

Flexural Behavior of Hybrid Tee Beams (Containing Reactive Powder Concrete and Normal Strength Concrete)

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Abstract

Reactive powder concrete has superior mechanical and structural properties but the major drawback of this new construction material is its high cost. This research presents experimental study to investigate flexural behavior of hybrid tee beams and study the ability of using normal strength concrete together with RPC in the same section to exploit the advantages of these two materials in optimal way. The experimental results showed that using RPC in the web and normal strength concrete in the flange effectively enhanced performance of hybrid T-section beams when compared with normal strength concrete T-beam, however, the increases in the first crack load, ultimate flexural load and ultimate deflection were 86.67%, 60% and 29.19% respectively, while, the increases for the case of using RPC in the flange and normal strength concrete in the web were 20%, 34.28% and 14.97% respectively when compared with normal strength concrete T-beam.

Keyword: Flexural Behavior, Hybrid Concrete, Reactive Powder Concrete & Tee Beams

سلوك الإنشاء للعتبات الهجينة ذات المقطع (T) (الحاوية على خرسانة المساحيق
الفعالة والخرسانة عادية المقاومة)

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الخلاصة

خرسانة المساحيق الفعالة تمتلك خصائص ميكانيكية وإنشائية متفوقة لكن العيب الرئيسي لهذه المادة الإنشائية الجديدة هو كلفتها العالية. يقدم هذا البحث دراسة تجريبية لتحري سلوك الإنشاء للعتبات الهجينة ذات المقطع (T) ودراسة إمكانية استخدام الخرسانة العادية سوية مع خرسانة المساحيق الفعالة في نفس المقطع للعتبات للاستفادة من مميزات هاتين المادتين بأفضل طريقة. النتائج التجريبية بينت أن استخدام خرسانة المساحيق الفعالة في الجذع (web)

والخرسانة العادية في ال شفة (flange) حسنت بشكل كفاء أداء العتبت الهجينة ذات المقطع (T)، حيث ان الزيادة في كل من حمل التشقق الاولي وحمل الإنثناء الاقصى والهطول الاقصى كانت ١٦,٦٧٪، ٦٠٪ و ٢٩,١٩٪ على التوالي، بينما كانت الزيادة في حالة استخدام خرسانة المساحيق الفعالة في ال شفة والخرسانة عادية المقاومة في الجذع كانت ٢٠٪، ٣٤,٢٨٪ و ١٤,٩٧٪ على التوالي بالمقارنة مع العتبة ذات الخرسانة عادية المقاومة.

1. Introduction:

Reactive powder concrete (RPC) is one of the latest and most important development in concrete technology , it has received great attention in recent years in the world due to its superior mechanical properties such as; high strength, high ductility, high durability, limited shrinkage, high resistance to corrosion and abrasion ^[1]. RPC is also known as ultra high performance concrete (UHPC) according to its superior structural performance. It consists of large quantity of cement , crushed quartz or fine sand (with particle size less than 600 μm) , silica fume , fibers, new generation of superplasticizers, low (w/c) ratio (less than 0.2) , and no coarse aggregate^[2]. With all superior properties the major drawback of RPC is that the material by itself is very expensive. The high cement content , the elimination of coarse aggregate and using special materials are what which elevates the cost of RPC. Therefore, in this study it is proposed to combine normal strength concrete and RPC in composite structures in order to exploit the advantages of the two materials in an optimal way.

The first production of RPC belongs to the **Richard and Cheyreyz**^[1,2] when they published their first papers about RPC in 1994 and 1995 respectively during their work in the scientific division at Bouygues company, latter many studies that were presented dealt with this new construction martial. **Roux et al**^[3] investigated the durability of RPC, **Biolzi et al**^[4] studied the effect of micro steel fibers on direct tensile strength, compressive strength and modulus of elasticity of RPC, **Colleparidi et al**^[5] studied the influence of superplasticizer type on the compressive strength of RPC. **Chan and Chu**^[6] studied the effect of silica fume on steel fibers characteristics in RPC, including bond strength, pullout energy.

Locally, **Husain**^[7] presented an experimental research on punching shear and flexural strength of fibrous modified reactive powder concrete flat plates, **Al-ne'aime**^[8] presented an experimental investigation on static and impact properties of reactive powder concrete, **Ibraheem**^[9] presented an experimental and theoretical research on stress-strain

relationships of reactive powder concrete, **Ridha**^[10] presented an experimental research on shear behavior of RPC rectangular beams.

In the field of flexural behavior of RPC beams ,limited number of researches were presented . **Mingbo et al** ^[11], studied flexural performance of RPC prisms (100×100×400mm) with several usual contents of steel fibers and without tensile reinforcement. **Ueda et al.** ^[12] performed theoretical study on dynamic flexural behaviors of RPC beams under high-rate loadings, **Jithu Raj and Jeenu** ^[13], studied flexural behavior of ultra high performance concrete composite rectangular section beams and **Hannawayya** ^[14] presented research to study the mechanical properties of RPC as a material as well as studying the flexural behavior of RPC rectangular section beams. All the previous researches did not dealt with behavior of hybrid T-section beams, therefore, this research present an experimental investigation to determine flexural behavior of hybrid (reactive powder concrete-normal strength concrete) T-beams.

2. Aim of the Research:

This research aim to present experimental investigation on flexural behavior of hybrid (reactive powder concrete-normal strength concrete) T-beams in order to exploit the advantages of these two materials in an optimal way.

3. Construction Materials:

3.1 Cement:

Ordinary Portland cement (Type 1) supplied from Iraq, Sulymania, Tasloga factory is used in this study. Test results indicated that the chemical and physical properties of this cement conform to the Iraqi specification No.5/1984 ^[15].

3.2 Fine Aggregate:

Two types of fine aggregate are used in this study:

1. Natural sand from Al-Ukhaidher region was used for normal strength concrete mix of this study. The fine aggregate has fineness modulus of (2.36)
2. Very fine sand with maximum size (600µm) is used for RPC. This type was separated by sieving.

The results indicated that the two types of fine aggregate grading were within the requirements of the Iraqi specification No.45/1984 ^[16].

3.3 Coarse Aggregate:

For normal strength concrete, crushed gravel of maximum size of 10mm obtained from Al-Nebai source was used as coarse aggregate. The results indicated that the coarse aggregate grading was within the requirements of the Iraqi specification No.45/1984 ^[16].

3.4 Silica Fume:

A gray densified silica fume (which is a byproduct from the manufacture of silicon or ferro-silicon metal) was used for RPC mix, which was imported from Sika company. The used silica fume conforms to the chemical and physical requirements of ASTM C1240-04^[17].

3.5 Superplasticizer (S.P.):

A high performance concrete superplasticizer (also named High Range Water Reduction Agent HRWRA) based on polycarboxylic technology, which is known commercially as Glenium 51, is used for RPC mix in this study. Glenium 51 is free from chlorides and complies with ASTM C494 type a ^[18].

3.6 Steel Fibers:

Hooked ends mild carbon steel fibers with aspect ratio of 80 are used for RPC mix in this study. According to ASTM-A820-04 ^[19], this type of steel fibers is classified as (Type D).

3.7 Steel Bars:

Deformed steel bars of nominal diameter (ϕ 12mm) with (458MPa) yield strength are used as tension reinforcement, while (ϕ 8mm) deformed steel bars with 419 MPa yield strength are used as stirrups and (ϕ 5mm) deformed steel bars with 376 MPa are used as transverse reinforcement of flange. The test results of bars satisfy ASTM A615 requirements ^[20].

4. Experimental Program:

Five beam specimens were used to investigate the influence of partially usage of RPC on behavior of T-beams as comparison with fully RPC beam and normal strength concrete beam. **Figure (1)** illustrates cross-sections of RPC, normal strength concrete, hybrid concrete beams. **Table (1)** shows reduction percentages of RPC in sections of the beams.

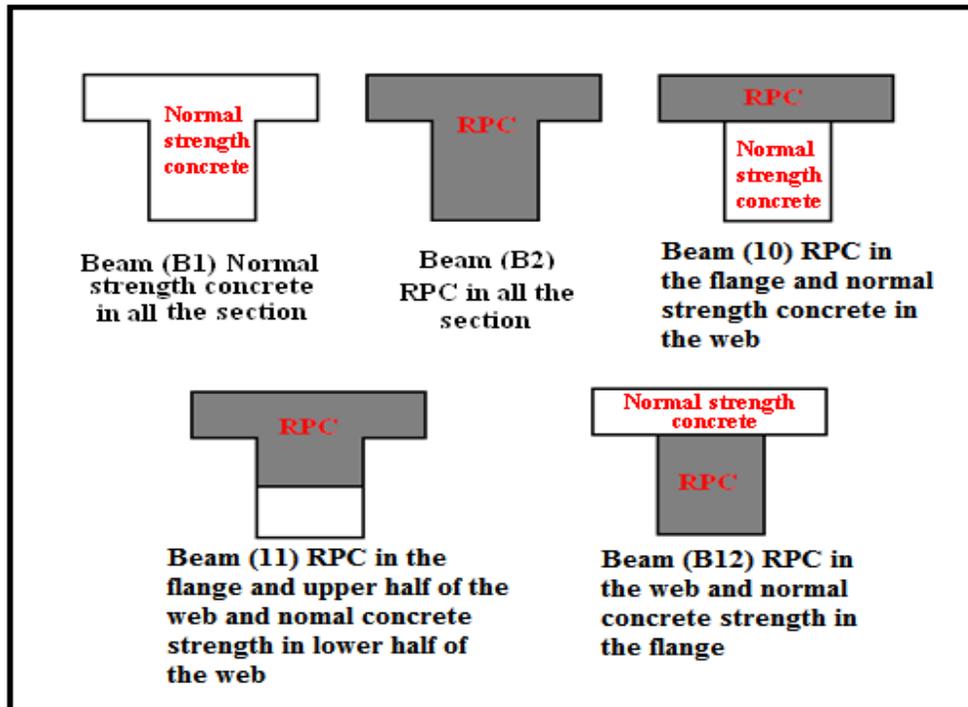


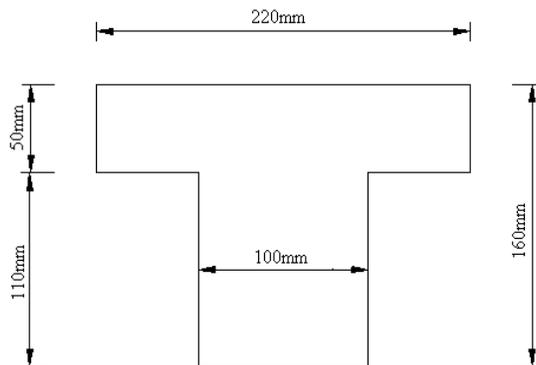
Figure (1) Cross-sections of the tested beams

Table (1) Reduction percentages of RPC in the sections of the tested beams

Beam No.	B1	B2	B10	B11	B12
Mix	Normal	RPC	RPC in the flange only	RPC in the flange and upper half of the web	RPC in the web only
Size of normal strength concrete in beam	0.0286	-	0.0143	0.007150	0.0143
Size of RPC in beam	-	0.0286	0.0143	0.02145	0.0143
Reduction percentage of RPC in the section	100%	0%	50%	25%	50%

5. Dimensions of Tested Beams:

The beam specimens were designed to have appropriate dimensions that can be manufactured, handled and tested as easy as possible. The nominal dimensions of the tested beams were (1300mm) in overall length and (160mm) in depth. The flange was made with (220mm) width and (50mm) thickness. The web of the beam was made with (110mm) clear height and (100mm) width. **Figure (2)** shows the dimensions of the test beams. All beam specimens are simply supported with clear span of (1200mm) and tested under the effect of two point static loads.



(a)



(b)

Figure (2) Details of tested beams (a) Beam cross-section (b) Isometric view

6. Reinforcement Details:

The longitudinal and shear reinforcement of the tested beams was designed to ensure the section to be failed in flexure with tensile mode of failure. For the flange, to prevent transverse bending failure, transverse reinforcement (5mm diameter bars at 100mm c/c spacing) were used at the top of the flange overhangs. This reinforcement was calculated by

treating the flange overhangs as cantilevers fixed at the face of the web and having a span equal to the length of the flange overhangs as shown in **Figure (3)**.

Also, to prevent shear failure of the section, 8mm diameter stirrups at 50mm c/c spacing in web was provided. Also to fix these stirrups and the transverse reinforcement of the flange, 4 ϕ 5mm smooth bars were used at the top of the flange. The steel details of all the bars used as longitudinal reinforcement, stirrups and transverse reinforcement at the top of the flange overhangs are shown in **Figure (4)**.

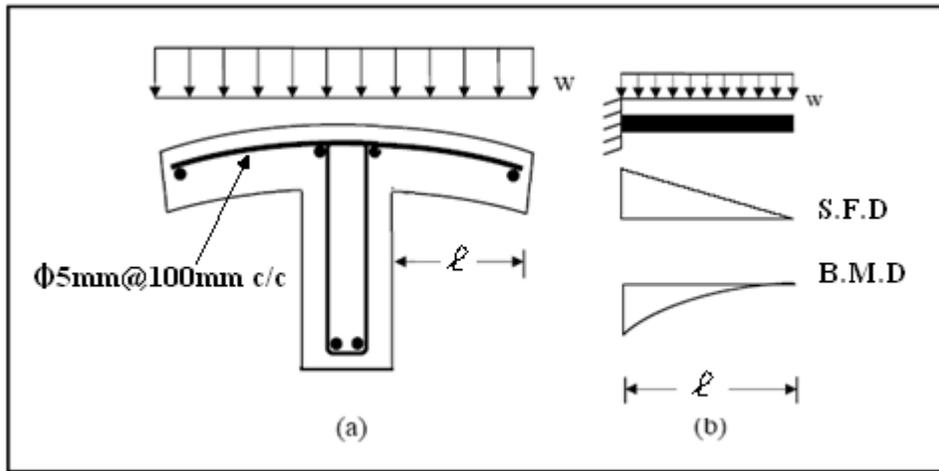


Figure (3) (a) Transverse bending of T-beam flange (b) Shear and moment diagrams for flange overhang

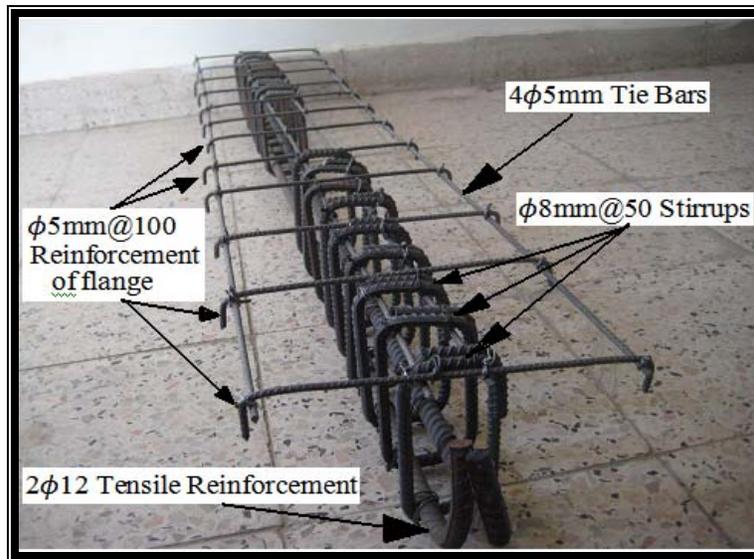


Figure (4) Details of flexural beam reinforcement

7. Mixes:

In this study two types of mixes were used (RPC mix and normal strength concrete mix). Reactive powder concrete mix consists of cement, fine sand, silica fume, steel fiber, superplasticizers and water, this mix was used to cast RPC beam and hybrid beams, as well as control specimens (cylinders and prisms) of RPC, the mix proportions are listed in Table(2). Normal strength concrete mix consists of cement, fine aggregate, coarse aggregate, and water were used to cast the normal and hybrid beams, as well as cylinders and prisms of normal strength concrete. The w/c of these mix was 0.45 and mix proportions of cement, fine aggregate, coarse aggregate were 1:1.5:3 respectively.

Table (2) Properties of RPC mix

Mix Type	Cement kg/m ³	Fine Sand kg/m ³	Silica Fume* %	Silica Fume kg/m ³	w/c	S.P. ** %	Steel Fiber*** %	Steel Fiber kg/m ³
RPC	1000	1000	25	250	0.2	1.7	2	156

* Percent of cement weight.

** S.P Superplasticizer, percent of binder (cement + silica fume) weight.

*** Percent of mix volume

8. Testing of Beams:

At the age of 28 days, all beams were lifted from the curing water container, left to dry, and then painted with white color so that cracks can be easily detected. All beam specimens were tested by using the universal testing machine (MFL system) of capacity 2500 kN under monotonic loads until failure occurs. A dial gauge of 0.002 mm accuracy was attached firmly to the bottom face of midspan to record midspan deflection. The schematic diagram for the beam is shown in **Figure (4)**. One of the beams under testing is shown in **Figure (5)**. The test beams were simply supported over an effective span of (1200mm) and loaded with two-point loads.

9. Mechanical Properties of RPC and Normal strength concrete:

The mechanical properties of RPC and normal strength concrete are listed in **Table (3)** the compressive strength tests were carried out on cylinders (100x200mm) in accordance

with ASTM-C39 ^[21]. Flexural strength (modulus of rupture) tests were carried out on prisms (50x50x500mm) in accordance with ASTM C78 ^[22]. While the indirect tensile strength (splitting tensile strength) testes were carried out on cylinders (150x300mm) in accordance with ASTM C496 ^[23]. Average of three specimens for each test were used to obtain the mean strength as required by ACI 318M-11 Code ^[24].

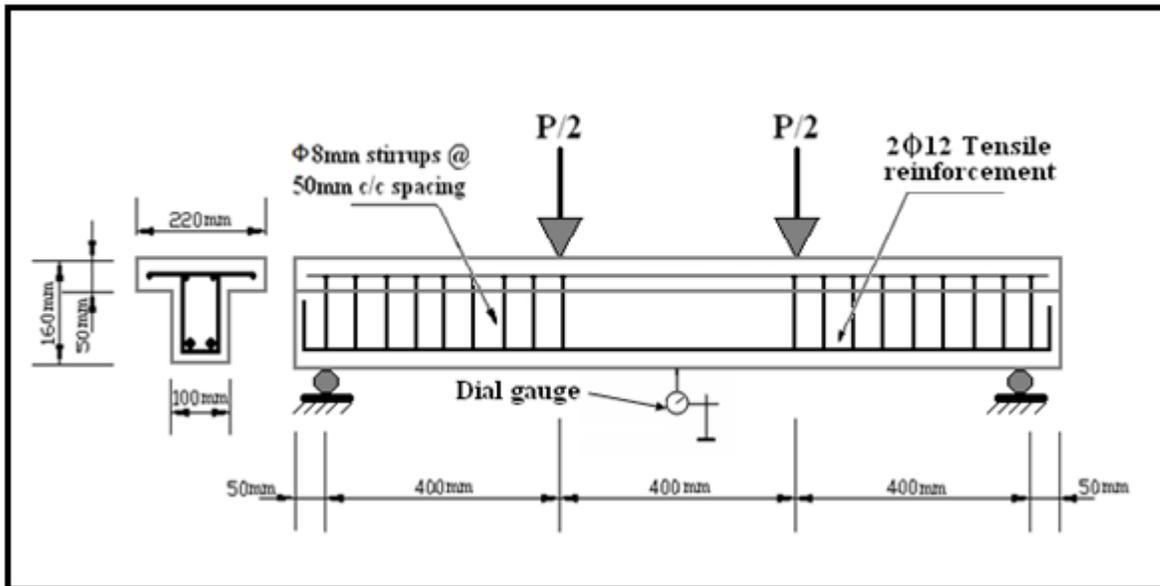


Figure (4) Details of the tested beams

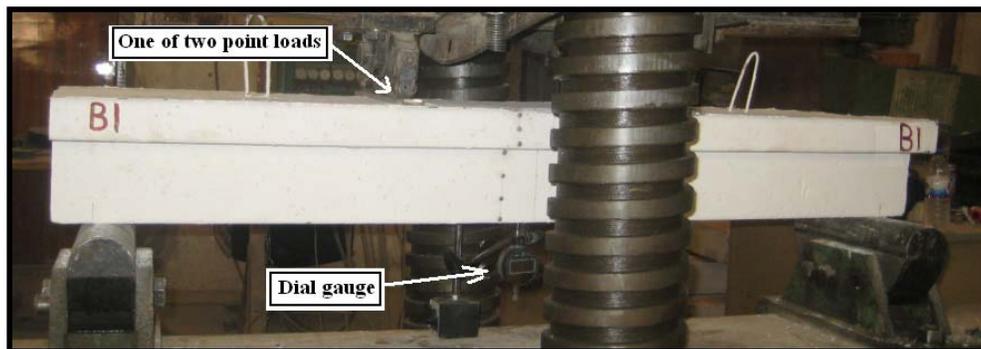


Figure (5) Tested beams set up

Table (3) Mechanical properties of RPC and normal strength concrete

Mix type	f_c' (MPa)	f_{sp} (MPa)	f_r (MPa)
RPC	124.95	16.29	19.0
Normal strength concrete	27.04	2.88	3.5

10. Results and Discussion:

Beams tests show that the general behavior of all beams under flexural loading can be described as follows: at early stage of loading, the first cracks appeared at bottom of mid span in the tension zone, the load in this stage is known as first crack load. With increasing the loads, these cracks became wider and propagate upwards, also other cracks developed in the same zone. Further loading made the cracks to propagate and extend faster; some of them reached the compression zone until the failure occurred at ultimate load capacity.

10.1 First Crack and Ultimate Load :

Table (4) shows the detailed and the results of these beams. The results show that the first crack load of full RPC beam increased at percentage 133.34 % as compared with that of normal strength concrete beam, while the increasing percentages were 20, 33.34 and 86.67% for beams B10 (RPC in flange and normal strength concrete in web), B11 (RPC in flange and upper half of web) and B12 (normal strength concrete in flange and RPC in web) respectively as compared with normal strength concrete beam (B1). It can be noted that beams B1, B10, B11 have approximate first crack load, this may be attributed to the reason that the lower part of web of these beams containing the same normal strength concrete and under flexural loads the initial cracks form in this layer. While beams B2 and B12 containing the same RPC; therefore, these beams also have approximate first crack load. The increases in first crack load for beams B2 and B12 as compared with B1 may be belong to the reason that presence steel fibers in tension zone which consists of RPC restricted growth and extension of the cracks across the initiating flexural cracks and transmit the

tensile stresses uniformly to the concrete surrounding the cracks resulting in more bearing capacity, also steel fiber improve the bond between the matrix and the reinforcing bars by inhabiting the growth of cracks, while using RPC in compression zone beams (B10 and B11) did not enhance the first crack load as compared with beam B1.

On the other hand, the ultimate flexural strength of full RPC beam B2 increased at percentage 84.28% as compared with that of normal strength concrete beam B1, while the increasing percentages were 34.28, 45.71 and 60.0% for beams B10, B11 and B12 respectively as compared with normal strength concrete beam B1. It can be noted that, presence RPC in the section improved the ultimate flexural strength especially presence RPC in tension zone. This behavior can be attributed to enhanced stiffness of the beams which contain RPC as well as the improvement in other mechanical properties such as modulus of elasticity, compressive strength and tensile strength.

As compared with other researches, these results is in compatibility with the results obtained by **Jithu Raj** and **Jeenu** ^[13] in their study on flexural behavior of hybrid rectangular beams, as they concluded that composite (hybrid) beams exhibit higher first crack load and load carrying capacity as compared with normal concrete beam.

10.2 Deflection :

The results of deflection (Δ) in **Table (4)** reveal that, the ultimate deflection increased by presence of RPC in the section, however, the ultimate deflection of full RPC beam B2 increased at percentage 52.02 % as compared with that of normal strength concrete beam B1, while the increasing percentages were 14.97, 14.33 and 29.19 % for beams B10 (RPC in flange and normal strength concrete in web), B11 (RPC in flange and upper half of web) and B12 (normal strength concrete in flange and RPC in web) respectively as compared with normal strength concrete beam B1. This behavior is normally explained by the efficiency of steel fibers which is present with RPC in arresting the propagation and controlling the growth of the flexural cracks within the beam when they are crossed by them; hence the beam could withstand greater loads and deflection before failure. steel fibers maintain the beam integrity throughout the post-cracking stages, this means that presence RPC especially in the tension zone makes the hybrid beams more ductile as compared with normal concrete beam and capable of undergoing large deflections before

reaching ultimate load carrying capacity. This property is very important for structural members as it makes concrete give warning before failure and prevents sudden collapse.

10.3 Load-Deflection Curves:

Figure (6) shows load midspan deflection curves of the tested beams. It is clear from the figure that the curves had three portions; the first portion is linear elastic zone until the first crack load, the second portion began beyond the elastic zone until yielding tensile reinforcement steel, and the final portion is the stage of yielding tensile steel and expansion the cracks until failure occurs.

These curves reveal that beams B1, B10, B11 have approximate slope in linear stage with approximate first crack loads, but after this load the curves become very different. On the other hand presence RPC in the web of beams B2 and B12, led to similar behavior for these beams at early stages of loading but presence normal strength concrete in the flange of beam B12 make the curve take different path beyond the first crack load because of weakness normal strength concrete as compared with RPC.

It can be noted also that the area under load midspan-deflection curve which denote to energy absorption capacity of beams increased with presence RPC in the section of the beam , however, for hybrid beams, the beam B12 (normal strength concrete in flange and RPC in web) has area under load midspan-deflection curve lager than that of B10 (RPC in flange and normal strength concrete in web) and B11 (RPC in flange and upper half of web. On the other hand , presence RPC in the beam resulting in decrease deflection at all stages of loading as compared with normal concrete beam especially for the beams which have RPC in the tension zone due to the increase the stiffness of the beam.

Jithu Raj , Jeenu ^[13] and **Hannawayya** ^[14] in their studies also found that beams with RPC(which contains steel fiber) become more stiffer under loads and in the same times, the ultimate deflection and the ductility will increase.

From these results, it can be seen that the case of using RPC in web and normal strength concrete in flange has very significant effect in enhancement first crack load, ultimate flexural load and energy absorption capacity as compared with normal strength concrete beam and full RPC beam. Also the case of using RPC in flange and in upper half of web enhances the properties of beams but with less degree than the first case.

Table (4) Experimental results of tested beams

Beam No.	B1	B2	B10	B11	B12
Mix	Normal strength concrete	RPC	RPC only in the flange	RPC in the flange and upper half of the web	RPC in the web only
Silica fume (SF) %	-	25	25	25	25
Steel fiber (V_f) %	-	2	2	2	2
Tensile rein.	2 ϕ 12	2 ϕ 12	2 ϕ 12	2 ϕ 12	2 ϕ 12
ρ	0.007849	0.007849	0.007849	0.007849	0.007849
P_{cr} kN	15	35	18	20	28
$(P_{cr} - P_{cr B1}) / P_{cr B1} \times 100$	0	133.34	20	33.34	86.67
P_{ult} kN	70	129	94	102	112
$(P_{ult} - P_{ult B1}) / P_{ult B1} \times 100$	0	84.28	34.28	45.71	60
$(P_{cr} / P_{ult}) \%$	21.43	27.13	19.15	19.61	25
Δ_{max} mm**	9.42	14.32	10.83	10.77	12.17
$(\Delta_{max} - \Delta_{max B1}) / \Delta_{max B1} \times 100$	0	52.02	14.97	14.33	29.19
Type of failure	Tension steel yielding	Tension steel yielding	Tension steel yielding	Tension Steel yielding	Tension steel yielding

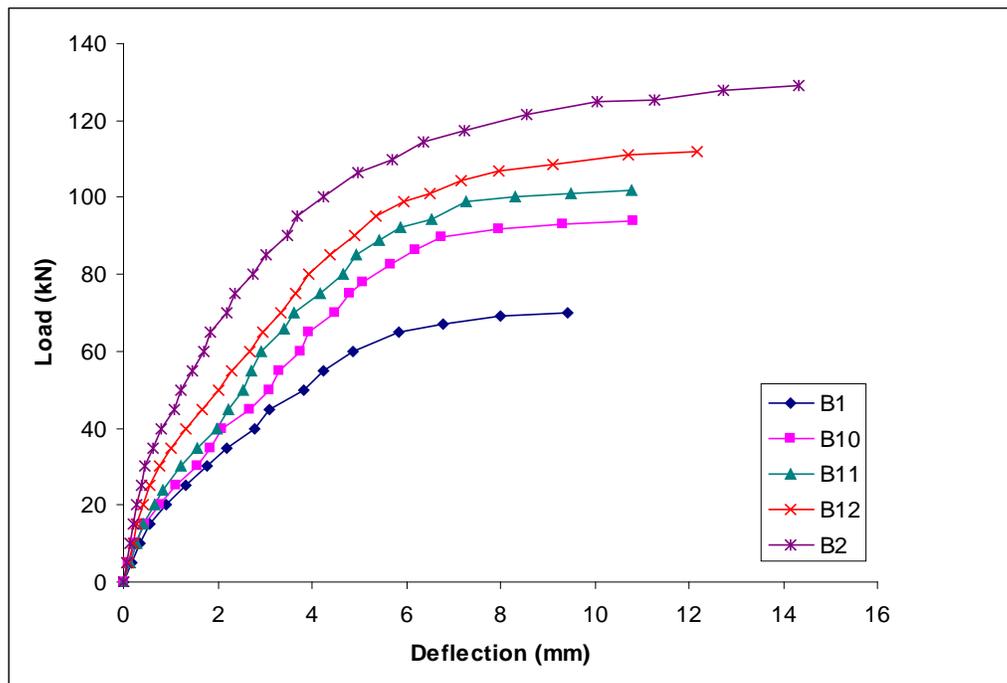


Figure (6) Load-deflection curves of tested beams

10.4 Crack Patterns:

Figure (7) shows crack pattern of normal strength, RPC and hybrid beams it can be noted that normal strength concrete beam (B1) and hybrid beams of normal strength concrete in web (B10 and B11) have less and wider cracks as compared with full RPC beam (B2). While beam (B12) with normal strength concrete in flange and RPC in web has narrow cracks in tension region and some crushing in flange due to weakness of flange concrete.

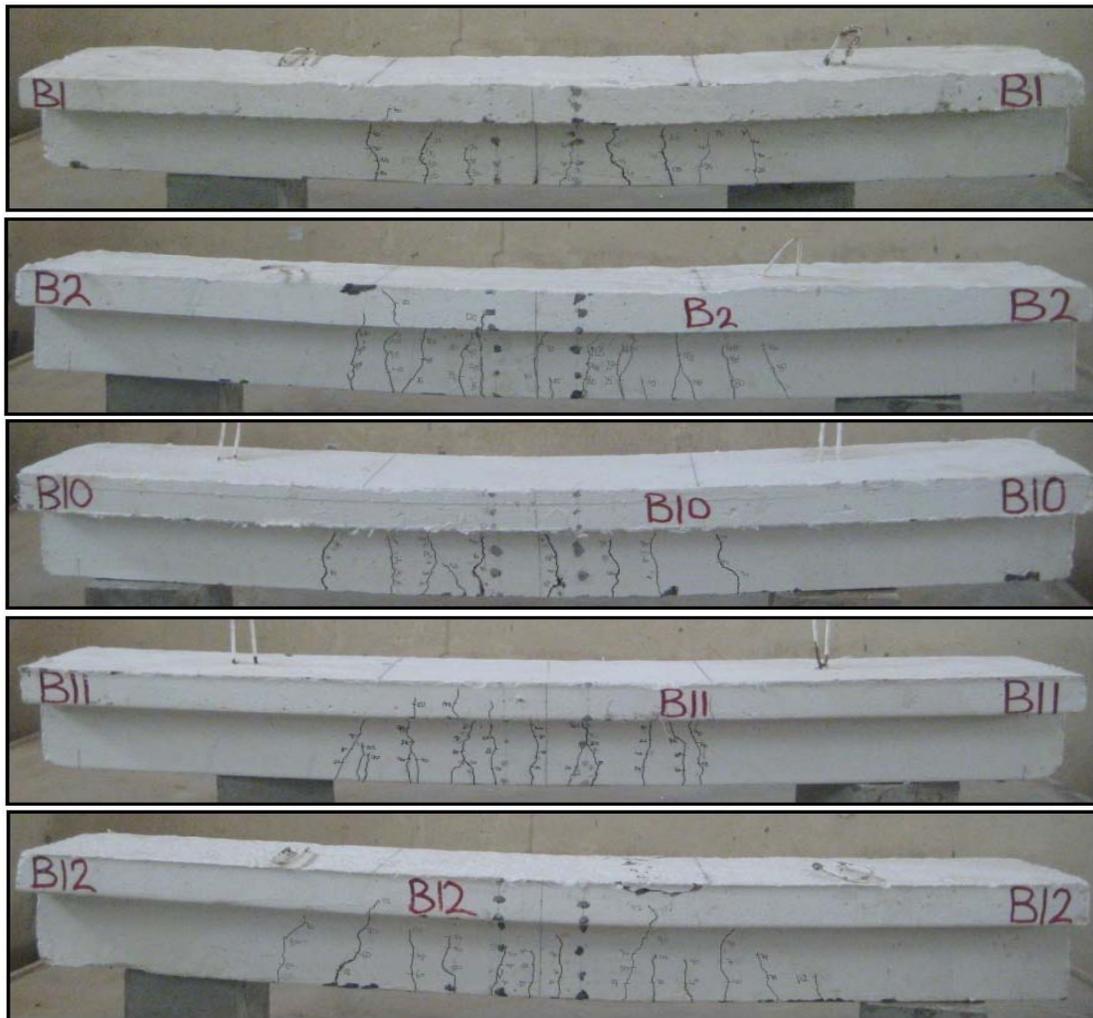


Figure (7) Crack pattern of the tested beams

11. Conclusions:

1. RPC T-beam (RPC in all the section) exhibits an increase in the first crack load, ultimate flexural strength and ultimate midspan deflection with percentages 133.34%, 84.28% and 50.02% respectively as compared with normal concrete T-beam.
2. Using RPC in the flange with normal strength concrete in the web (reduction percentage of RPC in the section equal to 50%) for hybrid T-section beam shows an increase in the first crack load, ultimate flexural strength and ultimate midspan deflection with percentages increase of 20%, 34.28% and 14.96% respectively as compared with normal strength concrete T-beam.
3. Using RPC in the flange and upper half of the web with normal strength concrete in lower half of the web (reduction percentage of RPC in the section equal to 25%) for hybrid T-section beam shows an increase in the first crack load, ultimate flexural strength and ultimate midspan deflection with percentages increase of 33.34%, 45.71% and 14.33% respectively as compared with normal strength concrete T-beam. Thus using RPC in the flange and upper half of the web with reduction percentage of RPC in the section equal to 25% enhances the flexural performance of hybrid T-beams more than using RPC in the flange only with reduction percentage of RPC in the section equal to 50%.
4. Using RPC in the web with normal strength concrete in the flange (reduction percentage of RPC in the section equal to 50%) for hybrid T-section beam shows an increase in the first crack load, ultimate flexural strength and the ultimate midspan deflection with percentages increase of 86.67%, 60% and 29.19% respectively as compared with normal strength concrete T-beam. Therefore, using RPC in the web does effectively enhance the performance of T-beams more than the case of RPC in the flange and upper half of the web.
5. Although the ultimate midspan deflection increases with presence RPC in the section of the beam , the load-deflection curves reveal that at particular load levels, the deflection of the beams containing RPC in the section especially in the tension zone decreases at all stages of loading as compared with normal strength concrete beam.

6. Presence RPC especially in the tension zone makes the hybrid beams more ductile as compared with normal concrete beam and capable of undergoing large deflections before reaching ultimate load carrying capacity.
7. The area under load midspan-deflection curve increases with presence RPC especially in the tension zone.
8. The cracks in all the tested beams of this study formed in the middle third of the beam at the tension zone . Normal concrete beam and hybrid beams of normal concrete in the web have less and wider cracks as compared with full RPC beam . While beam with normal concrete in the flange and RPC in the web has narrow cracks in tension region and some crushing in the flange due to weakness of flange concrete.
9. The failure mode of all tested beams is of the type of yielding tensile reinforcement. This indicates that all tested beams are under-reinforced.

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