Construction and Building Materials 170 (2018) 272–278

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Punching behavior of strengthened and repaired RC slabs with CFRP

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HIGHLIGHTS

- We test rectangular RC slabs unreinforced or reinforced by carbon fiber reinforced polymer (CFRP).
- We test rectangular RC slabs with pre loading (60 and 80)% ultimate load.
- Compare reinforced slab repairing slabs with control slab and the role of CFRP.
- Compare reinforced slab with different orientation of CFRP.

ARTICLE INFO

Article history:
Received 5 February 2018
Received in revised form 9 March 2018
Accepted 12 March 2018

Keywords:
Repair
Reinforcement
CFRP
RC slabs
Punching

ABSTRACT

This study investigated the punching behavior of reinforced concrete slabs strength with carbon-fiber-reinforced polymer (CFRP). We tested a total of thirteen RC slabs, each having 965 mm length, 680 mm width, and 60 mm thickness, each slab was reinforced with two layers of CFRP of area (40×40 cm^2). The variables in the experimental program were: pre loading (60% and 80%) of ultimate load (load of control slab) and orientation of the fiber of CFRP (0°, 45°, (0°/90°) and (45°/135°)). Test results showed that the capacity of ultimate load of strength of the slabs is increase (23%–65%) compared with slab unreinforced. The results illustrate that carbon-fiber-reinforced polymer (CFRP) reinforcement is perfect in reducing the deflection (3%–48%). The CFRP strengthening is perfect in reducing the strain.
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1. Introduction

The civil engineering field is in a constant evolution, despite this, we find a large number of civil engineering structures or buildings are found degraded for different reasons, such as damaged due to accidents, building redevelopment. More, there are also a large number of pathologies in civil engineering structures whose origins can be design errors, mechanical, physicochemical, accidental. To solve these problems, two main solutions available: demolition or repair, the latter solution is the perfect solution.

One of the applications that can successfully repair and reinforce structural elements made of reinforced concrete (such as columns) is the use of composite materials, such as external reinforcement (casing) [1] to plead to extreme mechanical actions (earthquake) where environmental (corrosion) [2]. This field of application is expanding more and more to other types of structures working mainly in flexion, such as slabs and beams [3,4]. With regard to this last type, more lines of research are expanding [5,6]. The slabs are generally reinforced on an important part of their surface) [7,8] by a reinforcement in the form of bands [9–12]. Composites are glued to their tension surfaces with the aim of repairing and improving their bearing capacity. This experimental work was carried out in the laboratory of Civil Engineering and Hydraulics (LGCH) and Architectural laboratory of the University of Guelma 8 May 1945(Algeria). In this paper, Its main purpose is to study the behavior under punching of reinforced concrete slabs, the work has been carried an experimental investigation on reinforced concrete slabs strengthened and repaired with Carbon fiber reinforced polymer. The slabs strengthen by surface of CFRP of 24% of the surface of the slab, with different orientations of composite layer (0°–45°–0°/90°–45°/135°). The second series, we repaired the RC slab after preload (60–80%) of ultimate load of control slab.

2. Experimental program

2.1. Material properties

The cement used is a Portland cement composed, CPJ-CEMII/A42.5, produced by Algerian company. Its mineralogical

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https://doi.org/10.1016/j.conbuildmat.2018.03.093
0950-0618/© 2018 Published by Elsevier Ltd.

Table 1
Physical characteristics of aggregate.

Characteristics	Absolute density (g/cm^3)	Apparent density (g/cm^3)	Sand equivalent (visual) (%)	Fineness modulus
Gravel	2.47	1.41	–	–
Sand	2.56	1.53	82	2.28

Table 2
Characteristics of CFRP and the adhesive.

	Modulus of elasticity (MPa)		Tensile strength (Mpa)	Fracture elongation (%)	Thickness (mm)	Density (kg/l)
	Bending	Tension				
CFRP	–	>230000	>4000	1.7	0.129	–
Adhesive	3800	4500	30	0.9	–	1.30 ± 0.1

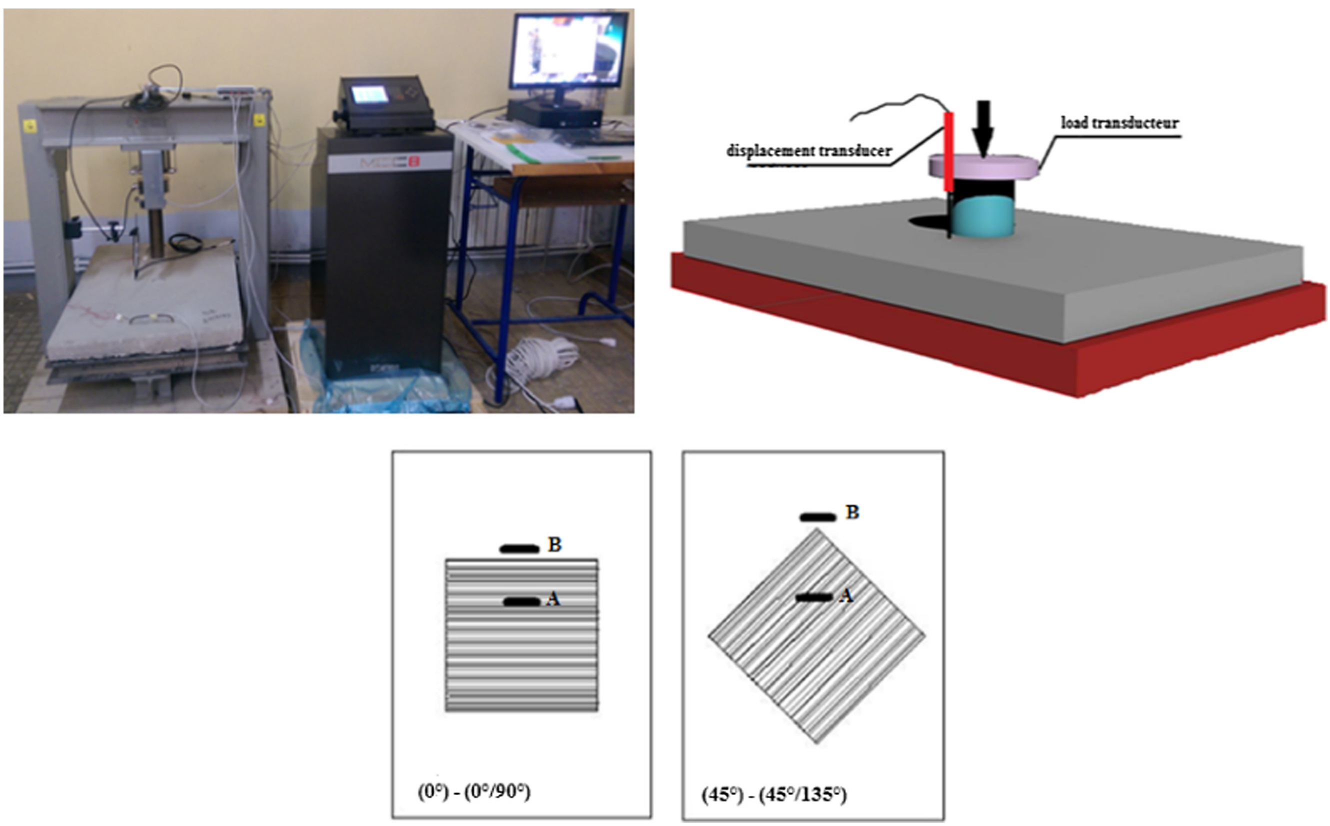

Fig. 1. Testing machine and positioning of the strain gages.

Table 3
Slab test descriptions.

Slab	Preload	Orientation of CFRP	
		1st layer	2nd layer
D1	–	–	
D2	–	0°	0°
D3	–	45°	45°
D4	–	0°	90°
D5	–	45°	135°
D6	60%	0°	0°
D7		45°	45°
D8		0°	90°
D9		45°	135°
D10	80%	0°	0°
D11		45°	45°
D12		0°	90°
D13		45°	135°

composition is $CaO = 55–65\%$, $SiO_2 = 22–28\%$, $Al_2O_3 = 5–6\%$ and Fe_2O_3.

The gravel used is a 5/15 gravel from the Bouslba-El-Fedjoudj quarry (Department of Guelma, northern Algeria). The sand used is a rolled sand (0/5) from Oum-Ali Department of Tebessa, northern Algeria) Table 1.

The composite material used in our experimental work is a unidirectionally woven CFRP produced by the Algerian company. Its mechanical characteristics are presented in Table 2.

The adhesive adapted to CFRP, according to the local society, is an epoxy resin with two components (A and B) according to its manufacturer. This glue complies with the requirements of the EN 1504-4 standard as a product for bonding reinforcement fabrics Table 2.

We used the Dreux-Gorisse formulation method for the composition of our concrete. The average compression strength of concrete is obtained from the compressive tests on cylindrical

Table 4
Load-Deflection for test slabs.

Slab	Cracking load (KN)	Cracking deflection (mm)	Ultimate load (KN)	Ultimate deflection (mm)	Ultimate load gain (%)
D1	15.2	1.3	33.81	7.63	–
D2	22	0.99	44.38	7.45	31.27%
D3	21.5	1.44	46.9	7.89	38.70%
D4	26	1.8	53.51	5.97	58.27%
D5	22	1.5	45.21	4.02	33.72%

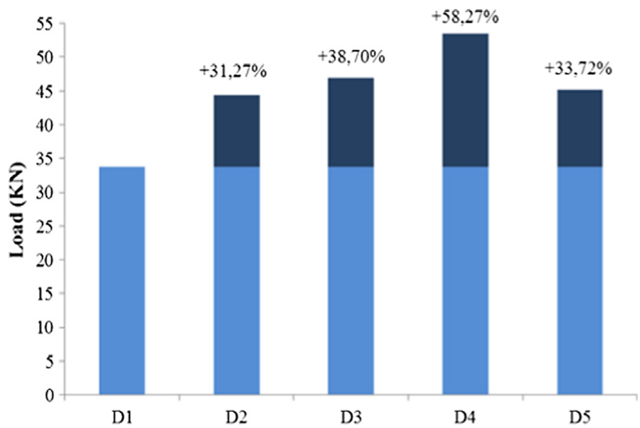

Fig. 2. Ultimate load of reinforced slabs.

specimens (16×32 cm^2) performed by a 3000 KN compression machine (Press Controls Model 50-00802 \ B) at 25.5 MPa.

2.2. Design of test slabs

Thirteen slabs in three groups were tested. All had the same sectional dimensions: 680 mm in width, 60 mm in depth and 965 mm in length. The slabs were reinforced with steel bars having a diameter of 6 mm spaced at 8.12 cm in x direction and 13.35 cm in y direction. When tested; the slab is supported in four sides and placed at a spacing of 915×630 mm^2. The load was applied centrally on the slab over 60 mm diameter area. For measured the strain we used the extensometry bridge and gages, strain gages were fixed at lower slab (point A for FRP strain, and point B for concrete strain) the characteristics of the strain gages used are: gauge resistance $120 \pm 0.3\ \Omega$, gauge length 60 mm, gauge factor 2.13 ± 1 %. To obtain the deflection, a linear variable displacement transducer was attached at the slab center Fig. 1.

Except for the reference slab D1, all other slabs were strengthened by two layer of CFRP, the area of CFRP is nearly 24% (40×40 cm^2) of the slab surface. The layer of CFRP was applied with deferent orientation (0°–45°–0°/90°–45°/135°), and other slabs (D6-D13) are first loaded with 60%, 80% (on average) of the ultimate load of control slab, after this slabs are unloaded for repaired with CFRP Table 3.

3. Experimental results

3.1. Cracking and ultimate loads

Table 4 shows the cracking load of control slab and reinforced slabs. The cracking load for control slab is average 15.2 KN, the cracking load of the rest RC slabs reinforced by CFRP is increase compared to the control slab. We observed the cracking load of slabs D1, D2 and D5 increase by (41%–45%) than cracking load of unreinforced slab. Also, the slab D4 is increase by 70.9% than control slab D1. according to the experimental results we finds, with the increase of cracking load also the stiffness is increase, this result is in the first step. These results is the same in the work of M. Laurent [13], he fined the cracking load of RC slab is increased by (40%–48%) for slab strength than control slab.

The ultimate load for control slab is average 33 KN. Table 3 summarized the results ultimate loads for RC slab reinforced with CFRP (control slab with CFRP). The ultimate load of all slab reinforced is increase than ultimate load of control slab Fig. 2. The ultimate capacity of slabs D2, D3 and D5 between (44 and 47) KN is increase than control slab by 31.2%, 38.7% and 33.72% respectively. Also, the slab D4 reinforced by CFRP with orientation (0°/90°) the failure ultimate load is increase by 58.27%. This result is confirmed by Rochdi [14], he tested the slabs were strengthened with externally bonded CFRP. He fined the increase of punching load ranged from 67% to 177% over the control slab Rochdi [14], and in experimental work of Laurent [13], the failure load increases by about (15%–30%) after addition of composite he experimental results for the rest slabs repaired by CFRP shows, for slab preload by 60% of load of control slab, we find the ultimate load of slabs

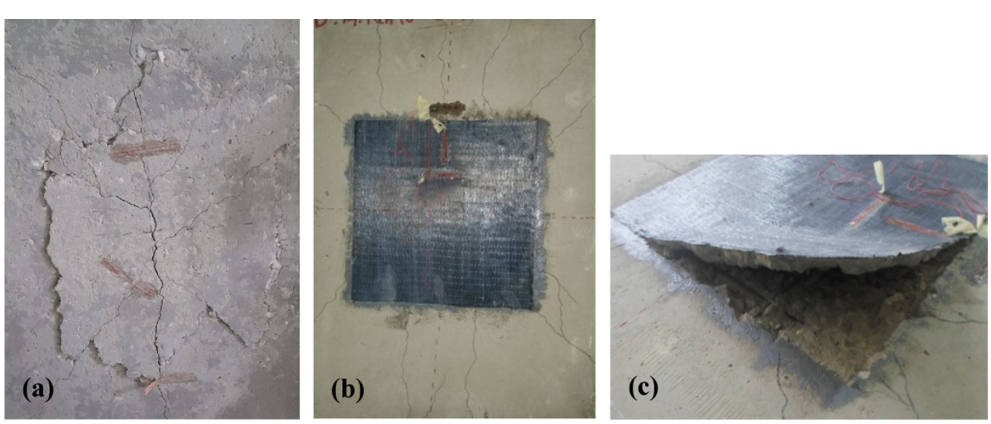

Fig. 3. (a) Failure of control slabs (b) failure of reinforced slab (c) debonding of CFRP.

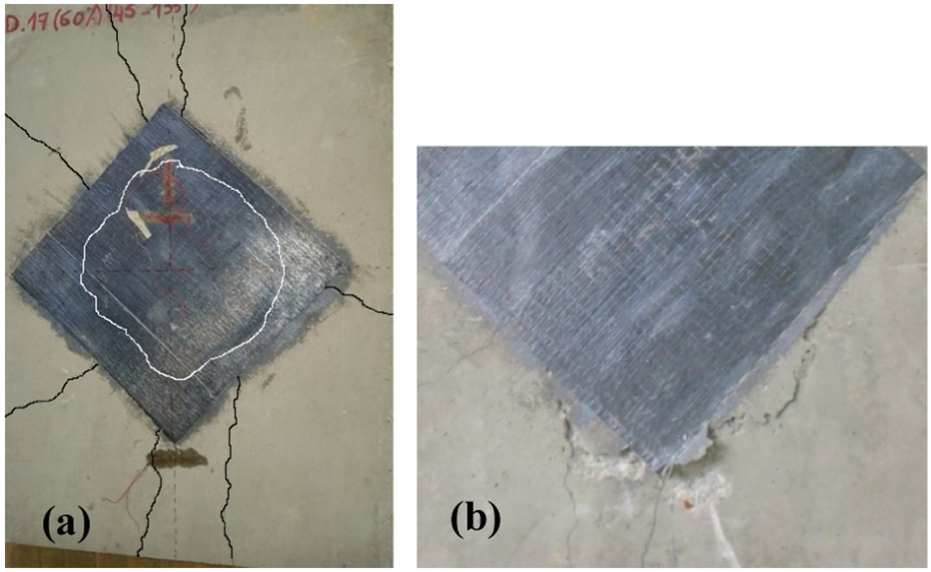

Fig. 4. (a) Failure of repaired slab (b) debonding of CFRP with concrete.

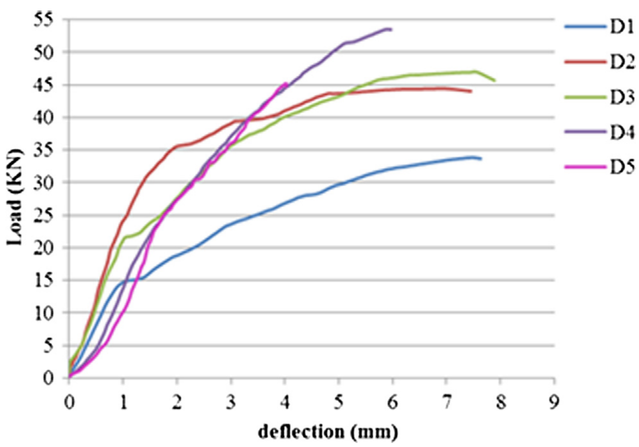

Fig. 5. Load–deflection curves for control and reinforced slabs.

reinforced by CFRP with orientation (0°/90°) and (45°/135°) is increase by 46.74% and 44.53% respectively, while the load of slabs D6 and D7 (slab strength by FRP with orientation 0° and 45°) is increase by (36%–38%) than control slab. The same result for slab preload by 80% of load of control slab, the slab strength by two layers of CFRP with orientation (0°/90°) and (45°/135°) is increase by (62%–65%) than control slab, and increase nearly by 30% and 40% than D10 and D11 respectively. The stiffness of all slabs repairs after preload is increase than slab unreinforced. The materials composite reinforcement gives an important increase of slab stiffness, cracking load and ultimate failure load [13,14,15]. With increasing of load, the CFRP reinforcement is cracked under load and started to delaminate, and finally, the failure occur by punching failure of the slab [14,15] Fig. 3. The load gain of slabs D4, D8 and D12 (orientation of fibers of composite 0°/90°) is important compare to other slabs tested can be explained by the effect of the orientation of the composite fibers compared with cracks (TFC layers are perpendicular and inclined from the direction of cracks) [16].

The cracks are concentrated under the loading area; these cracks are created the critical area of punching Fig. 3. Crack propagation and crack size continued to increase with the increase of loading, like slabs reinforced the cracks of slabs repaired after preload are increase in accordance with the load increase. We observed a diagonal cracks in all slabs and the cracks are narrower and more widely spread than to the cracks control slab. The mode of failure and cracks are shown in Fig. 4.

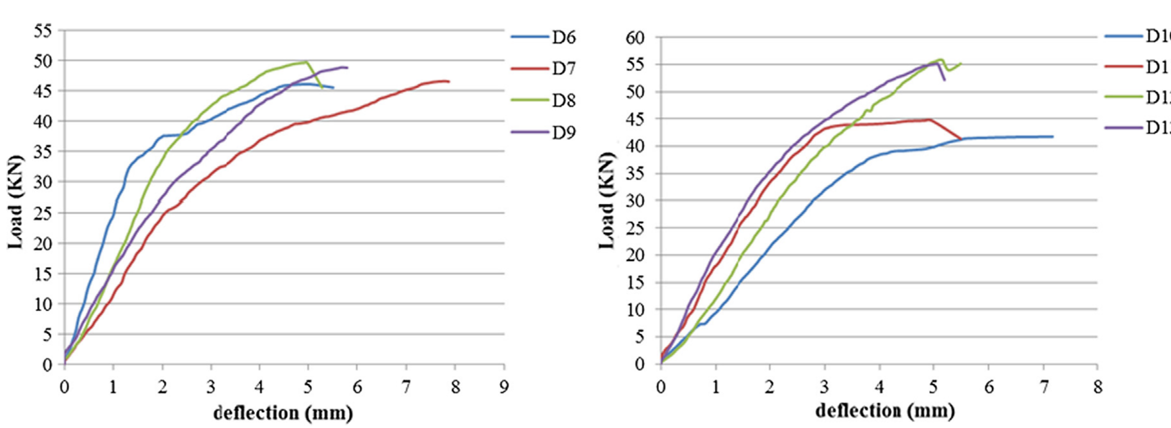

Fig. 6. Load–deflection curves for repaired slabs.

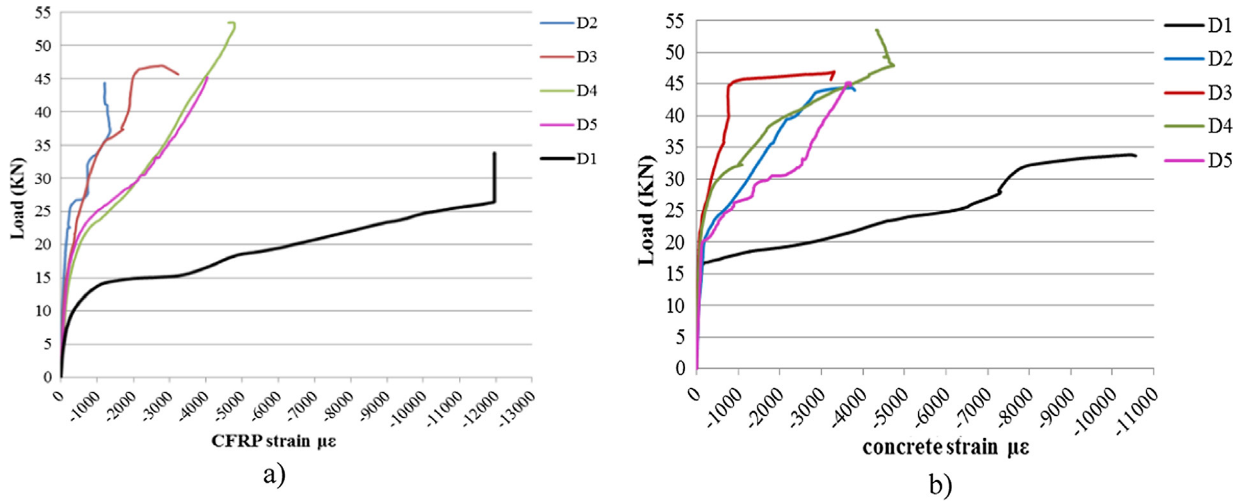

Fig. 7. (a) CFRP strain of control and reinforced slabs. (b) Concrete strain of control and reinforced slabs.

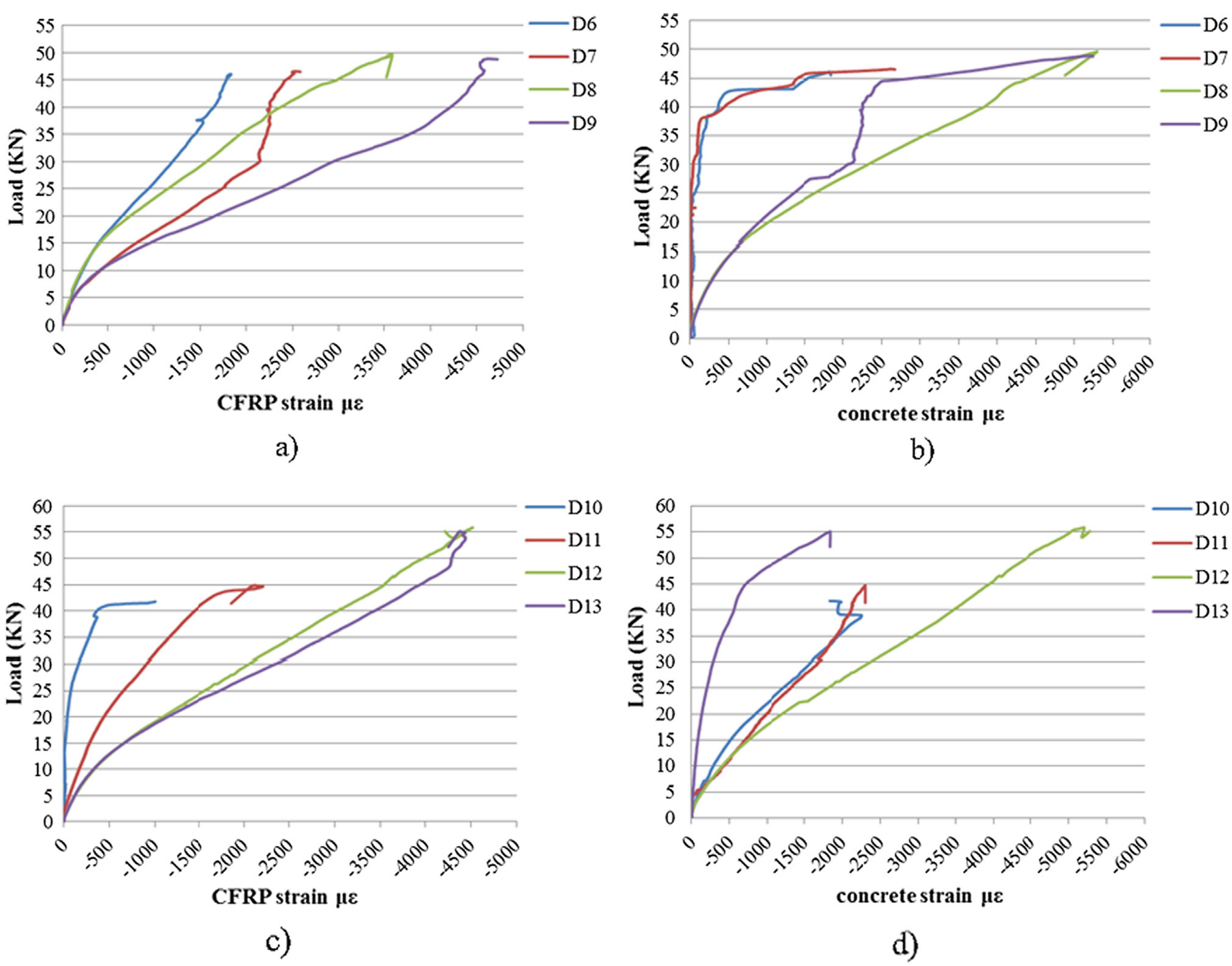

Fig. 8. CFRP and concrete strain of repaired slabs (preload slabs).

3.2. Load displacement behavior

Fig. 5 presents load deflection curves for strength slabs compared by control slab. All slabs are almost identical to the unreinforced slab in one third of ultimate capacity load this part is corresponding an elastic phase [17] (the not cracked concrete is characterized by a rapid increase of the load), after this interval the deflection of slabs D2 and D3 is nearly of deflection of control slab, but we observed the deflection of D4 and D5 is decrease than the deflection of unreinforced slab by (22%–48%). From this we find, the stiffness of slab reinforces is increase than stiffness of control slab especially the slab D4 and D5.

Fig. 6 illustrates the load-deflection for slab repaired with CFRP after preload (60% and 80%).

The deflection of slab preloaded by 60% is decrease than deflection of control slab by (25%–31%), except the slab D7 (slab repaired with CFRP with orientation 45°). The same as of slab repaired by FRP after preloaded 80%, the deflection is decrease by (28%–32%) than D1, also, the deflection of slab D10 is decrease only by 6% than D1.

3.3. Load strain behavior

Fig. 7 shows the curve of load –CFRP strain and load-concrete strain of control slab and reinforced slabs. The concrete and composite strain is nearly the same of all slabs in one third of ultimate load [18], this indicates before crack this part, the concrete is deformed in the maximum is the first phase (elastic phase). In Fig. 7 we find the CFRP strain of slab of slab D3, D4 and D5 are higher by (22.23%–35.24%–28.91%) respectively than CFRP strain of D2. The decrease in the CFRP strain of strengthen slabs compared with the unreinforced slab in the same point is in the range 59%–95%.

In other side, the concrete strain is the same in the control slab and strengthens slabs before the cracking, this indicate that the addition of the layers of composite contributes in the reduction of strain. The addition of composite is perfect for improve the ultimate load and of value of concrete strain, Fig. 7 explained the concrete strain of slabs reinforced is decrease than concrete strain of D1. The concrete strain of D3, D4 and D5 is higher by (17.69%, 31.28% and 21.39%) respectively than D2. while the concrete strain of specimen D2 is decrease by 86% than concrete strain of D1, the concrete strain of other slab is decrease by (55%–68%). The addition of composite has a positive effect on the deformation (reduction of deformations) [18].

The result experimental of concrete and composite strain for repaired slabs is presented in Fig. 8a and b. The strain of control slab is higher than all slabs repaired; the strain composite of slab D8 and D9 is higher by 28.94% than D6, and higher by 22.69% than D7. Also the concrete strain of D6 and D7 is very lower in three-quarters of ultimate load; the concrete strain of D6 is lower by (7.88%–16.57% and 27.32%) than D7, D8 and D9 respectively, the concrete strain of slab repaired after preload of 60% of ultimate load is decrease by (55%–90%) than concrete strain of unreinforced slab.

Fig. 8c and d give the result experimental of load–strain (concrete and CFRP) for slab repaired after preload 80% of ultimate load. the same result of slab preload by 60%, the composite strain of slab reinforced by CFRP with orientation (0°/90°) and (45°/135°) is higher than slab reinforced by CFRP with orientation (0°) and (45°). The concrete strain of D12 is higher than D10, D11 and D13 by 40.49%, 29.1% and 32.55%, and the reduction of strain is (49%–90%) than D1.

Moreover, when we compared the slabs repaired (after preloading by 60% and 80% of ultimate load) with the reinforced slabs, we find that the results of the first slabs (repaired slabs) are better than the other slabs, this is due to the first slabs are preload this led to the work of composite materials the maximum to avoid failure of concrete. The addition of CFRP for slab after preload is decreases the concrete strain.

4. Conclusions

In this study investigated the punching behavior of reinforced concrete slabs strength with carbon-fiber-reinforced polymer (CFRP), thirteen RC slabs, each having 965 mm length, 680 mm width, and 60 mm thickness. Tests showed that the effect of reinforcement with CFRP was an increase in the failure load. The effect of strengthening with CFRP on preloaded slabs (partially degraded). With regard to this last test category we raise the following points:

The cracking load of reinforced slabs is increase by (41%–70%) than control slab.

The CFRP reinforcement the control slabs is increase the ultimate load (31%–58%) compared by unreinforced slab.

Strengthening with CFRP can prevent the growth of large cracks by smaller cracks larger number.

The ultimate load of slabs preload by 60% is improve by 36%–46% and for slabs preload by 80% is increase by 32%–62%, because the concrete of the second slabs is damaged almost to the phase of failure.

The deflection is decrease by 1 mm–2 mm for slabs preloaded by 60%, and is decrease by 1 mm–3 mm in slab preloaded with 80% of ultimate load of slab control.

The reinforcement by CFRP with orientation (0°/90°) is more effective compared to those reinforced by other orientations.

Acknowledgments

I wish to thank everyone who helped me complete this manuscript. Without their continued efforts and support, I would have not been able to bring my work to a successful completion. Dean of the Faculty of Science and Technology of the University of Guelma 8 May 1945(Algeria) Pr. Guenfoud Mohamed for his guidance, director of laboratory of Civil Engineering and Hydraulics (LGCH) of the University of Guelma 8 May 1945(Algeria) Pr. Nouaouria Mohamed Saleh, and the president of the Department of Architectural Engineering and Architectural laboratory of the university of Guelma (Algeria) Mr. Boudjehem Hocine to help us finish the experimental work, and Pr. Benmalek Mohamed Larbi – the University of Guelma 8 May 1945(Algeria) – for his notes.

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