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EXPERIMENTAL STUDY ON REACTIVE POWDER AND NORMAL CONCRETE RECTANGULAR BEAMS UNDER DIFFERENT LOADING RATE

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ABSTRACT: *The paper in hand reports the experimental results of loading rate influence on the loading characteristics and deformation behavior of normal strength and reactive powder concrete. Two types of beams were studied, normal and reactive concrete in different quantity of flexural reinforcement and compressive strength. The experimental work included (8) reinforced concrete simply supported beams with (1200)mm span length and (180×250) mm. Two kinds of loading rates, reinforcement ratio and compressive strength were chosen for testing the beams. The shear strength, stiffness, cracking load and deflection were measured.* **.** *The experimental results presented in this paper clearly indicate that the ultimate load and initial stiffness increase with increasing loading***.**

KEYWORDS: Reactive Powder, Normal Concrete, Rectangular Beams, Loading Rate

INTRODUCTION

Reactive powder concrete (RPC), a cement-based composite material well known for the ultra-high- strength, high-durability and low-porosity, made its international debut in 1994 (Richard, 1994)[(1)] .The advance mechanical and physical properties of (RPC) are obtained by optimizing packing density of concrete mixture with precise gradation of all mix particles, and by using highly refined silica fume to improve the microstructure of hydrated cement pastes through the pozzolanic reaction. To produce a very high compressive strength of (RPC), applications of pressure before and during setting and heat-treating after setting are normally required. Compressive strengths of (200 to 800) MPa, moduli of elasticity of (50 to 60) GPa and flexural strength of(6 to 13) MPa have been achieved with (RPC) (Richard, 1995)[(2)] .

In order to determine guidelines for the production of (RPCs) the effects of the following parameters on fresh and/or hardened properties have been determined: (a) superplasticizers obtained from different suppliers, (b) water-binder ratio, (c) quartz sand grading, (d) silica fume content, (e) ternary blends, i.e. pulverised fly ash or ground granulated blast furnace slag in combination with silica fume, and (f) volume and type of fibers. Tests on the mechanical properties indicate that RPC has enhanced tensile strength and ductility, i.e. flexural strengths are likely to be between (30 and 60) MPa and fracture energies above 10000J.m^2.The basic principles in the selection of the above materials for the production of these ultra- high performance concrete are:

• Enhancement of homogeneity by elimination of coarse aggregate,
• Enhancement of compacted density by optimization of the granular mixture, i.e. the reason for the high silica fume content and use of fine quartz sand as the only aggregate,

• Optional enhancement of the microstructure by post-set heat-treating, i.e. the quartz sand may become reactive at these elevated temperatures,
• Enhancement of ductility by incorporating small-sized steel fibers,
• Maintaining mixing and casting procedures as close as possible to existing practice for normal and high strength concretes(3).

An experimental study was carried out where the main objective was to investigate the effect of loading rate on failure characteristics of concrete reinforced normal and reactive powder concrete with different longitudinal reinforcement ratio and different values of compressive strength.

Effect of Loading Rate in Previous Works

It is well known that loading rate significantly influences the structural response. The structural response depends on the loading rate through three different effects: (1) through the creep of the bulk material between the cracks, (2) through the rate de- pendency of the growing microcracks and (3) through the influence of inertia forces, which can significantly change the state of the stresses and strains at the crack tip. Depending on the type of material and the loading rate, the first, second or third effect may dominate. For quasi-brittle materials, such as concrete, which exhibit cracking and dam- age phenomena, the first effect is important for relatively low loading rates (creep-fracture interaction).(4)

XiaoXin and et.al(5) in (2009) tested (18) simply supported rectangular beams to study the effect of loading rate on crack velocities at a wide range of loading rate. The peak load is sensitive to the loading rate. Under low loading rates, the rate effect is slight, while it is pronounced under high loading rates, under low loading rates, the crack velocity increases with an increase in loading rates, the loading rate effect is pronounced, whereas loading rate effect on the crack velocity is slight under high loading rates.Shiyun X. and et.al(6) in (2012) conducted a study on the loading rate effect on the mechanical behaviors of RC beams, it was concluded that the failure configurations of five RC beams were the same at different loading rates and the width of the crack decreased with the increasing loading rates and they distributed more uniform.Georgia E. and et.al(7) in (1998) studied experimentally influence of the loading rate on the axial compressive behavior of concrete specimens. In that study, a total of 9 prisms were tested with different loading rate. It was found that, The fast loading rate of the applied axial compressive load results in an 11% decrease of the obtained strength of unconfined prismatic specimens.

EXPERIMENTAL PROGRAM

Beams Geometry

All beams were geometrically similar, having dimensions (180x 250x1200) mm and loaded through two point load, the distance between the two point load is (350 mm). The beams are simply supported and the distance from c/c of` supports was (1050 mm).

Beams Reinforcement

Two longitudinal bottom reinforcement ratios were used (2ϕ16 and 3ϕ16). The tensile strength of deformed bars are (422 MPa) and (385 MPa) for longitudinal and shear reinforcement respectively.

Compressive Strength

Cubical (150x150) specimens were used to test the compressive strength of concrete. The compressive test was done according to ASTM C39[8] and B.S 1881[9] by using a computerized compression machine. The Table (1) below show the compressive strength of each specimen.

Table (1) Characteristics of the Tested Beams

Specimens	Type of Concrete	Flexural Reinforcement	Shear Reinforcement	Compressive Strength (MPa)
B1	Normal concrete	2Ø12 top 2 Ø16 bottom	Ø10@100mm	29
B2	Normal concrete	2Ø12 top 2 Ø16 bottom	Ø10@100mm	30
B3	Normal concrete	2Ø12 top 3 Ø16 bottom	Ø10@100mm	28.3
B4	Normal concrete	2Ø12 top 3 Ø16 bottom	Ø10@100mm	29.7
B5	Reactive powder concrete	2Ø12 top 2 Ø16 bottom	Ø10@100mm	93
B6	Reactive powder concrete	2Ø12 top 2 Ø16 bottom	Ø10@100mm	89
B7	Reactive powder concrete	2Ø12 top 3 Ø16 bottom	Ø10@100mm	90
B8	Reactive powder concrete	2Ø12 top 3 Ø16 bottom	Ø10@100mm	87

Loading Rate

To investigate the influence of the loading rate on the response of concrete beams, two values of loading rates were used (1 kN/min and 2 kN/min) for each type of concrete (normal and reactive beams). The beams (B1, B3, B5 and B7) were tested with (1 kN/min) loading rate, while the beams (B2, B4, B6 and B7) were tested at (2 kN/min) loading rate.

Mix proportions

Table (2) show the mix proportions are used in tested beams.

Table (2) Mix Proportions

Concrete Strength (MPa)	Cement (Kg/m^3)	Sand Kg/m^3 Passing Through 600Microne Sieve	Gravel Kg/m^3 Passing Through 4.75mm Sieve Size	w/c Ratio	SP Ltr/m^3	Silica Fume
30	415	535	1250	0.44	-	-
92	800	900	1000	0.30	7%	5%

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RESULTS

Load- deflection Behavior

Measured load-displacement curves obtained for static loading with different loading rates are shown in Figures (1, 2, 3 and 4). As indicated, by increase of loading rate, the peak load and the initial stiffness increase.Through the careful observation and comparison, the crack width decreased with the increasing loading rates. This is may be attributed to the obstruction of the growth of internal cracks as a result of increasing loading rate, which caused the developments of the external cracks.

At the first stage of load-deflection curve, there is a linear relationship between load and deflection the reinforced steel and concrete were within their elastic stages and work together and become nonlinear slowly with the increasing load application because the deceasing of stiffness of the RC beam through the loading application.

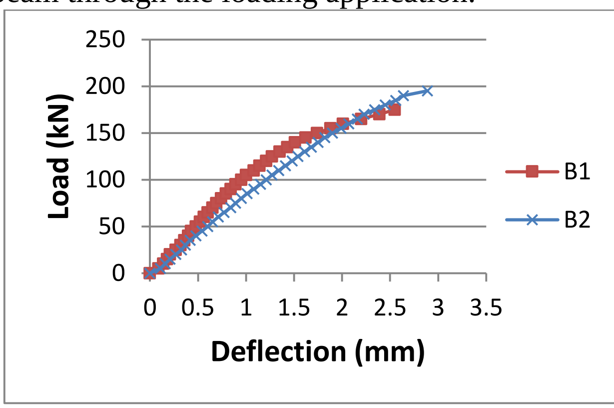

Figure (1) Load-deflection Curve of Beams (B1 and B2)

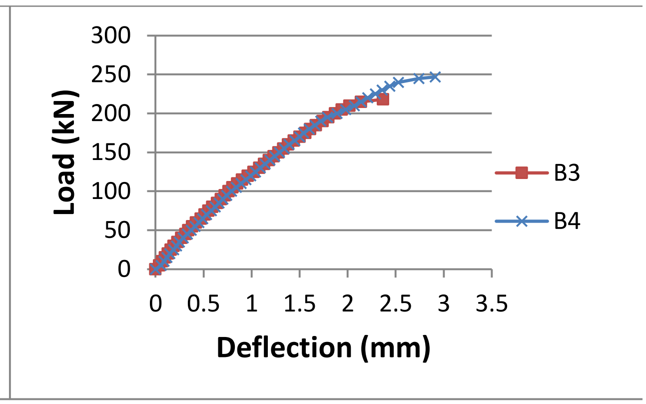

Figure (2) Load-deflection Curve of Beams (B3 and B4)

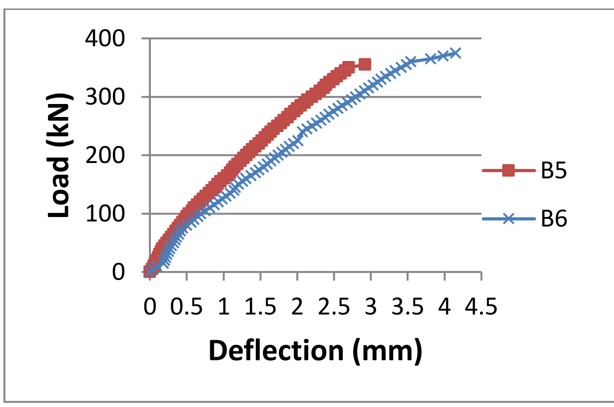

Figure (3) Load-deflection Curve of Beams (B5 and B6)

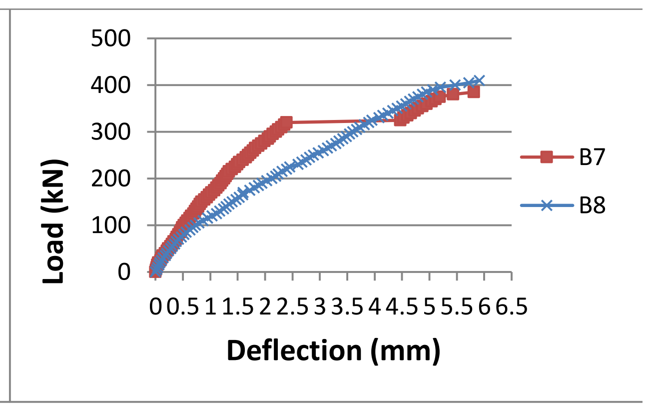

Figure (4) Load-deflection Curve of Beams (B7 and B8)

Effect of Loading Rates on Failure and Cracking Load

It is clear that the cracking load and the failure load increased with increasing rate of loading. As shown in Table (3) below, compared with the beam B1, B3, B5 and B7, the cracking load of the beams (B2, B4, B6 and B8) increased (23.34, 10.7, 22 and 7)%, respectively. Similarly, the failure loading of the beams (B2, B4, B6 and B8) increased (11.42, 13.3, 5.63 and 6.5)%, respectively.

Table (3) Load Characteristics of Tested Beams

Sample No.	Failure Load	% of Difference	Cracking Load	% of Difference
B1	175	11.42	60	23.34
B2	195		74	
B3	218	13.3	84	10.7
B4	247		93	
B5	355	5.63	132	22
B6	375		161	
B7	385	6.5	172	7
B8	410		184	

The concrete carried most of the loading during the first linear stage of loading application, so the effect of the loading rate on the crack loading was more clear in the specimens with reactive powder concrete (high compressive strength).
The effect of the loading rate at the advanced state of load application was determined by the combination of loading rate on the concrete and steel, because the tensile load on the bottom of the section is carried by the steel bars.

Influence of Loading Rates on the Deformation Behavior
The mid-span crack displacement and the ultimate displacement were listed in Table (4). It was concluded that the crack displacement and the ultimate displacement of the RC beam increased with the increasing loading rate. Compared with the normal beams (B1 and B3), the crack displacement of the beam (B2 and B4) increased (58.92 and 10.6) % respectively. Similarly, the crack displacement of the reactive powder beam B6 and B8 increased (66.6, 75.7)% if compared with the reference specimens (B5 and B7). The mid-span ultimate deflection increased (13.33 and 22.78, 42.13 and 1.7)% for (B1, B3, B5 and B7) with respect to the references specimens B2, B4, B6 and B8 respectively. The increment in the strength of concrete with the increasing loading rate was greater than that of the steel. So, the compressive zone of concrete section on the yield state decreased with the increasing loading rate, which caused the decreasing curvature of the RC beam. All the tested beams (normal and reactive concrete) were failed by diagonal cracks which the shear stresses exceed the shear strength of the beams. See Figures (5, 6, 7, 8, 9, 10, 11 and 12) below.

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Table (4) Displacement of Tested Beams

Sample	**Crack Displacement (mm)**	**% of Difference**	**Ultimate Displacement (mm)**
B1	0.56	-	2.55
B2	0.89	58.92	2.89
B3	0.66	-	2.37
B4	0.73	10.6	2.91
B5	0.78	-	2.92
B6	1.3	66.6	4.15
B7	1.07	-	5.81
B8	1.88	75.7	5.91

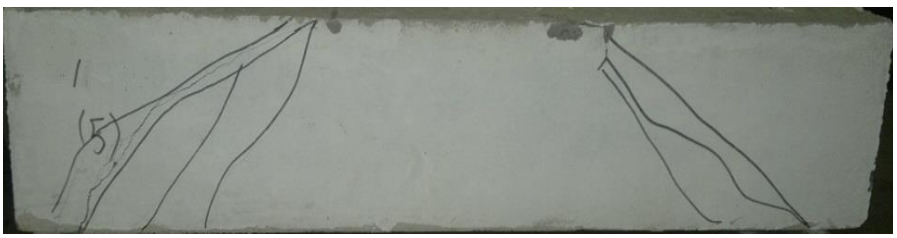

Figure (5) Crack Pattern of Beam (B1)

Figure (6) Crack Pattern of Beam (B2)

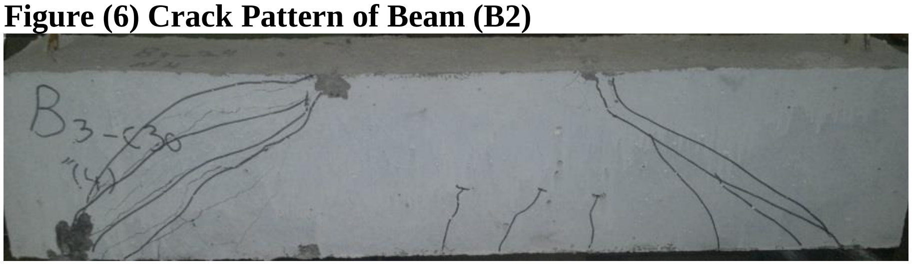

Figure (7) Crack Pattern of Beam (B3)

Figure (8) Crack Pattern of Beam (B4)

Figure (9) Crack Pattern of Beam (B5)

Figure (10) Crack Pattern of Beam (B6)

Figure (11) Crack Pattern of Beam (B7)

Figure (12) Crack Pattern of Beam (B8)

Effect of Flexural Reinforcement

The effectiveness of flexural reinforcement on the carrying capacity of the beams (normal and reactive concrete beams) is clearly shown in Table (3). There is an improvement in ultimate load capacity; this is due to that the tensile stresses applied on the section are carried by steel bar only beam section appears cracked at advanced stages of loading application.

Figures (13, 14, 15 and 16) trace the experimental load-deflection history of a tested beams. Initially, the beams were uncracked and stiff. With further loading, cracking occurs at mid span as the applied moment exceeds the cracking moment M_{cr} causing a reduction in stiffness. The same behavior of load-deflection curve can be seen in two types of reinforced concrete beams.

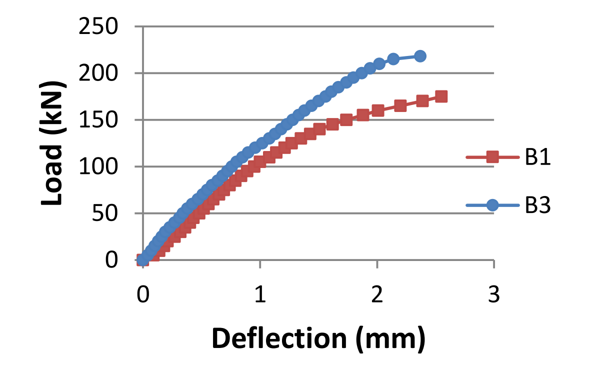

Figure (13) Load-deflection Curve of Beams (B1 and B3)

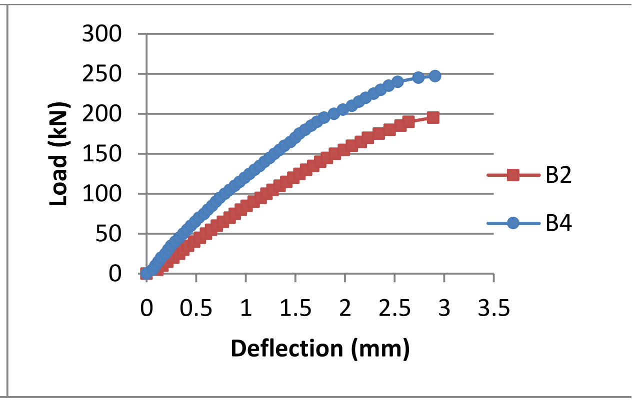

Figure (14)Load-deflection Curve of Beams (B2 and B4)

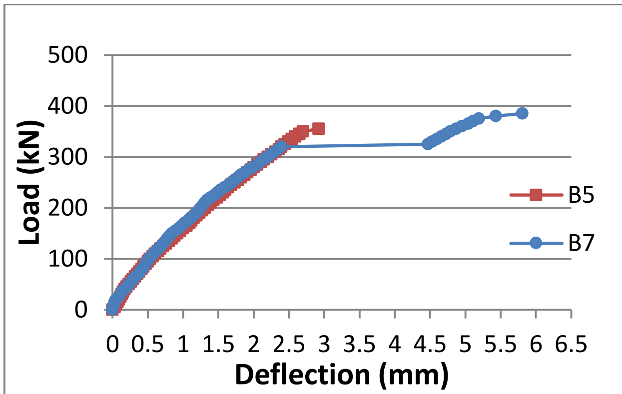

Figure (15) Load-deflection Curve of Beams (B5 and B7)

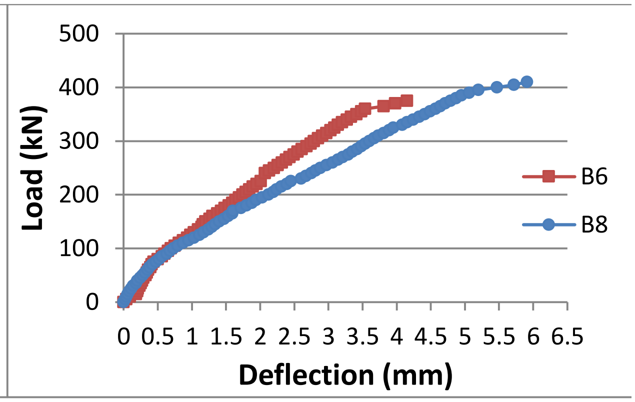

Figure (16) Load-deflection Curve of Beams (B6 and B8)

Effect of Concrete Type

Tests results on effect of type of concrete are presented in Figures (17, 18, 19 and 20). The first flexural cracks appeared approximately (120, 117.5, 104.7 and 97.85) % of reactive powder beams (B5, B6, B7 and B8) over the normal beams (B1, B2, B3 and B4) respectively. The reason of that is may be due to direct relationship between modulus of rupture (f_r) and the compressive strength which is (the modulus of rupture increase with increasing the compressive strength)[10] where modulus of rupture is that the point which the crack start to open.

The ultimate shear capacity of tested beams are affected directly with using reactive powder instead of normal beams, the stiffness of concrete paste between the aggregate particles itself, so the crack exhibits difficulty extension through the aggregates particles this naturally leads to delay the crack opening through the section. See Table (5) below.

Through the extensive study of the load-deflection curve, the general stages of curve behavior is the same in normal and reactive powder concrete beams, but the difference in ductile behavior between them, the normal beams is more ductile than the reactive powder beams.

Table (5) Effect of Compressive Strength

Sample No.	Failure Load	% of Increasing	Cracking Load	% of Increasing
B1	175	102.85	60	120
B5	355		132	
B2	195	92.3	74	117.5
B6	375		161	
B3	218	76.6	84	104.7
B7	385		172	
B4	247	66	93	97.85
B8	410		184	

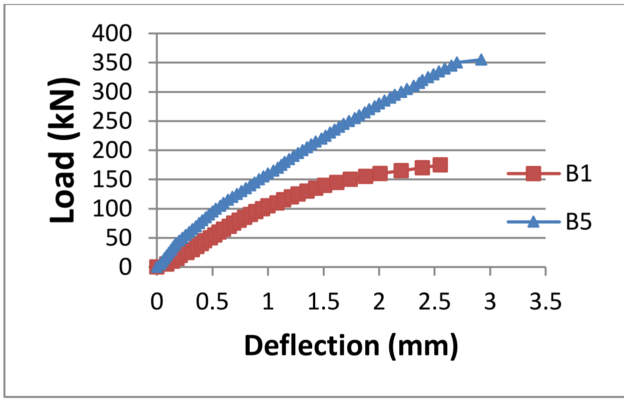

Figure (17) Load-deflection Curve of Beams (B5 and B7)

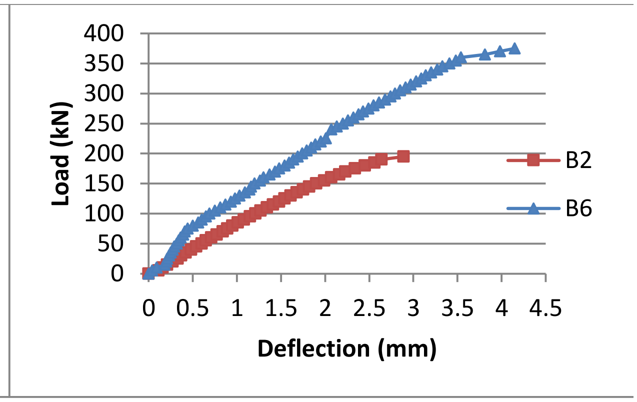

Figure (18) Load-deflection Curve of Beams (B5 and B7)

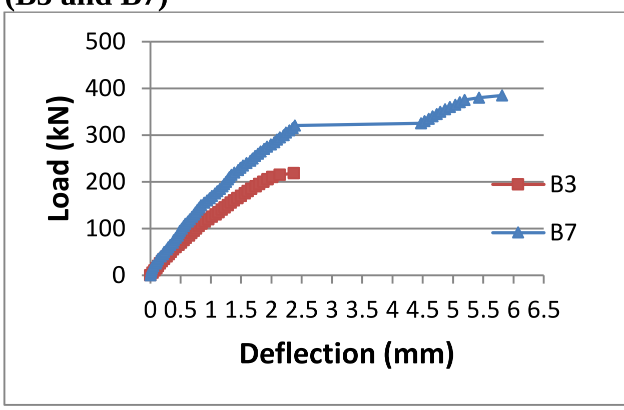

Figure (19) Load-deflection Curve of Beams (B5 and B7)

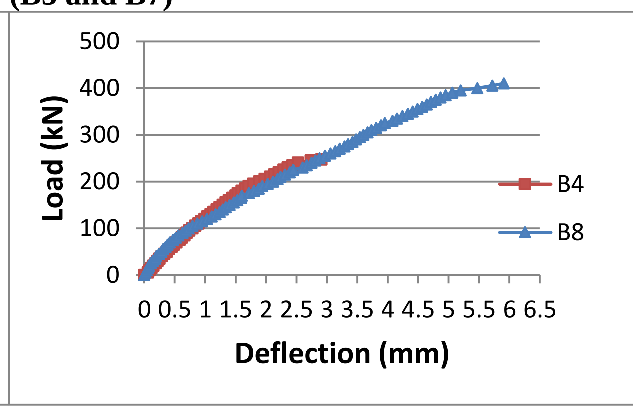

Figure (20) Load-deflection Curve of Beams (B5 and B7)

Conclusions

Based on the results of this study, the following conclusions can be drawn :

1. The load-displacement behavior of the normal beams is similar to that of the reactive powder beams. Failures in both cases are characterized by diagonal cracking in the shear spans.
2. The increase in shear capacity of the repaired beams is relatively higher for reactive powder concrete beams than normal concrete beams.

3. The normal beams show a lower stiffness and greater ductility compared with the reactive powder beams.
4. There is an improvement in shear capacity when using flexural reinforcement.
5. The crack displacement and the ultimate displacement of the RC beam increased with the increasing loading rate.
6. The cracking load and the failure load increased with increasing rate of loading.
7. The ultimate load and the initial stiffness increase with increasing loading rate.
8. The crack width decreased with the increasing loading rates.

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