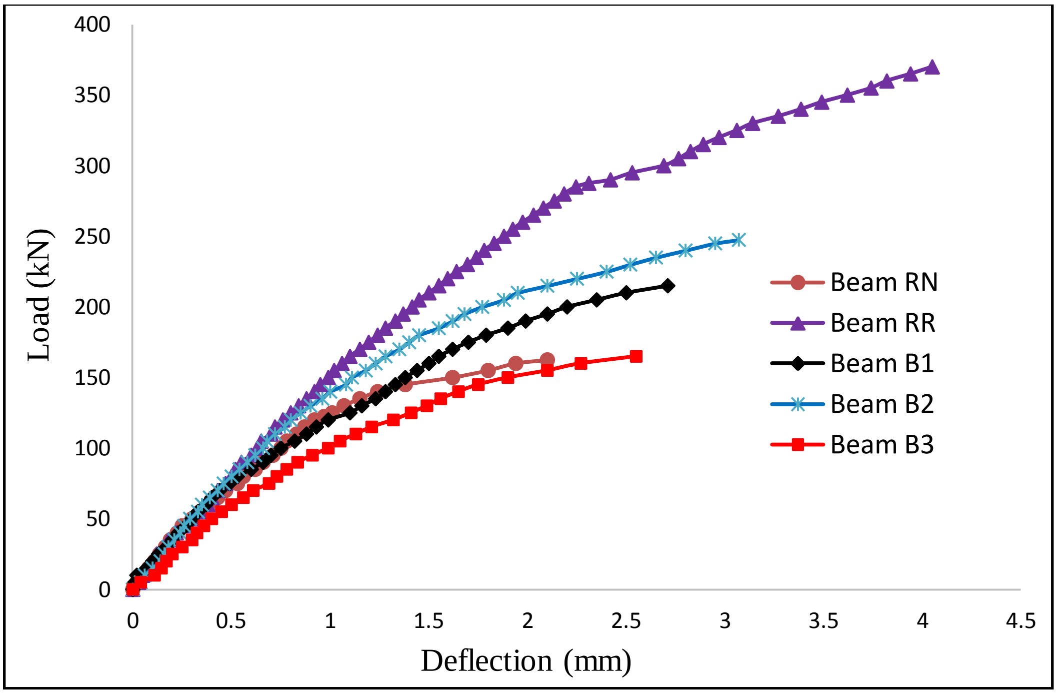

Fig. 5. Load-deflection curves of tested specimens

General Behavior and Failure Pattern

For reference specimen (RN), the specimen initially being stiff through low deflection readings. At load (122.5 kN), the flexural-shear cracks began to appear, these cracks are thin and limited in height, shear cracks initiate at supports and extend diagonally to the upper zone of the beam, and finished at load points, as shown in Plate 1(a). These cracks increased in width, this increasing in crack dimension resulted a decrease in beam stiffness. In a specific load, the cracks stable due to transfer the stresses to the steel reinforcement, this indicates yielding of reinforcing bars. After that, the crack width increased dramatically until the failure of the beam by diagonal shear mode.

The reactive powder concrete specimen (RR)appeared high stiffness, the deflection readings are small under loading, the high performance of beam specimen continued until appearance of first crack at load (287.5 kN), the first cracks appeared at supports, then extended diagonally towards the inclined ribs, the shear cracks increased in width and height. At load (335 kN), a flexural-shear crack was appeared. At advanced loading stages, the cracks are propagated, caused reduction in stiffness of the beam, as shown in Plate 1 (b), accordingly the specimen failed by shear. Through visual observation, the reactive powder concrete specimen failed in ductile mode.

The specimen B1 that contains normal strength concrete at ribs and top chord and reactive powder concrete at bottom chord, have first crack load 85 kN, the first crack appeared at shear span near supports, these cracks pass in a diagonal direction until joint of ribs with bottom chord. Later, at load 170 kN, new shear crack initiated at top chord below load points toward the joint between the external inclined rib and top chord. At load 185 kN, a crushing of concrete occurred at load points, as shown in Plate 1 (c). The crushing is may be attributed to the effect of the difference in mechanical properties of concrete in different layers, i.e. high tensile strength of RPC compared with low compression and tensile strength of NSC, caused compression failure.

The behavior of beam B2 similar to the behavior of beam B1, where the first crack load of beam B2 appeared at 110 kN at shear zone near supports, then extended diagonally through bottom chord to the top, the new shear thin cracks initiated at the top chord at load 215 kN, and extended to the bottom of top chord, the failure took place at load 247.5 kN. Finally, the beam failed under diagonal shear, as shown in Plate 1 (d).

The Beam (B3) appeared weak response to loading in comparison with other specimens, this may be due to low tensile strength of normal strength concrete of ribs and bottom chord, the cracks propagation are rapid compared with other specimens; this specimen achieved first crack (Pcr) at 72.5kN, the first crack load (Pcr) detected at supports then extended diagonally to the upper surface of bottom chord. Very Thin cracks appeared and extended diagonally at the top chord under load points at 140 kN. The beam finally failed by shear failure at load 167.5 kN, as shown in Plate 1 (e).

(a) Beam RN

(b) Beam RR

(c) Beam B1

(d) Beam B2

(e) Beam B3

Plate 1: Failure Pattern for Tested Beams of Group One

Energy Absorption

Energy absorption can be defined as the energy that the specimen can absorbed through loading life before failure. It gives an indication on the ductility of the specimen [102]. Mathematically, the energy absorption value can be calculated from the area under load-deflection curve. The calculated values are shown below in Table 17.

Table 17: Energy Absorption of Tested Beams

Specimens	Energy Absorption (kN.mm)	% of Improvement of Energy Absorption
RN	233.04	R*
RR	983.23	321.91
B1	373.33	60.20
B2	502.58	115.66
B3	309.97	33.01

As shown in Table 17, the reference specimen (RN) recorded energy absorption about 233.04 kN.mm, the reactive powder concrete RPC coupled beam (RR) achieved energy absorption about 983.23 kN.mm, the improvement of energy absorption reached to 321.91%, this improvement is may be attributed to enhancement in tensile strength of concrete due to using steel fiber in the reactive powder concrete mix. The specimen B1, that having normal strength concrete NSC at top chord and reactive powder concrete at bottom chord, achieved energy absorption about 373.33 kN.mm, here the role of reactive powder concrete limited in the bottom chord only, vice versa the specimen (RR) that having reactive powder concrete at top and bottom chords.

In general, the energy absorption increased when the load increment accompanied with large deflections. The specimen B2 that have fibrous high strength concrete at bottom chord achieved 115.66% an increase in energy absorption in comparison with reference specimen (RN), also the 2% of steel fiber having the main contribution to increase the tensile strength of bottom chord. For the specimen B3, that have high strength concrete HSC 50MPa at top chord, there is an increase in energy absorption reached to 33.01% in comparison with reference specimen (RN), but less than other specimens because of low tensile strength of normal concrete at bottom chord. From the above, it can be concluded that the main way to increase the energy absorption is increasing the tensile strength for the bottom chord of the specimen.

Load-Strain Relationship for Group One

Figures from (7) to (9) show the relationships between loading steps and the corresponding strains of concrete, which studying the effect of changing the concrete type at bottom chord of each specimen for three positions of strain gauges.

Load-Strain Relationship at Top Chord

The experimental results of load-strain relationships at top chord are shown in fig.6 and Table 18. When comparing between strains for normal strength concrete specimen (RN), reactive powder concrete specimen (RR), and hybrid specimens B1, B2 and B3, it is noticed that at ultimate load, the maximum strain of normal strength concrete specimen RN was 146μƐ, lower than the maximum strain of specimens B1, B2 and B3, that have maximum strain 338μƐ,344μƐ and 232μƐ respectively, it may be belong to low load level that normal concrete specimen was failed. Approximately, the behavior of top chord is similar in specimens B1 and B2, which casted with normal strength concrete at top chord. The reference beam achieved strains higher than the coupled beam specimens until approximately one-third of ultimate load, due to high tensile strength of reactive powder concrete and fibrous high strength concrete at bottom chord caused load carry capacity higher than reference specimen (RN).The specimen RR achieved lower values of strains than other specimens with same level of loading, due to high compressive and tensile strengths of the reactive powder concrete. The maximum strain of specimen (RR) was 260μƐ at ultimate load.

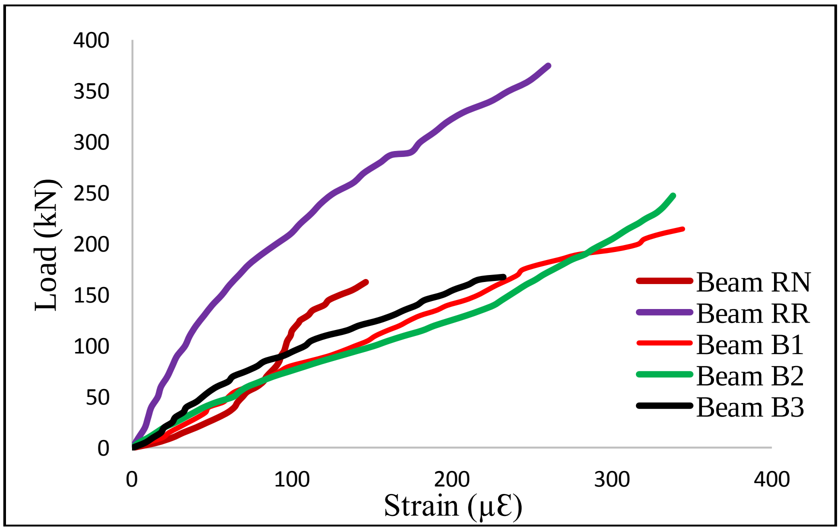

Fig. 6. Load-strain curves of specimens RN, B1, B2 and B3 at top chords

Load-Strain Relationship at Ribs

The load-strain behavior of the concrete at ribs depends also on the effect of type of concrete at top and bottom chords sequentially. As shown in fig.7, through loading life, the tested specimens B1, B2 and B3 having strain values higher than reference specimen (RN). These three specimens recorded strains 605μƐ, 371μƐ and 545μƐ respectively at ultimate load, while reference specimen recorded strain at ultimate load 224μƐ as shown in Table 18, it's may be due to high deformations of concrete under load points (normal concrete) with low deformations of bottom chord, specimen (RR) recorded maximum strain 283μƐ, lower than other specimens with higher ultimate load.

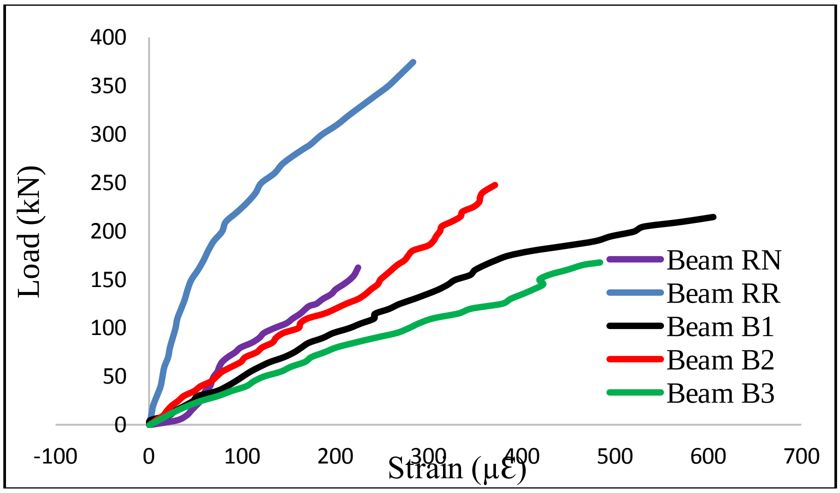

Fig.7. Load-strain curves of specimens RN, B1, B2 and B3 at ribs

Load-Strain Relationship at Bottom Chord

As shown in fig.8, the high tensile strength of reactive powder concrete and fibrous high strength concrete at bottom chord, due to presence of steel fiber, contribute to good extent in reducing the deformations and propagation of cracks of specimens RR, B1 and B2 compared with reference specimen RN. The bottom chord was casted with normal strength concrete for specimen B3, hence strains higher than all specimens because of low tensile strength of normal concrete.

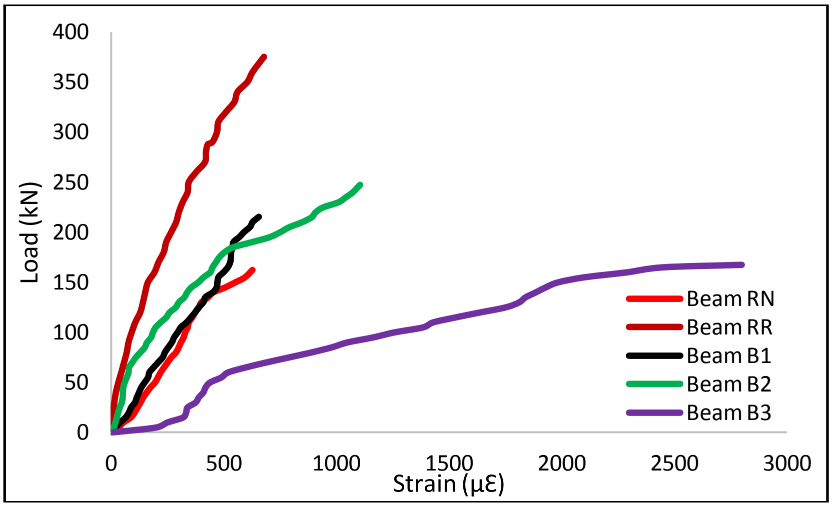

Fig.8. Load-strain curves of specimens RN, B1, B2 and B3 at bottom chords

Table 18: Strain at Ultimate Load of Tested Beams

Specimens	Ultimate Load (kN)	Strain at Top Chord (μƐ)	Strain at Ribs (μƐ)	Strain at Bottom Chord (μƐ)
RN	162.5	146	224	627
RR	375	260	283	678
B1	215	338	605	657
B2	247.5	344	371	1104
B3	167.5	232	484	2800

VI. CONCLUSION

The following conclusions are achieved from the experimental results of the present study:

1. Reactive powder concrete coupled beam attained improvement by about 130.8 %, 134.7 %, 16.77 % and 321.91 % in ultimate load, first crack load, stiffness and energy absorption respectively, compared with normal strength concrete solid beam.
2. Due to high tensile strength and ductility for reactive powder concrete coupled beam, it achieved ultimate deflection at mid-span higher than all other specimens accompanied with high failure load.

3. Due to high performance of reactive powder concrete, it achieved strains at top chord, ribs and bottom chord lower than all other specimens through loading life.
4. When using steel fibers with volumetric ratio 2 % in high strength concrete at bottom chord of specimen, it gave increase in ultimate load, stiffness and energy absorption about 52.3 %, 4.19 % and 115.66 %respectively compared with normal strength concrete solid beam.
5. The high ratio of steel fiber volume to the total volume of concrete at bottom chord registered strain values lower than all other specimens.
6. The good mechanical properties of concrete type (i.e high strength concrete and reactive powder concrete) at top chord and ribs produced strain readings lower than normal concrete due to the resulted increase in stiffness.
7. In general, there was a decrease in first crack load for hybrid coupled beams depending on type of concrete used in top chord, bottom chord and ribs.
8. There was a decrease in strains of hybrid coupled beams in comparison with normal strength coupled beam.
9. All the hybrid coupled beams failed by shear regardless of the concrete type used.
10. The use of high performance concrete as reactive powder concrete and high strength concrete decrease the deflections and strains of specimens.

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