IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Annales de Chimie - Science des Matériaux
Vol. 49, No. 6, December, 2025, pp. 643-651
Journal homepage: http://iieta.org/journals/acsm

Behavior and Flexural Strength of Composite Steel-Reactive Powder Concrete Decks

Maryam Hameed*, Abdulamir Atalla Almayah, Kadhim Z. Naser

Department of Civil Engineering, College of Engineering, University of Basrah, Basrah 61001, Iraq

Corresponding Author Email: maryam.zaboon@uobasrah.edu.iq

https://doi.org/10.18280/acsm.490606

Received: 19 November 2025
Revised: 20 December 2025
Accepted: 25 December 2025
Available online: 31 December 2025

Keywords:
reactive powder concrete, composite structures, studs, shear connectors, flexural response

ABSTRACT

The performance of composite structures employing reactive powder concrete (RPC) has received limited attention. The special components of RPC may affect interface response, crack distribution, and shear transfer mechanisms. The current study investigates the experimental behavior of simply supported composite decks that consisted of steel sections and RPC under axial loading. The influence of parameters such as the thickness of the concrete deck, the number of studs, and the contribution of thread bolts and angle sections as shear connectors was investigated. It was found that the value of the ultimate load increases as the thickness of the RPC deck increases. On the other hand, a reduction in the relative end slip was noticed with the increase of deck thickness. The contribution of increasing the number of studs in enhancing the behavior of composite structures was clear. Moreover, using an insufficient number of shear connectors caused the development of longitudinal cracks along the top surface of the deck. Results showed that employing transversal channels as shear connectors had a positive impact on reducing end slip and preventing longitudinal cracks. On the other hand, using threaded bolts may cause local slip around the bolts.

1. INTRODUCTION

The need for construction materials with superior chemical, physical, and mechanical properties has led to important developments in the concrete industry. One of the most recent advancements is reactive powder concrete (RPC), which is a special high-strength cementitious material with favorable behaviour for civil engineers.

Ordinary concrete and RPC are considerably different in their composite materials and physical properties. By eliminating coarse aggregate and incorporating materials like steel fiber, silica fume, and very fine sand, mixed with a low W/C ratio, RPC can show ultra-high performance in tension and compression compared to ordinary concrete. Tension resistance is developed as a result of steel fiber, which is also responsible for preventing or reducing cracks [1-3]. Sections made of RPC are nearly impermeable due to the high density achieved by adopting fine materials. Due to its low permeability and resistance to aggressive environmental agents, the corrosion resistance of reinforcement in RPC is better than that in ordinary concrete [4]. The most important feature of the RPC is its remarkably high compressive strength, which can be greatly developed through optimized mix design and suitable curing procedure [5].

However, in some cases, using a single construction material is insufficient to meet structural requirements. Therefore, two or more materials are mixed or combined to take full advantage of their properties. The resulting structural section is known as a composite member.

The application of composite sections covers a range of areas, including buildings with long spans between columns [6], where load-bearing capacity can be increased, and cross-sectional dimensions can be reduced. Moreover, the response of bridge structures, including durability and deflection, can be enhanced by providing composite girders [7]. Also, composite members are a favorable choice in industrial, underground, and seismic-resistance structures [8].

Although composite beams or decks with normal concrete are extensively researched [9-12], the performance of composite structures employing RPC has received relatively limited attention [13, 14]. The special components and the produced microstructure densification of RPC may affect interface response, crack distribution, and shear transfer mechanisms.

One essential aspect in composite action is the behaviour of shear connectors, which are provided to prevent or reduce slip and enable one-unit behavior of the composite structure. Various types of shear connectors can be used in composite structures, such as bolts, studs, and steel sections.

Dakhil and Dawood [15] investigated the response of composite RPC beams, focusing on the effect of the number of studs. It was found that this parameter had a negligible impact on the deflection values. On the other hand, it had a great influence on the ultimate load of the composite beam.

Ali et al. [16] carried out a numerical investigation to study the influence of the number of studs and their distribution on the response of composite beams. The study showed that the asymmetry in the distribution of shear connectors involved in staggered distribution could lead to fluctuations in deflection values from one pattern to another.

The current study addresses the flexural performance of RPC composite decks. Experimental investigations were utilized for this purpose. A total of 7 tests were conducted on simply supported composite decks aimed to study the influence of several parameters, such as the thickness of the RPC deck, the number of studs used, and the type of shear connectors (studs, bolts and angle steel-sections.

2. EXPERIMENTAL PROGRAM

2.1 Material properties

Ordinary Portland cement (Type I) was used in the mix. For fine aggregate, sand with a maximum particle size of 0.6 mm was used in the mix. The sand is locally available. However, it has been washed and dried before being passed through the sieves. The superplasticizer used in the current study is supplied by the Sika company and commercially provided under the name of (NANO MIX 1200). Superplasticizer can be produced from various chemical components. According to the study [5], the most suitable type that can be efficiently used in RPC is the Polycarboxylate-based superplasticizer, which is the one used in the current study. As an additive, a densified gray silica fume, known commercially as MegaAdd MS(D), was used in the RPC mix.

The steel fibers added to the RPC mix have an end hook shape with a length of 35 mm and a diameter of 0.55 mm. In general, RPC with deformed steel fibers may exhibit better behavior when compared to that with straight steel fibers [17, 18].

The steel beams used in the experiments were of I-section hot-rolled steel. All beams have the same dimensions given in Figure 1, and a weight of 13 kg/m length. Mechanical test of the steel beam showed that the values of yield stress and ultimate strength are 370 MPa and 480 MPa, respectively.

All decks were reinforced by using deformed steel bars of 8 mm diameter distributed longitudinally and transversely, as shown in Figure 2.

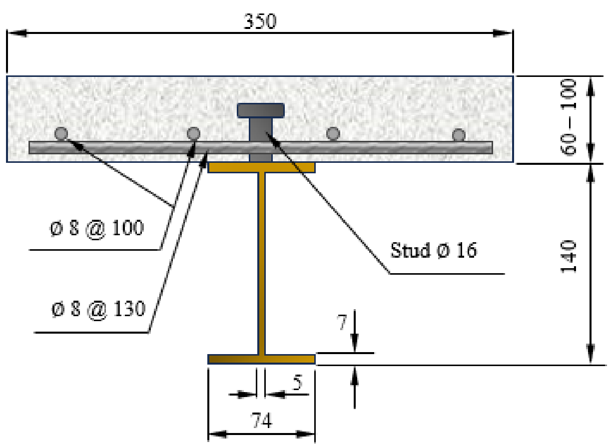

Figure 1. Details of the tested composite decks (all dimensions in mm)

Three types of shear connectors were used in the current study, namely studs, bolts, and steel channels (Figure 3). All shear connectors were welded to the steel I-section in one row at its centre. Studs used in the experiments have a diameter of 16 mm, a head diameter of 23.5 mm, and a head height of 10 mm. The length of studs was varied according to the deck thickness. For decks with 60 mm thickness, studs of 40 mm length were used. On the other hand, 60 mm length studs were used with decks having 80 and 100 mm thickness.

One single test was carried out with headed bolts as shear connectors. The bolts had a total length of 60 mm, divided into 50 mm for the shank and 10 mm for the head, with a diameter of 16 mm for the shank and 23.5 mm for the head.

Another specimen was connected by a mild steel angle (L-section) as shear connectors. Dimensions of the section used are 40 mm in length and width, and 2 mm in thickness.

Figure 2. Steel reinforcement

a. studs

b. bolts

c. angles

Figure 3. Shear connectors used in the study

2.2 RPC mix design

In order to obtain specimens that meet the requirements and specifications of RPC, several trials were conducted. Before considering the compressive strength value, priority was given to the mix workability. Low-speed rotary mixers can not develop the fluidity required to prepare a concrete mix with workability that would allow the concrete to be poured into molds. The mixing of RPC needs a high shear mixer to wet particles. Otherwise, the mix stays dry and clumpy with no workability.

In the current study, small mixers with medium to high speeds were used. Three mixers working at the same time were used to prepare the mix. Several blending trials were conducted by changing the W/C ratio each time. Finally, the mixed proportions shown in Table 1 were chosen for the materials' ingredients.

Table 1. Details of mix proportions

Material	Quantity
W/C ratio	0.24
Cement, kg/m^3	850
Sand, kg/m^3	950
Silica Fume, kg/m^3	200
Super-plasticizer, kg/m^3	40
Steel Fiber, kg/m^3	100

Table 2. Mechanical properties of reactive powder concrete

Compressive Strength, MPa	Splitting Strength, MPa	Modulus of Rupture, MPa
93.5	8.3	8.2

A combination of normal and hot curing procedures was adopted. After 48 hours of casting, the specimens were taken out of their molds and placed in a tank of water having a temperature of 60-80°C for 6 hours a day. For the rest of the day, the temperature of the water tank decreases to 30-40°C. The combined curing lasts for 7 days. After that, the specimens were stored in the water tank at 30-40°C until testing.

The mechanical properties of the hardened RPC is a critical indicator of the validity of material types and ingredients, mixing procedure and curing method. The mechanical performance of RPC was evaluated in terms of compressive strength, splitting tensile strength and modulus of rupture. The results are illustrated in Table 2.

2.3 Details of the specimens

The experimental program includes testing 6 composite beams subjected to axial load for flexure up to failure. For each specimen tested, the following data were recorded: load-deflection response at the beam mid-span, ultimate load, split (the relative displacement between the RPC beam and the steel section) at the end of the specimen, first cracking load, and crack pattern after failure.

The effects of RPC deck thickness, the number of studs, the use of thread bolts, shear connectors, and angle-section shear connectors were studied.

The details of composite decks are listed in Table 3 and shown in Figure 4.

Table 3. Details of the composite decks

No.	Thickness of RPC Deck, mm	Type of Shear Connectors	Number of Shear Connectors
CRB1	60	Studs	10
CRB2	80	Studs	10
CRB3	100	Studs	10
CRB4	80	Bolts	10
CRB5	60	Studs	5
CRB6	60	Angles	5

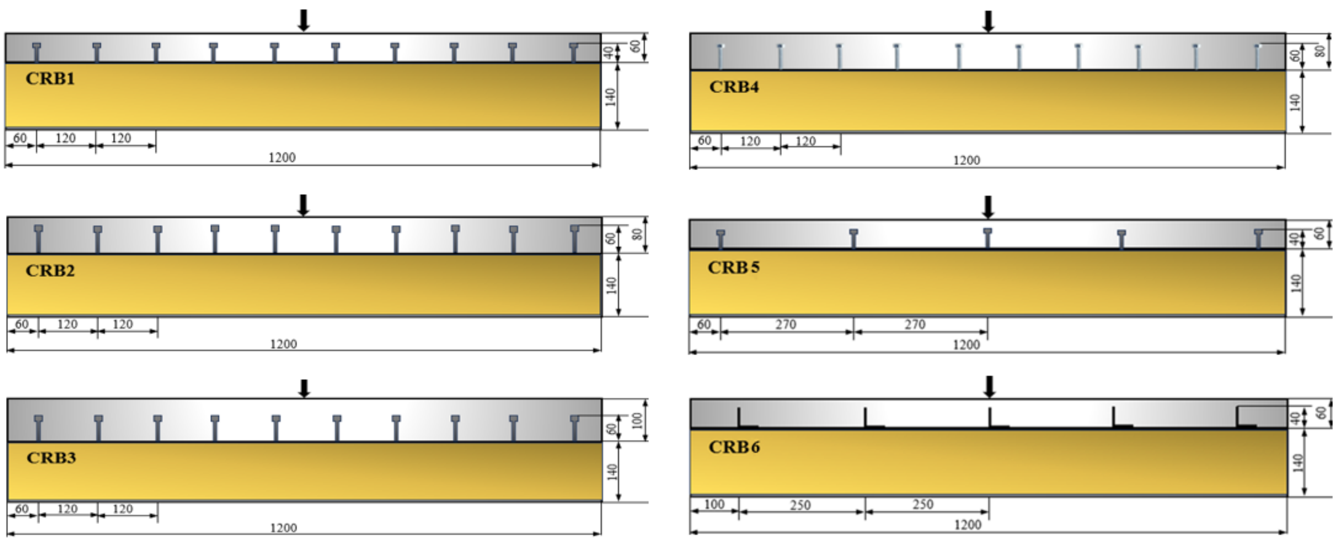

Figure 4. Details of the composite decks for the parameter tested

2.4 Testing procedure

Specimens were placed on roller supports under a 2000 kN capacity testing machine. Dial gauges were attached to the bottom and at the end of the specimen to measure deflection and slip, respectively. Then, the mid-span load was applied with a rate of 1 kN/sec, while dial gauge readings corresponding to each 5 kN were recorded.

3. RESULTS OF THE EXPERIMENTAL TESTS

3.1 Effect of the reactive powder concrete deck thickness

The thickness of RPC in composite structures may have a big impact on the overall response of the structure, including ultimate load, cracking load, maximum deflection, crack pattern, and slip [19]. In order to investigate the influence of RPC deck thickness on the behavior of the composite decks, three specimens (CRB1, CRB2, and CRB3) were considered. The specimens had deck thicknesses of 60, 80, and 100 mm, respectively, with all other parameters kept unchanged.

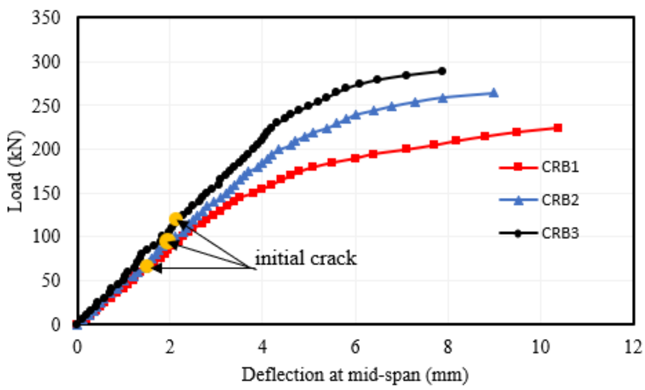

Figure 5. Load-deflection curves for the tested specimens

Figure 5 illustrates the load-deflection plots for the three specimens. Each curve showed a two-stage response starting with linear elastic behavior for both RPC and steel sections, followed by a decrease in the slope of the linear portion up to a nonlinear curve. From the figure, it can be concluded that the ultimate load increases as the deck thickness increases. The thicker specimen (CRB3) recorded an ultimate load of 288 kN, which is higher than the two other specimens by about 9% for CRB2 (264 kN) and 28% for CRB1 (224 kN). This result reflects the well-known engineering concept that a thicker deck or slab can enhance section stiffness (EI), increase the compression zone, and provide a larger moment arm.

The corresponding mid-span deflections of each specimen at the value of ultimate load are listed in Table 4. The table also shows the values of the overall stiffness of the deck (P_u / δ_u) up to the ultimate load. It can be seen that the stiffness values rise as the ultimate load values rise (i.e., thickness increases). This explains the reduction in ultimate deflection values as deck thickness increases, although higher loads are recorded, as a result of the fact that higher stiffness members show less deflection [20].

Table 4. Test results of specimens CRB1, CRB2 and CRB3

Specimen No.	Ultimate Load, P_u (kN)	Deflection, δ_u (mm)	First Crack Load, P_{cr} (kN)	Secant Stiffness, (kN/mm)
CRB1	224	10.4	65	21.54
CRB2	264	9.0	94	29.33
CRB3	288	7.9	129	36.46

To describe the relationship between deck thickness and the recorded ultimate load, two models have been fitted (linear and quadratic), as shown in Figure 6. It can be seen that linear fitting gives a reasonable fit with (R^2 = 0.98) for the range of thicknesses adopted. However, the quadratic fitting (nonlinear) represented by the equation shown in the figure passes exactly through the points, reflecting a strong nonlinear relationship between thickness and ultimate load. The nonlinear relationship was also noticed by Ibrahim and Ahmed [21].

For a rectangular slab (not a composite slab), the cracking load is proportional to t^2 ($P_{cr} \propto t^2$), which is the case in the current study, as can be seen by the quadratic equation of the trend line illustrated in Figure 6.

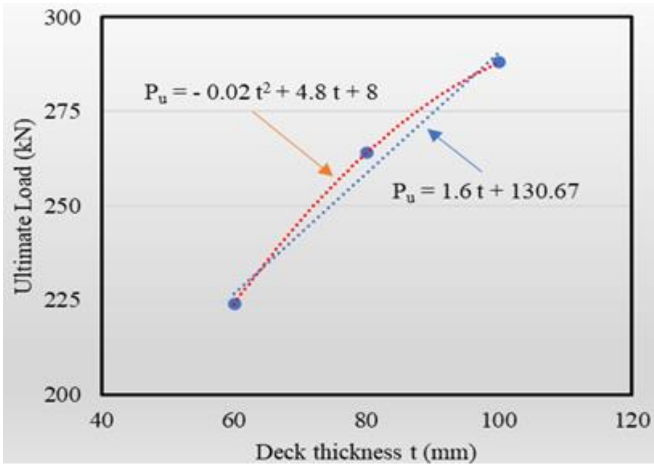

Figure 6. Ultimate load – deck thickness relationship

However, for composite slabs or beams, the steel I-section contributes to a portion of the tensile force, leading to a reduction in the contribution of the RPC deck. This could be the possible reason for the approximated linear or near-linear response, which can be used with reasonable results.

The visual observations of the first crack loads have recorded the same trend of ultimate load, with almost a direct proportionality between deck thickness and initial cracking load P_{cr} (P_{cr} = 65, 94, and 129 kN for CRB1, CRB2, and CRB3, respectively). Figure 7 shows the trend line of the recorded initial cracking load as a function of deck thickness, which can be approximated as a linear line with R^2 = 0.9843. However, this trend is for the small range of thicknesses considered (t = 60 to 100 mm).

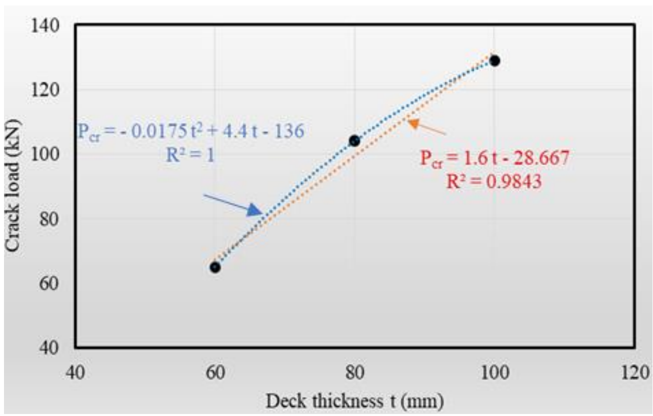

Figure 7. Cracking load – deck thickness relationship

Figure 8 shows the crack pattern of the specimens at the ultimate load. The crack was first observed at the bottom of the deck, then developed up to the upper boundary of the deck thickness. It can be seen that the cracks were concentrated in the mid-point of the slab, where the load was applied.

Crack patterns showed that only a few cracks with a limited network were developed in the RPC decks. This can be attributed to the nature of RPC materials, where its high density is achieved by fine contents and the presence of steel fibers enhances its tensile strength even at ultimate load. Furthermore, the big contribution of the steel section in carrying the tension is also an important factor in limiting the number and distribution of cracks. The limited or no crack appears in RPC structures was also noted by Zhong et al. [22] and Cao et al. [23].

Figure 8. Crack pattern of the specimens

Figure 9 shows the relative end slip at the ultimate load for the three specimens as recorded by the dial gauges attached to the deck and steel section, as an indicator of the composite action provided by the studs. Although all specimens had the same number of studs (10), they showed varying relative slip. The comparison reveals that the thicker deck experienced relatively less value of end slip. The reduction of end slip with increasing deck thickness may be a result of increasing overall stiffness of the RPC deck, as the concrete effective zone surrounding each stud increases, causing better restraint to the slip deformation.

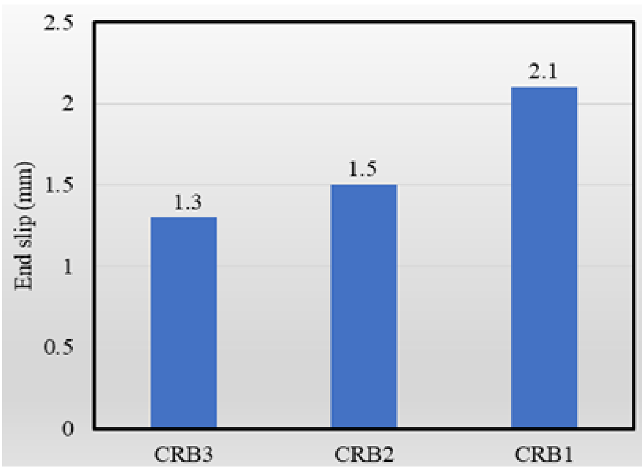

Figure 9. End slip at ultimate load

3.2 Effect of the number of studs

Two specimens named CRB1 and CRB5 with 10 and 5 studs, respectively, were tested and compared, with all other properties kept the same. Figure 10 illustrates the comparison of the load-deflection curve up to ultimate load for both specimens. Table 5 lists a summary of the test results.

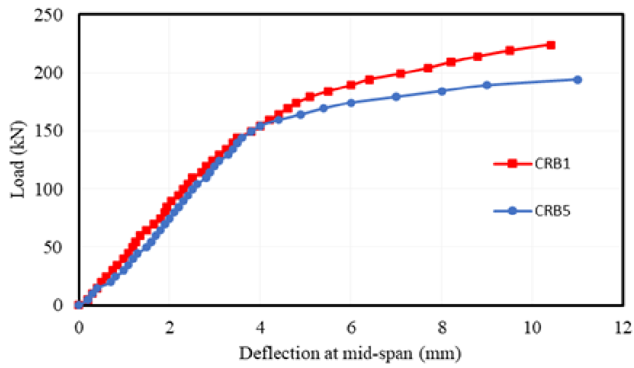

Figure 10. Load-deflection relationship of CRB1 and CRB5

Table 5. Test results of specimens CRB1 and CRB5

Specimen No.	Ultimate Load, P_u (kN)	Deflection, δ_u (mm)	First Crack Load, P_{cr} (kN)
CRB1	224	10.4	65
CRB5	194	11.0	50

It is obvious from the figure. that the ultimate load of specimen CRB1 is greater than that of specimen CRB5. The ultimate load recorded for CRB1 was 224 kN, which is about 15% greater than that recorded for CRB5 (194 kN). This reflects the contribution of increasing the number of studs in enhancing the behavior of composite structures. This response can be attributed to the fact that more shear connectors lead to an increase in the composite action between concrete and steel, in which the composite structure behaves as one unit. However, both specimens experienced the same performance with an initial linear followed by a nonlinear response.

The deflection at the ultimate load recorded by the mid-span dial gauge was 10.4 mm for CRB1 and 11 mm for CRB5.

The crack pattern of specimen CRB5 (Figure 11) was slightly different from that observed in CRB1. The top surface of the deck showed longitudinal cracks along its length, i.e., along the axis along which the studs were distributed. These cracks have appeared before reaching the ultimate load (at load 130 kN). The possible reason for such a type of shear crack is the insufficient number of shear connectors used (5 studs), which may cause a reduction in bond along the axis of studs. This phenomenon was also observed by Dakhil and Dawood [15]. It is important to mention that the first crack, in CRB5, was appeared at a load of 50 kN, which is less than that of CRB1 (65 kN).

The relative slip between the RPC deck and the steel section at the end of specimen CRB6 was 2.4 mm. This value is only a little bit greater than that observed in specimen CRB1 with 10 studs (2.1 mm). Although the longitudinal crack that appeared in CRB5 may indicate a slip problem and a reduction in composition, this slip may occur locally and does not propagate towards the ends of the deck.

As for specimen CRB1, the transverse cracks that appeared in specimen CRB5 were few in number and narrow in distribution. This indicates that the reduction in the number of studs does not negatively affect the transverse cracks. This result can be argued by (1) with all other material and section properties are the same, changing the number of studs will not chang the tensile strain caused by bending stress at the concrete mid-span, and (2) it appears that the composite action is reduced but not completely lost by using 5 studs, especially at early stage of loading when first and few other cracks were appeared. In this stage, both specimens behave the same way, as the induced shear stress can be carried effectively by 10 or 5 studs. After that, the shear stress applied to the 5 studs exceeds their shear capacity, causing local slip and longitudinal cracks, with no big effects on the transverse cracks.

Figure 11. Crack pattern of specimen CRB5

3.3 The response when thread bolts are used as shear connectors

Welded bolts are not commonly used in real structures, although some researchers, e.g., researcher [11], have used this type of connection in their tests. However, this approach was adopted to ensure full connection in a way that eliminates any possible slip or looseness that may happen during loading at the bolt-steel section interface.

In order to study the influence of using bolts as shear connectors, a composite specimen (CRB4) with 10 bolts welded to the top flange of steel was tested and compared to another specimen of 10 studs (CRB2), with all other parameters kept unchanged.

Figure 12 portrays the load-deflection response for both specimens. It can be noticed that both specimens had almost the same behavior in the early stages of the linear part. However, the difference in load-deflection response gradually increased up to the value of the ultimate load. At this point, the values of ultimate load recorded were 264 kN and 249 kN for CRB2 and CRB4, respectively. Also, the final deflection for CRB2 was 9.0 mm, while that for specimen CRB4 was 9.5 mm.

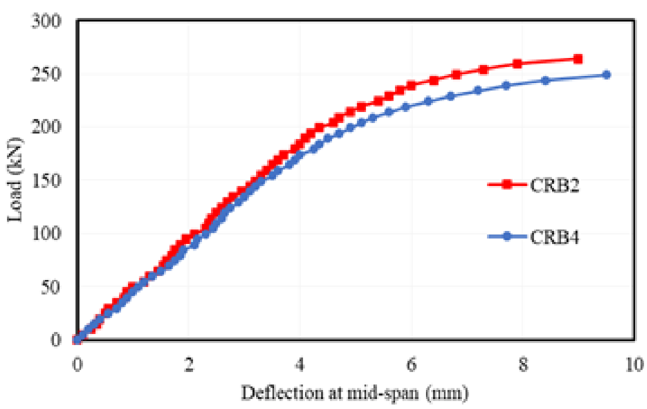

Figure 12. Load-deflection relationship of CRB2 and CRB4

In spite of the similarity in load-deflection curves, specimen CRB4 showed additional longitudinal cracks that were not visible in specimen CRB2, as can be seen in Figure 13. The possible reason for this behaviour can be attributed to the shape of the bolts. Although the threaded shanks of the bolts can provide high bond and interaction with the RPC compared to the smooth stud, they may have a negative influence. In addition to the slight reduction in the bolt diameter at its roots (Figure 14), the thread crest can show high stress concentration, which may cause damage to the concrete surrounding, leading to cracks along the longitudinal axis of bolts to appear.

Figure 13. Longitudinal cracks of specimen CRB4

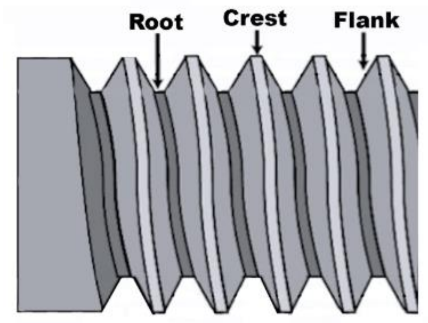

Figure 14. Details of the threaded bolt

The internal cracks that may develop in the RPC around the bolt thread can lead to loss of interaction and, then, to slip. This may explain why the magnitude of relative slip in CRB4 was 5.7 mm, which is higher than that noted in CRB2 (1.5 mm).

It is important to mention that the first crack appeared at the top surface of the deck and not at the tension zone, as it was expected. The local stresses generated around the bolts may be developed to longitudinal shear along the bolt's axis, causing cracks to the upper compression surface before flexural cracks appear in the tension zone.

3.4 The response when angles are used as shear connectors

In order to investigate the efficiency of steel sections as shear connectors, a test with angle steel sections welded transversely to the top flange of the steel beam was carried out (specimen CRB6). Different shapes and orientations of steel sections can be used to transfer shear between the RPC deck and the steel I-section [24]. In the current study, 5 angle steel sections distributed equally over the entire 1000 mm of the beam length were used.

The load-deflection curve for specimen CRB6 is illustrated in Figure 15. For the purpose of comparison, the figure also portrays the response of specimen CRB5, which had 5 studs and a 60 mm deck thickness. It can be seen that there was no significant difference between the responses of the two specimens, especially at early stages (linear portion). The ultimate load of specimen CRB6 (204 kN) was slightly greater than that for the specimen with 5 studs (194 kN).

In spite of the similarity in load-deflection curve, a significant benefit of using angle shear connectors can be identified in preventing the longitudinal cracks that were propagated on the top surface of specimen CRB5, as can be seen in Figure 16. This can be attributed to the geometry of the angle shear connectors, which can distribute the shear over a greater contact area compared to the contact area provided by studs, making the shear stress less concentrated around the shear connectors. On the other hand, tension cracks were, as in specimen CRB5, few in number, narrow in distribution, and concentrated at the mid-span.

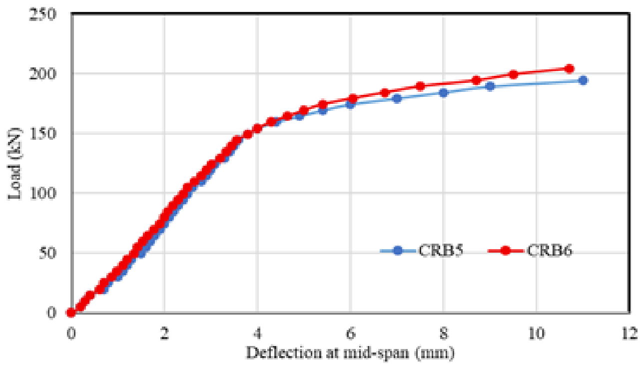

Figure 15. Load-deflection relationship of CRB5 and CRB6

Figure 16. Crack pattern of specimen CRB6

For the first crack records, the specimen CRB6 showed the first crack at 80 kN, which is greater than that observed in CRB5 (50 kN). The likely reason for this specimen to show the first crack at a higher load is the large contact area that the steel angles are acting on. This may lead to spreading the shear over a larger area, making the local tensile stresses decrease in the RPC deck.

Concerning the slip, specimen CRB6 recorded only 1.0 mm for the value of relative slip, which is the least value among all other specimens. This result suggests that the force causing slip can be resisted effectively by employing transversal channels as shear connectors.

3.5 Modes of failure

There are several scenarios in which a composite RPC deck can fail, depending on factors such as shear connection, material characteristics, and applied loads. Failure may be related to the RPC deck (concrete) when crushing or excessive flexural/longitudinal/shear cracking appears. On the other hand, studs may fail as a result of exceeding their shear capacity, pulling out the studs, or slip failure. Another way of failure is related to the steel I-section, which can be due to buckling of the steel section or yielding, which may happen in the flange or web. It is important to mention that experimental tests [25], for example, showed a combination of the above failure modes with varying sequence.

In the current study, no visible separation or slip was noticed between the RPC deck and the steel section at the ends of the specimen. This means that the studs used have provided an adequate interaction and composition between the steel and concrete, with only limited relative slip recorded. Moreover, no crushing was observed at the top compression surface of the RPC deck.

In general, all specimens tested with a central load applied on the RPC deck experienced a flexural mode of failure. This type of failure was characterized by an initial linear elastic response for both concrete and steel sections. This stage includes the appearance of the first crack at a certain point of loading. Then the composite deck behaves nonlinearly. The ultimate load was reached prior to the crushing of concrete, slipping of studs, and buckling of the steel section.

3.6 Sources of experimental limitations

Before conducting the tests, it was decided not to strengthen the steel sections for all specimens. However, while carrying out the first trial test, an unexpected scenario occurred. After completing the elastic stage, the steel section showed a gradual buckling at one end. The test has been stopped when buckling is rapidly increased (Figure 17). This case of failure was also noticed by Dakhil and Dawood [15].

Figure 17. Crack pattern of specimen CRB6

In order to prevent this defect from recurring, a decision was made to strengthen the ends of the steel sections at the supports by placing two steel angles back-to-back on both sides of the steel section, as can be seen in Figure 16.

Moreover, it is known that the mixing of RPC needs a high shear mixer to wet particles. Otherwise, the mix stays dry and clumpy with no workability. However, the rotating mixers available in the laboratory were of low speed and, thus, can not develop the fluidity required to prepare a concrete mix with workability that would allow the concrete to be poured into molds. To overcome this issue, small mixers with medium to high speeds were used as alternatives. Three mixers working at the same time were used to prepare the mix.

4. CONCLUSIONS

The responses of composite decks were presented in terms of ultimate load, mid-span deflection, first-cracking load, crack pattern, relative slip, and mode of failure. Based on the experimental results, the following conclusions can be drawn:

(1) Tests on composite decks showed that the value of the ultimate load increases as the thickness of the RPC deck increases. The additional enhancement that thicker slabs provide to the overall response of the composite deck was found to include the initial crack load. The relationship between cracking load and deck thickness can be approximated as linear, with almost a direct proportionality between them.

(2) The contribution of increasing the number of studs in enhancing the behavior of composite structures was clear, as the ultimate load recorded for the specimen with 10 studs was 15% greater than that recorded for the specimen with 5 studs. Moreover, the insufficient number of shear connectors caused a reduction in bond along the axis of the studs, which resulted in the appearance of longitudinal cracks along the top surface of the deck.

(3) Test results revealed that the slip in RPC composite decks may occur locally and does not propagate towards the ends of the specimen.

(4) Testing the applicability of threaded bolts as shear connectors in RPC composite decks showed good results regarding the ultimate load. However, a high value of relative slip was recorded compared to the specimen with stud shear connectors.

(5) Employing transversal channels as shear connectors had a positive impact on the response of composite decks, namely reducing end slip and preventing longitudinal cracks.

(6) Despite the longitudinal cracks that some specimens with an insufficient number or type of shear connectors have shown, the dominant features of the tension crack are that the cracks were few in number, narrow in distribution, and concentrated at the mid-span.

Although the results of the present investigation provide additional knowledge to better understand the response of composite RPC decks under the tested conditions, future research is recommended to take into account the incorporation of additional influencing factors, such as the RPC ingredients and other loading conditions.

REFERENCES

[1] Abbass, W., Khan, M.I., Mourad, S. (2018). Evaluation of mechanical properties of steel fiber reinforced concrete with different strengths of concrete. Construction and Building Materials, 168: 556-569. https://doi.org/10.1016/j.conbuildmat.2018.02.164

[2] Abtan, Y.G., Hassan, H.F. (2019). Flexural strength of modified reactive powder concrete one-way slabs. The Open Civil Engineering Journal, 13(1): 260-270. https://doi.org/10.2174/1874149501913010260

[3] Khamees, A.A., Jawad, R.R., Al-Rammahi, A.A. (2024). Performance evaluation of reactive powder concrete structural members based on experimental and numerical analysis: A review. Revue des Composites et des Matériaux Avancés -Journal of Composite and Advanced Materials, 34(6): 807-814. https://doi.org/10.18280/rcma.340615

[4] Jiang, H., Wang, K., Wang, H. (2023). The corrosion resistance of reinforced reactive powder concrete with secondary aluminum ash exposed to NaCl action. Materials, 16(16): 5615. https://doi.org/10.3390/ma16165615

[5] Richard, P., Cheyrezy, M. (1995). Composition of reactive powder concretes. Cement and Concrete Research, 25(7): 1501-1511. https://doi.org/10.1016/0008-8846(95)00144-2

[6] Wang, A.J. (2016). Studies on structural behaviour of long-span continuous composite beams with flexible shear studs of limited ductility. Australian Journal of Structural Engineering, 17(2): 109-135. https://doi.org/10.1080/13287982.2016.1196572

[7] Blais, P.Y., Couture, M. (1999). Precast, prestressed pedestrian bridge: World's first reactive powder concrete structure. PCI Journal, 44(5): 60-71. https://doi.org/10.15554/PCIJ.09011999.60.71

[8] Hajjar, J.F. (2002). Composite steel and concrete structural systems for seismic engineering. Journal of Constructional Steel Research, 58(5-8): 703-723. https://doi.org/10.1016/S0143-974X(01)00093-1

[9] Tran, M.T., Van Do, V.N., Nguyen, T.A. (2018). Behaviour of steel-concrete composite beams using bolts as shear connectors. IOP Conference Series: Earth and Environmental Science, 143: 012027. https://doi.org/10.1088/1755-1315/143/1/012027

[10] Sangeetha, P., Ramana Gopal, S., Jai Vigneshwar, A., Vaishnavi, K., Srinidhi, A. (2020). Flexural strength of steel–concrete composite beams under two-point loading. Civil and Environmental Engineering Reports, 30(4): 21-32. https://doi.org/10.2478/ceer-2020-0047

[11] Alharthi, Y.M., Sharaky, I.A., Elamary, A.S., Al-Sharef, A., Al-Salmi, A., Al-Sufyani, A., Al-Osaimi, O., Al-Mufti, A. (2023). Flexural behavior and capacity of composite concrete-steel beams using various shear connectors. Arabian Journal for Science and Engineering, 48(4): 5587-5601. https://doi.org/10.1007/s13369-022-07485-y

[12] Victoire, A.B., Mwero, J.N., Gathimba, N. (2024). Experimental study on the effect of partial shear studs layout on flexural behavior of steel-concrete composite beams. Results in Engineering, 21: 101959. https://doi.org/10.1016/j.rineng.2024.101959

[13] Bujnak, J., Michalek, P., Bahleda, F., Grzeszczyk, S., Matuszek-Chmurowska, A., Mordak, A. (2020). Mechanical testing of composite steel and reactive powder concrete structural element. Materials, 13(18): 3954. https://doi.org/10.3390/ma13183954

[14] Zhu, Z., Zhu, R., Xiang, Z. (2023). A review on behavior and fatigue performance of orthotropic steel–UHPC composite deck. Buildings, 13(8): 1906. https://doi.org/10.3390/buildings13081906

[15] Dakhil, R.Y., Dawood, M.B. (2019). Structural behavior of continuous steel–reactive powder concrete composite member under repeated loads. Journal of University of Babylon for Engineering Sciences, 27(4): 303-316. https://doi.org/10.14419/ijet.v7i4.19.28007

[16] Ali, Y.A., Falah, M.W., Ali, A.H., Al-Mulali, M.Z., Al-Khafaji, Z.S., Hashim, T.M., Al Sa'adi, A.H.M., Al-Hashimi, O. (2022). Studying the effect of shear stud distribution on the behavior of steel–reactive powder concrete composite beams using ABAQUS software. Journal of the Mechanical Behavior of Materials, 31(1): 416-425. https://doi.org/10.1515/jmbm-2022-0046

[17] Yoo, D.Y., Sohn, H.K., Borges, P.H., Fediuk, R., Kim, S. (2020). Enhancing the tensile performance of ultra-high-

performance concrete through strategic use of novel half-hooked steel fibers. Journal of Materials Research and Technology, 9(3): 2914-2925. https://doi.org/10.1016/j.jmrt.2020.01.042

[18] Naser, K.Z., Lafta, Y.J., Alhussein, T.H. (2024). Effect of steel fiber type and curing regimen on the mechanical properties of reactive powder concrete. Advances in Civil Engineering, 2024(1): 6616375. https://doi.org/10.1155/2024/6616375

[19] Nie, J., Cai, C.S. (2003). Steel–concrete composite beams considering shear slip effects. Journal of Structural Engineering, 129(4): 495-506. https://doi.org/10.1061/(ASCE)0733-9445(2003)129:4(495)

[20] Tao, M.X., Li, Z.A., Zhou, Q.L., Xu, L.Y. (2021). Analysis of equivalent flexural stiffness of steel–concrete composite beams in frame structures. Applied Sciences, 11(21): 10305. https://doi.org/10.3390/app112110305

[21] Ibrahim, A.M., Ahmed, Q.W. (2013). Nonlinear analysis of simply supported composite steel–concrete beam. Diyala Journal of Engineering Sciences, 6(3): 107-126. https://doi.org/10.24237/djes.2013.06308

[22] Zhong, X.Y., Zhuang, L.D., Ding, R., Tao, M.X. (2024). Experimental and numerical study on the performance of steel–coarse aggregate reactive powder concrete composite beams with uplift-restricted and slip-permitted connectors under negative bending moment. Buildings, 14(9): 2913. https://doi.org/10.3390/buildings14092913

[23] Cao, J., Shao, X., Zhang, Z., Chen, B., Huang, Z. (2012). Research on stress state in composite bridge deck system with orthotropic steel deck and thin reactive powder concrete layer. IABSE Congress Report, 18(2): 1980-1987. https://doi.org/10.2749/222137912805112671

[24] Arevalo, D., Hernández, L., Gómez, C., Velastegui, G., Guaminga, E., Baquero, R., Dibujés, R. (2021). Structural performance of steel angle shear connectors with different orientation. Case Studies in Construction Materials, 14: e00523. https://doi.org/10.1016/j.cscm.2021.e00523

[25] Abbas, N.Y., Alshimmeri, A.J.H. (2024). Flexural behavior of a composite concrete castellated double channel steel beams strengthening with reactive powder concrete. Tikrit Journal of Engineering Sciences, 31(2): 28-42. https://doi.org/10.25130/tjes.31.2.4