Journal of Materials and Environmental Sciences
ISSN : 2028-2508
CODEN : JMESCN



J. Mater. Environ. Sci., 2018, Volume 9, Issue 2, Page 701-708

https://doi.org/10.26872/jmes.2018.9.2.77

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# Repairing reinforced concrete slabs by composite materials

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*Received 01 Feb 2017,*
*Revised 07 Sep 2017,*
*Accepted 14 Sep 2017*

*Keywords*

- epoxy resin,
- reinforcement
- reinforced concrete,
- punching,
- Composite materials,

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**Abstract**

This paper describes the results of the testing of reinforced concrete slabs to the comprehension and control of the phenomenon of transmission of effort and reinforcement, by composite materials, of reinforced concrete slabs subjected to punching. The purpose of this study is the experimental analysis of reinforced concrete slabs that are control and reinforced (repaired) by composite materials [carbon fiber reinforced polymer (CFRP)] subjected to punching after degradation at various levels of load. The experimental results obtained show the strong success of the reinforcement by composite materials with respect to the increase in the failure load on the one hand and prevention of the propagation of cracks on the other hand.

## 1. Introduction

Thecivil engineering domain is in a constant evolution, despite this, a large number of civil engineering structures or buildings are found degraded for various reasons, such as damaged due to accidents, building redevelopment is any new construction on a site that has pre-existing uses such as the redevelopment of a block of townhouses into a large apartment building. More, there are also a large number of pathologies in civil engineering structures whose origins can be mechanical (shock…), physicochemical (Corrosion [1]…) and accidental. To solve these problems, two main solutions are available to project managers: demolition or repair, possibly reinforced, the latter solution is the most effective.).

The choice of the method of repair and materials to implement is defined depending on the nature and significance of these disorders, taking account of the economic requirements for construction materials, the conditions of construction site and the constraints of the site.

The traditional techniques have shown their limits in long-term behavior (oxidation of the steel plate, durability of shotcrete …). But, the composite reinforcement technique remains the most effective method especially in the case of repair. The cost is acceptable and the implementation of this technical solution is rapid.

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) [2] to plead to extreme mechanical actions (earthquake) or environmental (corrosion) [3]. This field of application is expanding more and more to other types of structures working mainly in flexion, such as slabs and beams [4.5]. With regard to this last type, more lines of research are expanding [6-8]. The slabs are generally reinforced on an important part of their surface) [9-12] by reinforcement in the form of bands [13-16]. 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) of the University of Guelma 8 May 1945(Algeria). Its main purpose is to study the behaviour under punching of reinforced concrete slabs that are simply supported and not reinforced or reinforced by carbon fiber reinforced polymer (CFRP) after imposition of degradation at various load levels compared to the charge of destruction of healthy slabs.

## 2. Preparation of test pieces and slabs

2.1.*Material Properties*

Cement

The cement used is a Portland cement compound, CPJ-CEMII / A42.5, produced by Hdjar El Soud cement factory (Department of Skikda, northern Algeria). Its chemical composition and mechanical characteristics are presented in Table 1.

**Table 1:** Chemical and physical characteristics (%) of cement

| Chemical composition | | Physical characteristics | |
|---|---|---|---|
| CaO | 55–65 | Consistency [%] | 27 |
| $SiO_2$ | 22–28 | Apparent density [g/cm$^3$] | 1.1 |
| $Al_2O_3$ | 5–6 | Absolute density [g/cm$^3$] | 3.1 |
| $Fe_2O_3$ | 3–3.6 | Fineness modulus | 63.33 |
| MgO | 1–2 | | |
| $K_2O$ | 0.3–0.6 | | |
| $Na_2O$ | 0.1–0.16 | | |
| $SO_3$ | 1.8–2.5 | | |

Aggregate

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 2

**Table 2:** Physical characteristics of aggregates

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

Composite

The composite material used in our experimental work is a unidirectionally woven CFRP called SikaWrap-230C produced by the Sika Company. Its mechanical characteristics are presented in Table 3. [17]

**Table 3:** Characteristics of CFRP

| Characteristics | |
|---|---|
| Modulus of elasticity (tension) (MPa) | > 230000 |
| Tensile strength (Mpa) | > 4000 |
| Fracture elongation (%) | 1.7 |
| Thickness (mm) | 0.129 |
| Fiber density (g/cm$^3$) | 1.82 |

Glue

The adhesive adapted to CFRP, according to the manufacturer (Sika) [18], is an epoxy resin with two components (A and B) called Sikadur-330 according to its manufacturer. This glue (Sikadur-330) complies with the requirements of the EN 1504-4 standard as a product for bonding reinforcement fabrics Table 4.

**Table 4:** Properties of the adhesive (Sikadur-330).

| Characteristics | | |
|---|---|---|
| Chemical natural | | Epoxy resin |
| Modulus of elasticity (MPa) | Bending | 3800 |
| | Tension | 4500 |
| Tensile strength (Mpa) | | 30 |
| Fracture elongation (%) | | 0.9 |
| Density(Kg/l) | | 1.30 ± 0.1 |

Concrete formulation

We used the Dreux-Gorisse formulation method for the composition of our concrete [19]. The average compression strength of concrete is obtained from the compressive tests on cylindrical specimens (16 × 32 cm$^2$) performed by a 3000 KN compression machine (Press Controls Model 50- 00802 \ B) at 25.5 MPa. Table 5

**Table 5:** Formulation of "Dreux-Gorisse" concrete

| | **1 $m^3$ concrete** |
|---|---|
| Cement (kg) | 400 |
| Sand (kg) | 658 |
| Gravel (kg) | 1035 |
| Water (kg) | 210 |
| W/C | 0.52 |
| G/S | 1.57 |

2.2.*Slab description*

For experimental program, thirty slabs were tested. All had the same dimensions: 965 mm in length, 680 mm in width and 60 mm in thickness. 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 mm². The load was applied centrally on the slab over 60 mm diameter area figure 1. The objective was to compare the result between different slab configurations:

- Control slab.
- Slabs strengthened with CFRP with one layer and two layers.
- Slabs strengthened with CFRP with two surfaces (20x20 cm² to 40x40 cm²).
- Slabs reparation with CFRP after preloaded (60% and 80%)

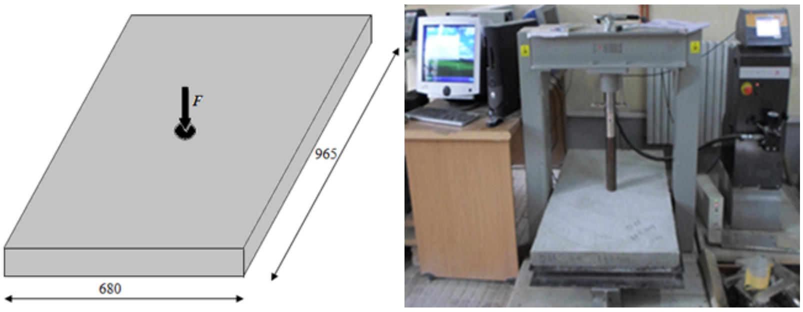


**Figure 1:** slab dimensions and Bending Testing Machine

## 3. Test results

*3.1 Control slab*

The test results are summarized in Figure 2 The average ultimate load is 32KN.

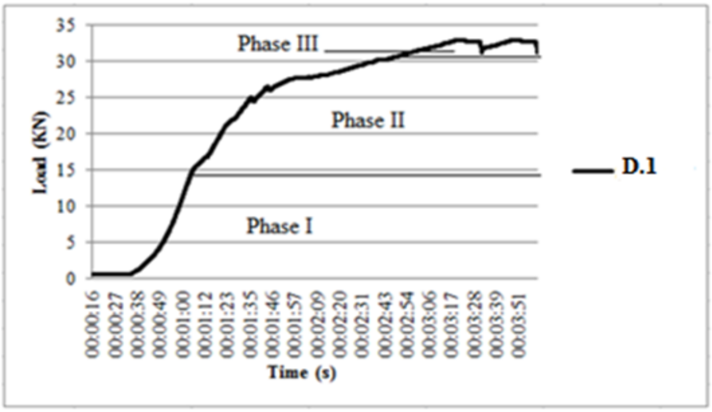


**Figure 2:** Load–time diagrams for Control slab

In these tests, we see that the slab behaviour is characterized by three phases:

- In the first phase, the elastic behaviour of the not cracked concrete is characterized by a rapid increase of the load.
- In the second phase, diagonal cracks appear on the tension face of the slab, which continues to bear the load. The appearance of cracks starts from the centre of the slab (point punching) and spreads to the extremities (the four corners) of the slab.

- The third part is the breaking phase. For the last, there is a slight increase in load, resulting in an unstable equilibrium that causes the collapse of the slab.
Thus, we observe the appearance of an area (nearly 36x36 cm) of the concrete that is almost completely degraded and detaches from the rest of the slab see figure 3.b.
Finally, when the failure of the slab is reached, the four areas between diagonal cracks remain rigid. (Figure 3.a).

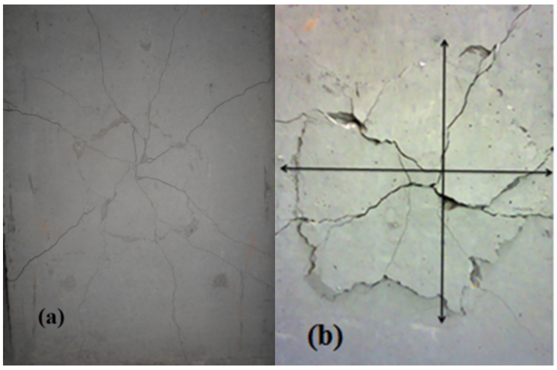


**Figure 3:** (a) control slabs after failure, (b) Critical punching perimeter of control slabs

*3.2 Tests on slabs reinforced*

This part concerns the punching tests on slabs reinforced with a single layer and two layers for area of CFRP (20x20 cm$^2$) and single layer for surface (40x40 cm²), these area equivalent to the detachable surface in the previous tests (Section 3.1) namely a surface area six times that of the punch, which is equivalent to a surface of 36 × 36 cm$^2$. Compared with the reference test slab (control slab), we note that the addition of a composite one layer for area (20x20 cm$^2$) increases the ultimate capacity of the slab by 13% on average and the addition of two layers increases the load by 17% on average, these results are consistent with those obtained by Michel and al, Abdul-Salam and al, Abadel and al [13-20-21]. Michel and al. [13] where they found that a 35% and 45% increase in the load for slab reinforced by one layer and three layers respectively, and the ultimate load capacity was increased by 25% in slab reinforced with one layer (40x40 cm²). The load of slab reinforced by second area (40x40 cm$^2$) is increase by 7% - 12% than the slabs reinforced by (20x20 cm²), this increase is observed by Rochdi [22], where they found thatthe load of slab reinforced by large area is greater than load of slab reinforced by small area (Figure 4).

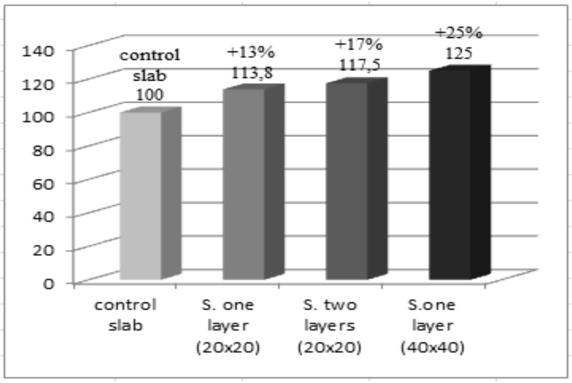


**Figure 4:**Ultimate capacity increase of reinforced slabs with CFRP

Figure 5 shows the diagram for a test slab reinforced by two types area (20x20 cm² & 40x40 cm²). In surface (20x20 cm²) as the punching load is increased, we observe that the composite starts to detach from the concrete along a line parallel to the length of the slab and this from the centre of the composite on the largest dimension of the slab (length of the slab) both for slabs reinforced with one layer of CFRP and for slabs reinforced with two layers. Then, with continuing increases of the punching load, we note that a surface area six times the surface area of the punch (including the reinforcement zone) is detached from the rest of the concrete. Thus we note a retardation of cracking. We also observed that crack sizes in these tests (slabs reinforced with one or two layers) are small compared with the tests on control slabs (Figure 6).

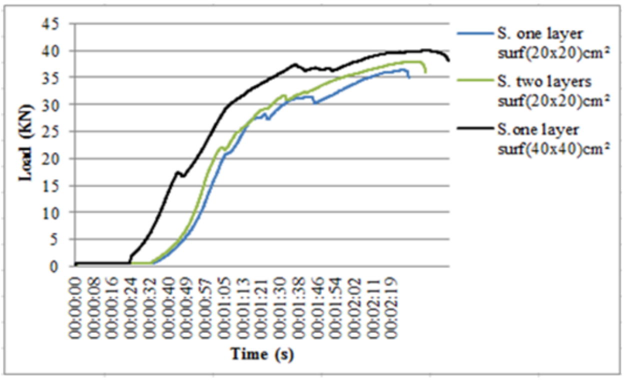


**Figure 5:**Load–time diagrams for reinforced slabs by CFRP

**Figure 6:** Final breakage of reinforced slabs (20 x 20 cm²)

In second part of slabs reinforced by surface (40x40 cm²) on observing Figure 7, which shows a reinforced slab tested with a single layer of FRP of 40x40 $cm^2$, the following remarks can be made:
- There is longitudinal adhesion of the composite.
- There is an area which is detached out from the rest of the slab of the same area as that described in the tests (see Figure 7).
- Parallel to the width, we observe a detachment of the composite, including a layer of concrete, the rest of the panel (see Figure 7).
- A decrease in the size and density of cracks is observed.
- The cracks are diagonal, as in previous trials

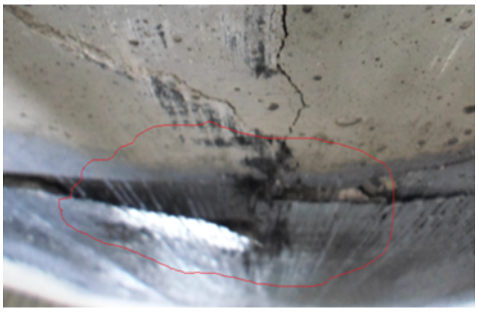

**Figure 7:**Breaking of slab with the composite peeling off (slab reinforced by 40x40 cm²)

*3.3 Test on pre-loaded and repaired slabs*

*3.3.1 Preloading to 60% of the failure load*

In this series of tests, the slabs are first loaded with 20 KN, corresponding to 60% (on average) of the ultimate load on control slabs and they are then unloaded in order to apply a CFRP repair. We repaired these slabs once with a CFRP surface of 20x20 $cm^2$ and once with a 40x40 $cm^2$ surface.
The tests on the slabs repaired with CFRP with a surface of 20x20 $cm^2$ show an increase of the ultimate load. The load of slab repaired by two layers is 37.6 KN, corresponding to a 17.7% increase compared with control slabs, and load of slab repaired by a single layer is 35 KN. In the tests of slabs repaired with a 40x40 $cm^2$ surface, we recorded an increase of 30% on average corresponding to 41.6 KN. this result is confirmed by Thanoon and al.[23], the ultimate load of slabs reinforced by CFRP after preloading is increase than ultimate load of control slab by 129% (figure 8).

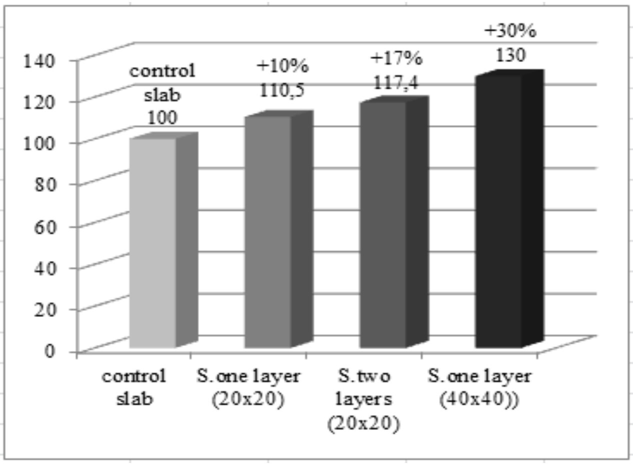


**Figure 8:** Ultimate capacity increase of repaired slab with CFRP (preloaded to 60%)

The results of these tests are presented in figure 9.

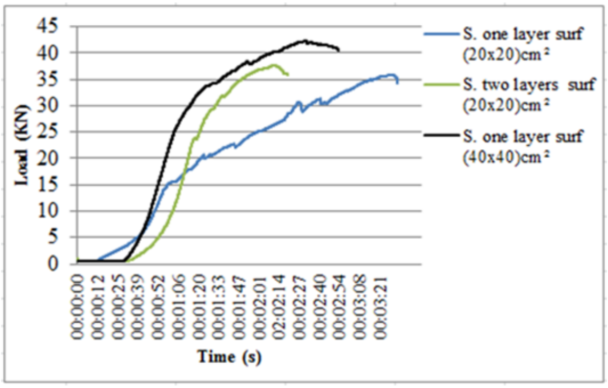


**Figure 9:**Load–time diagrams for slabs preloaded at 60% and repaired by one and two layers of CFRP with dimensions of (20 x 20 & 40 x 40) cm²

The following comments can be made:
- Longitudinal cracks appear in the composites.
- There is a separation of the FRP on the side parallel to the slab width.
- There is a decrease of the degraded surface from six (in control slabs) to five times the area of the punch (figure 10).
- Cracks have a large size on slabs reinforced by a single layer of 20x20 $cm^2$ compared with the others.
- The composite begins to detach from the centre of the slab and the final breakage occurs after the reinforcement detaches from the concrete.
- There is an increase in the failure load compared with the case of control slabs.

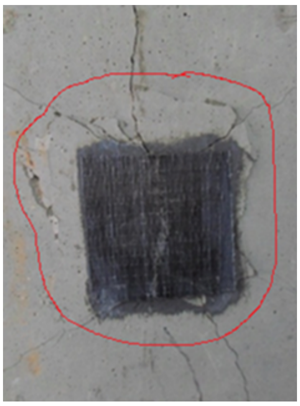

**Figure 10:**Critical punching perimeter (slab repaired with CFRP)

*3.3.2 Preloading to 80% of the failure load*

In order to see the behaviour of the slabs that had been charged at near to the failure load, we began a test series on slabs pre-loaded to 80% (on average) of the failure load of control slabs. For these tests, we observed an increase in the ultimate load (for reinforcements of 20x20 and 40x40 cm$^2$). The ultimate load is 41.8 KN in the case where slabs were reinforced with a surface of 40x40 cm$^2$; corresponding to a 30% increase compared to the control slabs. The ultimate loads are 34.2 and 37.2 kN for the cases of reinforcement by one layer and two layers, respectively, of a surface of 20x20 cm$^2$, corresponding to increases of 16.2 and 6.9% compared to the ultimate load of the control slab (Figure 11 – Figure 12)

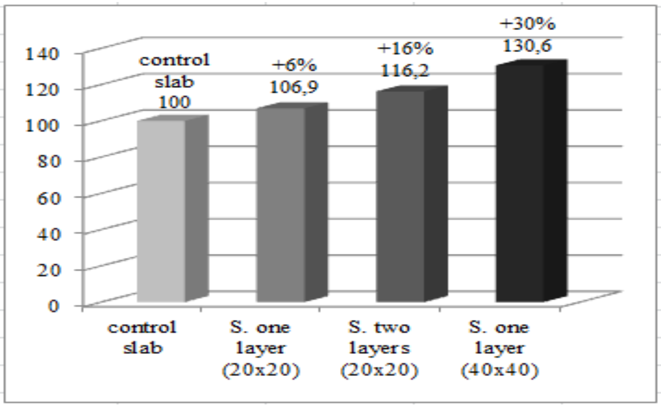


**Figure 11:** Ultimate capacity increase of repaired slab with CFRP (preloaded to 80%)

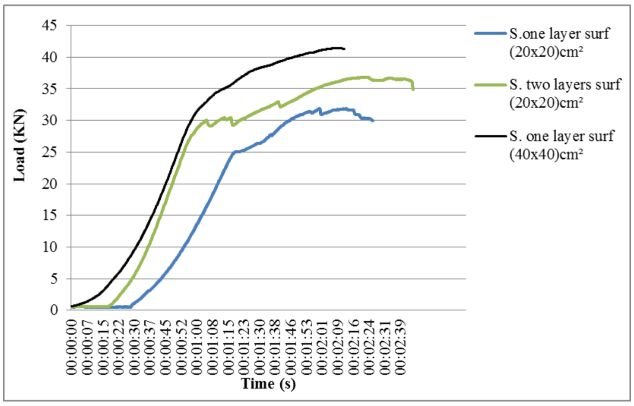


**Figure 12:**Load–time diagram for slabs preloaded to 80% and repaired by one and two layers of CFRP with dimensions of (20x20 & 40x40) cm²

The following comments can be made:

- There was an increase in the failure load compared with the case of control slabs.
- Longitudinal cracks were observed in the CFRP. Thus, a detachment of the FRP occurred on the side parallel to the width of the 20x20 cm$^2$ reinforced area of the slabs.
- There was a decrease of the degraded surface from six (in the case of healthy slabs) to five times the surface area of the punch.
- We noted that the sizes of the cracks were small in these tests (slabs reinforced by two composite surfaces) compared with the tests on control slabs. (Figure13)
- The composite begins to detach from the centre of the slab.

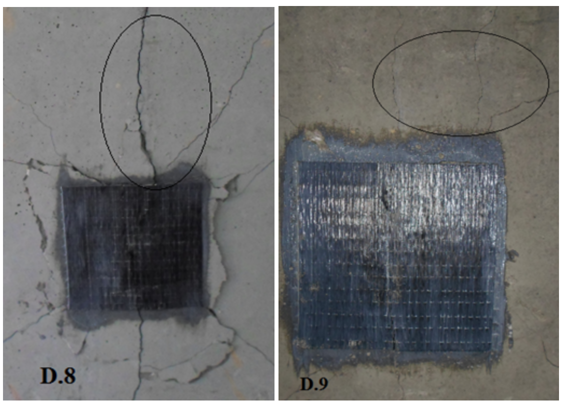


**Figure 13:**Cracks of slabs repaired with CFRP

## Conclusions

The experimental study, of our research on the behaviour of reinforced concrete slabs subjected to punching we tested thirteen slabs with different configurations (control slabs, reinforced slabs, and reinforced slabs after preloaded). Tests showed that the effect of reinforcement with CFRP was an increase in the breaking load. The effect of strengthening with CFRP on preloaded slabs. With regard to this last test category we raise the following points:

There is an increase in the tensile strength of reinforced slabs compared with control slabs.

The area and the thickness of the CFRP have a considerable effect on the load in reinforced slabs and reinforced slabs after preloaded.

The CFRP reinforcement provides significant gains (resistance), which explains that the CFRP plays the role of a weaver.

Strengthening with CFRP can prevent the growth of thickness cracks by smaller cracks.

The ultimate load of repaired slabs is increase by 10% - 30% for slabs preloading by 60% and 6% - 30% for slabs preloading by 80%.

**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. Director of Faculty Science and Technology of the University of Guelma 08 May 1945(algeria) 'Professor Guenfoud Mohamed ' for his guidance.

## References

1. M.A. Quraishi, V. Kumar, B.N. Singh, S.K. Singh, *J. Mater. Environ. Sci. X* (6) (2012) 1001-1008.
2. A.S. Mosallam, *Compos. Part B*. 31 (2000) 481±497.
3. A. Mirmiran, M. Shahawy, *J. Struct. Eng*. 1997.123:583-590.
4. B.B Adhikary, H. Mutsuyoshi, *Constr. Build. Mater*. 20 (2006) 296–307.
5. G. Spadea, F Bencardino, F. Sorrenti, R.N. Swamy, *Elsev. Engin. Struct*. 99 (2015)631–641.
6. T. Croston, L. Guillaumat, J.L. Lataillade, *Esplan.Arts. Métie*. 33405 Talence cedex France.
7. F. Bencardino, G. Spadea, R.N. Swamy, *Elsev. Engin. Struct.* 21 (2007) 1997–2006.
8. C. Gheorghiua, P. Labossière, J. Proulxb, *Compos.Part. A*. 37 (2006) 1111–1118.
9. E.H. Rochdi, D. Bigaud, E. Ferrier, P. Hamelin, *Compos. Struct*. 72 (2006) 69–78.
10. Z.S. Tabatabaei, J.S. Volz, J. Baird, B.P. Gliha, D.I. Keener, *Intern. J. Impa. Engine*. 57 (2013) 70e80.
11. M.H. Meisami, D. Mostofinejad, H. Nakamura, *Compo. Struct*. 99 (2013)112–122.
12. A. Abdullah, C.G. Bailey, Z.J. Wu, *Constr. Build. Mater*. 48 (2013)1134–1144.
13. L. Michel, E. Ferrier, D. Bigaud, A. Agbossou, *Compo. Struct*. 81 (2007) 438–449.
14. O. Liman, G. Foret, A. Ehrlacher, *Compo. Struct.* 60 (2003) 467–471.
15. J.B. Al-Sulayvani, N.D. Al-Talabani, *Constr. Build. Mater*. 84 (2015) 73–83.
16. Ö.Anil, N. Kaya, O. Arslan, *Constr. Build. Mater*. 48 (2013) 883–893.
17. Sika., Fiche technique., *1st Edition*., SikaWrap R -230 C45 (2009).
18. Sika., Fiche technique., *N° 2012- 012 Version*, Sikadur®-330 (2012).
19. J.S. Baron, J.P. Ollivier, Les bétons bases et données pour leur formulation. *3th Edition., Eyrolles* (1999).
20. B. Abdul-Salam, A.S. Farghaly, B. Benmokrane, Constr. Build. Mater. 127 (2016) 959–970.
21. A. Abadel, H.Abbas, T.Almusallam, Y. Al-Salloum, N. Siddiqui, *Proce. Engin.* 173 (2017) 85_92
22. E.H. Rochdi, Contribution à l'analyse du comportement mécanique de dalles en béton arme renforcées par matériaux composites, *doctoral thesis France* (2004).
23. W.T. Thanoon, M.S. Jaafar, M. Razali, A. Kadir, J. Noorzaei, *Constr. Build. Mater*. 19 (2005) 595–603

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