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Comportament flexibil - forfecare a grinzilor de beton armat Întărit de diverse rețele de compozite încorporate.

Flexural–Shear behavior of RC beams Strengthened by various embedded composites grids.

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Rezumat. *Această lucrare evaluează comportamentul de forfecare-forfecare a grinzilor de beton armat prin grile de polimer întărit cu fibră de carbon încorporate (grile CFRP) și grile metalice cu ochiuri hexagonale, sub test de îndoire în patru puncte. A fost efectuată o investigație experimentală pentru a evalua performanța acestui nou tehnic de întărire, Au fost testate trei fascicule de control și cincisprezece grinzi întărite în forfecare flexibilă cu diferite configurații. Câțiva parametri au fost considerați pentru a evidenția eficiența tehnicii utilizate, cum ar fi; Moduri de încărcare finală, ductilitate și defecțiune. Rezultatele experimentale arată că întărirea grinzilor prin rețelele de carbon și metalice încorporate a oferit o îmbunătățire mare a rezistenței, a devierii în timp și a indicelui de ductilitate; de fapt, se observă o influență directă asupra modului de eșec.*

Cuvinte cheie: Grinzi, grile compozite, întărirea forței de forfecare, moduri de avarie, ductilitate.

Abstract. *This paper evaluate the flexural–shear behaviour of reinforced concrete beams strengthening by embedded carbon fiber reinforced polymer grids (CFRP grids) and metallic grids with hexagonal meshes, under four-point bending test. An experimental investigation was carried out to evaluate the performance of this new technical of strengthening, Three control beams and fifteen beams strengthened in flexural–shear with different configurations have been tested. Several parameters were considered to highlight the efficiency of the technical used, such as; ultimate load, ductility and failure modes. The experimental results show that the beams strengthening by embedded carbon and metallic grids offered a great improvement in strength, midspan deflection and ductility index; in effect, an influence directly on the failure mode is observed.*

Key words: Beams, composite grids, flexural- shear strengthening, failure modes, ductility.

1. Introduction

Applications of fiber reinforced polymer (FRP) composites in civil engineering have increased significantly in the recent decades. As FRPs are non-corrosive, high-strength and lightweight, their use in civil infrastructure has extended from the strengthening of existing structures to new construction [1,2]. The FRPs systems are presented different forms, namely sheets, strips, laminates, and composite grids.

Composite grids shows very good mechanical characteristics and excellent resistance to corrosion and chemical attacks, it does not require substantial cover and may instead of steel to solve the problems of steel corrosion in harsh environments. Many experimental works investigated the different strengthening technical of RC beams with FRPs [3-7].

Taouche F et al. (2012) [8], examine the effectiveness of the reinforcement of beams by oblique connecting rods confined by a metallic embedded grid material, laid out in the zone of influence of the shear force tilted to 45° to improve the behaviour of concrete from the point of view strength to shear force. The obtained results show that the use of confined rods by metallic grid, leads to a significant rise in the ultimate load. The profit of strength is average of 13kN in the beam reinforced by confined rods. In addition, a decrease in crack width of 0.6 cm compared to unconfined beam. Rahman et al. (2000) [9], used heavy carbon grids as reinforcement in a section of concrete deck manufactured in a laboratory. The deck was supported on Steel I beams. They reported that the behavior of the deck was satisfactory and the carbon grid could replace steel reinforcement in bridge decks. Yost et al. (2001) [10], used the same type of heavy carbon grid as reinforcement in concrete beams. The use of the grid as flexural reinforcement resulted in brittle failure since the carbon has no yield point and is linear elastic to failure. Harries and Gassman (2003) [11], conducted tests on reinforced concrete basin knockout panels that employed a light carbon grid to control cracking. The grid reduced cracking of the panel. (Shao et al. 2003) [12], used the same light carbon grid to control plastic shrinkage cracking in concrete. They concluded that the plastic shrinkage crack reduction was in the range of 50% to 65%.

In this study, we will evaluate the effectiveness of a new technic of reinforcement in flexural–shear of RC beams based in the embed of CFRP grids and metallic grids in the beams of dimension 100mm width, 150mm height, and 1000mm length.

2. Experimental program

2.1 Materials

a) Concrete

The mix proportions used in this work for 1m^3 of concrete is; 350kg of cement type CEM II 42.5, 162Kg of fine sand, 657Kg of coarse sand, 555Kg of gravel 8-15 and 448Kg of gravel 15-25mm, the Water/cement ratio is equal to 0.5 . Compressive and flexural tensile strengths of concrete at 28 days are 23 MPa and 4MPa, respectively.

a) Steel bars

The beams were reinforced with high-adherence steel bars of diameter equal to 8mm (Ø8), and mild steel bars of diameter equal to 6mm (Ø6). The steel Ø8 is of type S400, and the steel Ø6 is of type S235, their values of the stress at the elastic limit is equal to 450 MPa for the type S400 and 250MPa for the type S235. Their values of Young's modulus and the Poisson ratio are equal to 210 GPa and 0.3 respectively. The stirrups are made from mild steel bars with 6mm diameter (Ø6). For all beams, the first stirrup is spaced at 2.5cm, the others spacing's of stirrups are variable according to the studied variant. The concrete cover of all beams is 25mm on top, bottom, and sides.

c) Composite grids

For strengthening RC beams, two types of composite grids have been selected, carbon fiber reinforced polymer grids (CFRP grids), and metallic grids with hexagonal meshes.

The CFRP grids were fabricated from carbon fibers embedded in an epoxy matrix. The strand spacing in the longitudinal direction was 46 mm and in the transverse direction 41 mm. The CFRP grid had an openness of 69%, which means that only 31% of the surface area was covered by the carbon fibers (Figure 1.b).

The metallic grids used in this work is made of hexagonal meshes with dimensions of hexagonal hole are 18 mm in horizontal and 34 mm in vertical (Figure 1.a). The sizes of grids of metallic and carbon these agree with the granulometry of usual concrete works. The geometrical properties of the CFRP and metallic grids are summarized in table 1.

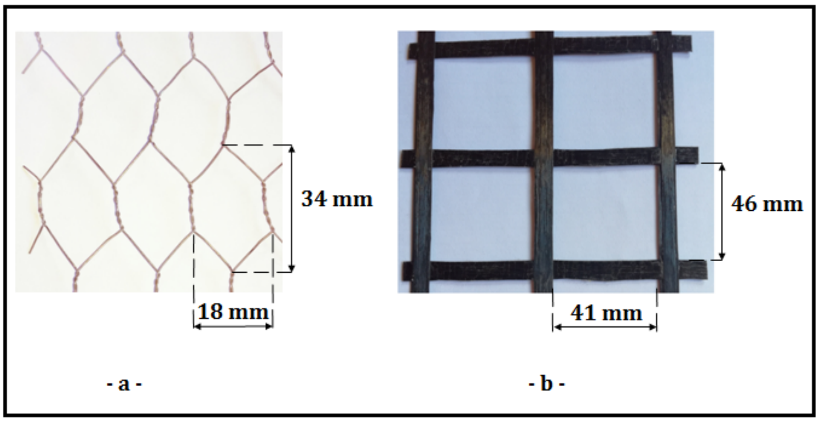

Fig. 1 Dimensions of: (a) metallic grid and (b) CFRP grid

Table 1. **Geometrical properties of CFRP grid and metallic grid.**

Properties	CFRP Grid	Metallic grid
weight	500 g/m2	250 g/m2
Diameter	/	0.43 mm
Cross-sectional area	5.18 mm^2	0.145 mm^2

Tensile tests were conducted to determine the mechanical properties of CFRP and metallic grids. The tested coupons were cut from one segment of each grid. The total length of each specimen was 300 mm, with an anchorage length of 100 mm at each end according to the ASTM D7205 / D7205M [13]. Tensile test was carried out on three samples by using digital testing machine ZWICK / Z010 of 250kN capacity with a loading rate of 3 mm/ min. The tensile test results of CFRP composite grid and metallic grid were shown in table 2.

Table 2. **Mechanical properties of CFRP composite grid and metallic grid.**

Properties	CFRP Grid	Metallic grid
Peak load (KN)	3.90	0.141
Tensile strength (MPa)	753.007	971.10
Elastic modulus in tension (GPa)	84.05	8.74
Ultimate elongation in tensile (%)	0.86	10.90

2.2 Reinforcement details and strengthening configuration of tested beams

The tested beams were divided into three (03) groups. The reinforcement schemes of the tested beams are presented in figure 2. The beams codes and strengthening details of beams are presented in figures 3, a, b, c.

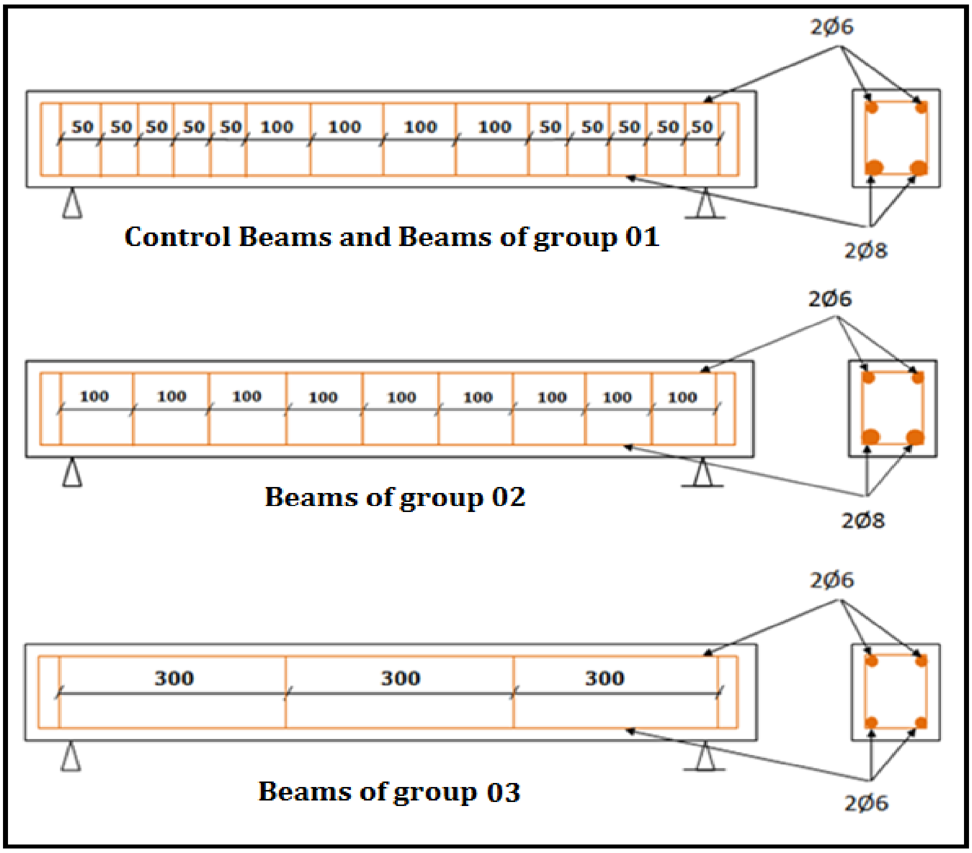

Fig. 2 Reinforcement details of the beams tested

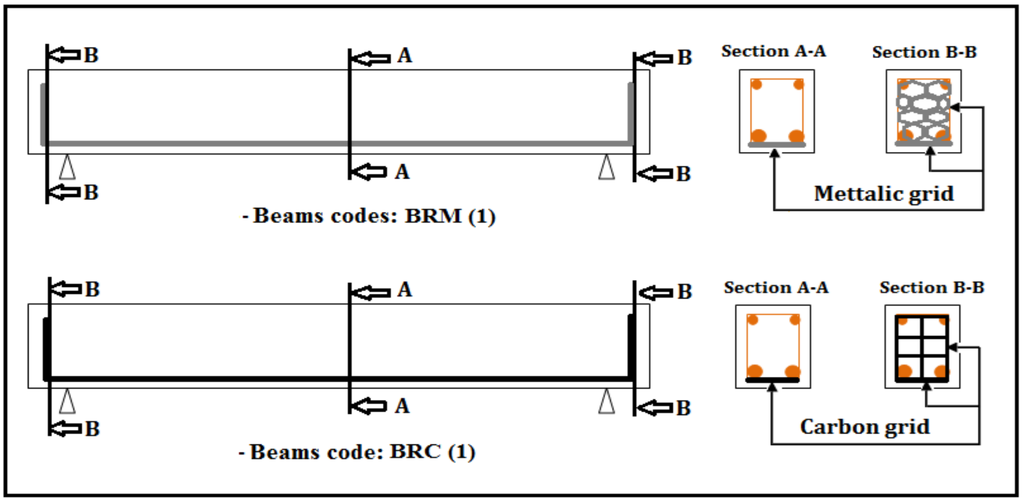

Fig. 3,a Strengthening details of beams of group 1

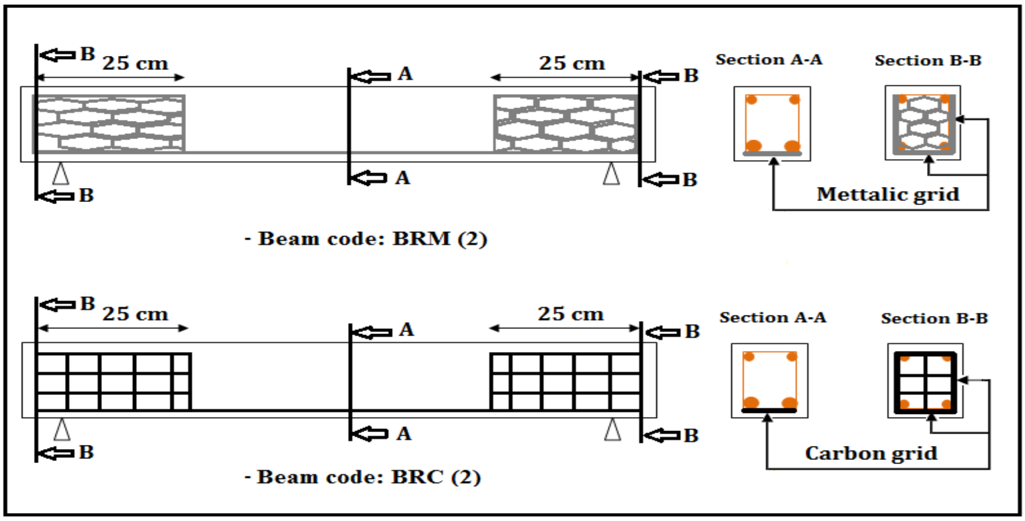

Fig. 3,b Strengthening details of beams of group 2

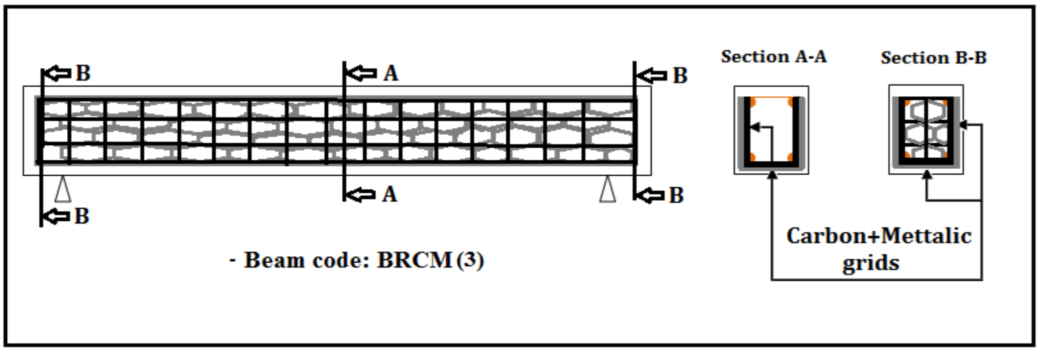

Fig. 3,c Strengthening details of beams of group 3

2.3 Preparation of RC beams

After applying of strengthening on the beams and preparation of mixing concrete, we filled the beams in three phases. After demolding (Figure 4), the specimens were deposited in a water vat for 28 days. Then, they were submitted to the bending test.

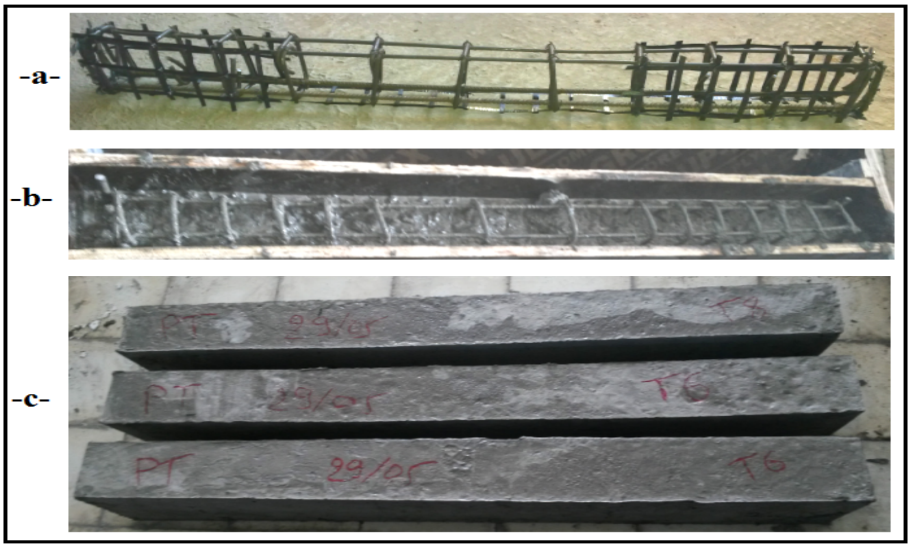

Fig. 4 Preparation of the RC beams strengthened by composite grids

2.4 Bending test

The beams were loaded in 4-point bending using a controlled universal testing machine (Controls) with a static loading capacity of 250kN with a loading rate of 0.05 MPa/s, the machine is connected to a system of automatic data acquisition managed by a computer. The effective span of the beams was 800 mm and the distance between the loads was 150 mm. Each test beam was instrumented by two linear variable differential transformers (LVDTs) placed at right and left of the middle of the beam to measure the mid-span displacement (Figure 5). The values of the vertical force and the corresponding displacement were recorded simultaneously.

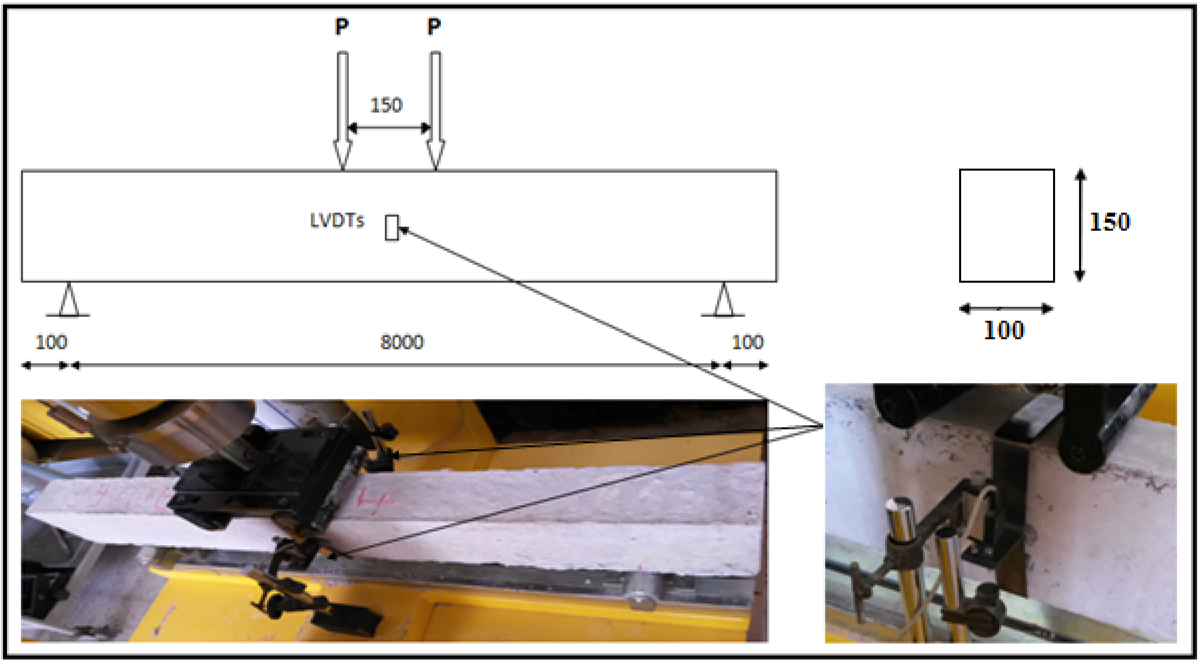

Fig. 5 Test setup and instrumentation.

3. Experimental results and discussions

3.1 Failure modes

Figures 6 to 8 shows the failure modes of all beams observed in the tests. The control beams (CB) undergoes a conventional breaking of concrete loaded in bending, the failure mode observed on the beams has high propagation of cracks, and then it notices a crushing of the concrete in the compression zone due to the fragility of concrete and extensive cracks propagation (Figure 6), All beams strengthened were failed in flexure by crushing of concrete in compression zone with evenly distributed narrow cracks throughout the flexural span followed by fracture of CFRP grids and metallic grids (Figures 7 and 8). For all beams strengthened, the appearance of cracks has been considerably delayed compared to the control beams, which shows the effectiveness of the confinement of the beams by CFRP grids and metallic grids in the limitation of the propagation of cracks despite the increase in spacing of stirrups and the decrease in the diameter of the bottom longitudinal reinforcement bars compared to control beam.

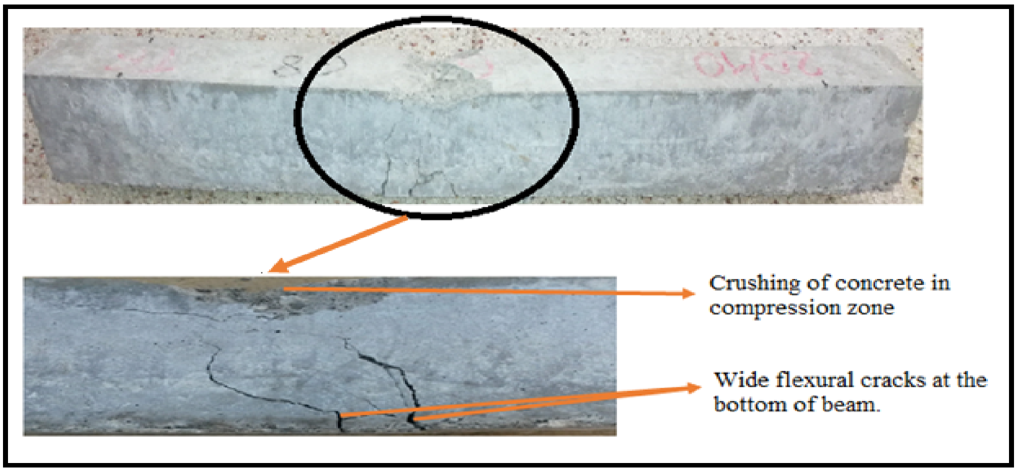

Fig. 6 Failure mode of control beams [CB]

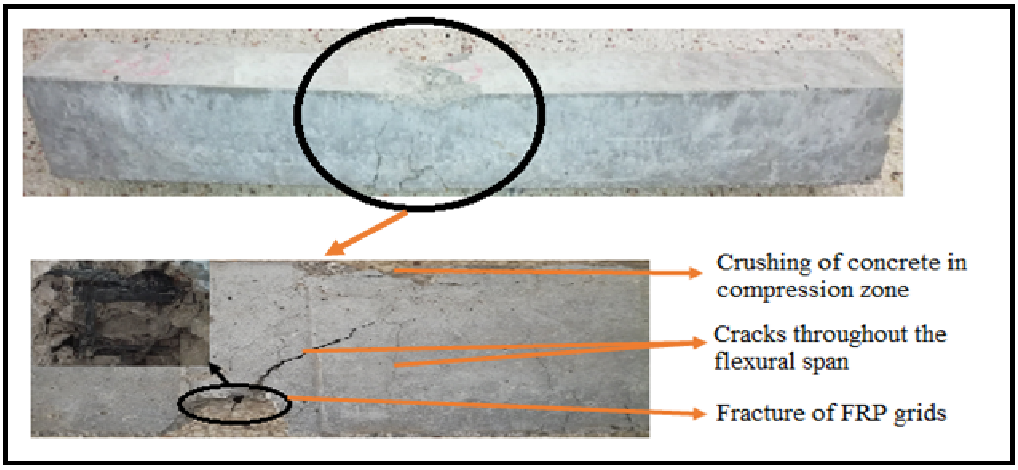

Fig. 7 Failure mode of beams [BRMBL (1), BRCBL (1), BRM (2) and BRC (2)]

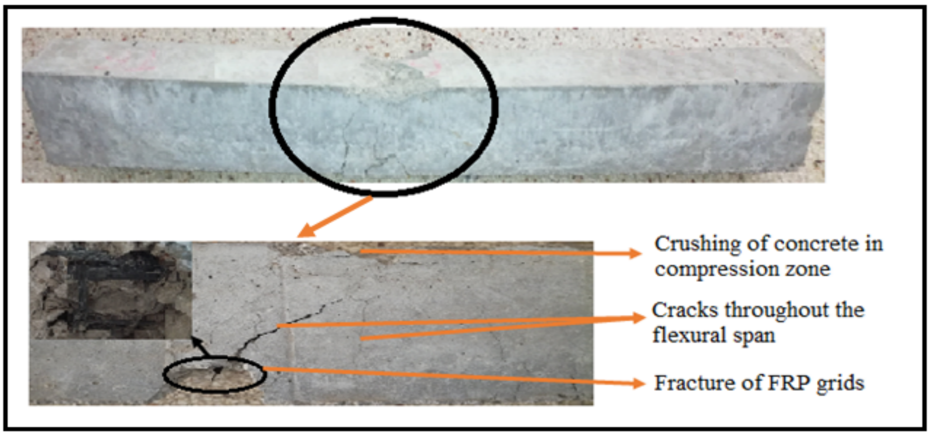

Fig. 8 Failure mode of beams BRCM (3)

3.2 Load–mid-span deflection responses

The results obtained from the bending test, in particular, the load–mid-span deflection curves of control beam in comparison with all strengthened RC beams, are illustrated in figures 9 to 11. As can be seen from these figures, the first region of the curves is linear and shows the rigidity of the beams. It can be clearly observed from the load–mid-span deflection curves, that the slope is greater in all strengthened beams comparatively with the CBs; the value of the rigidity obviously increases from the strengthening specimens to the control specimens. For strengthening RC beams, some authors [14 and 15] use the ductility notion based on energy. To quantify the ductility (μE), the deformation index can be used. This index is defined as the ratio between the energy at break (Eu) and energy at elastic limit (Eγ). The energy can be calculated as the area under the load–displacement curve.

Table 3 summarize the results in terms of the ultimate load, mid-span deflection at ultimate load, ductility, increase of ultimate load, deflection, and ductility compared to that of the CB. According to the results presented in table 3, it can be observed that the flexural load, the mid-span deflection and the ductility value of all strengthening RC beams are higher than that of the CB.

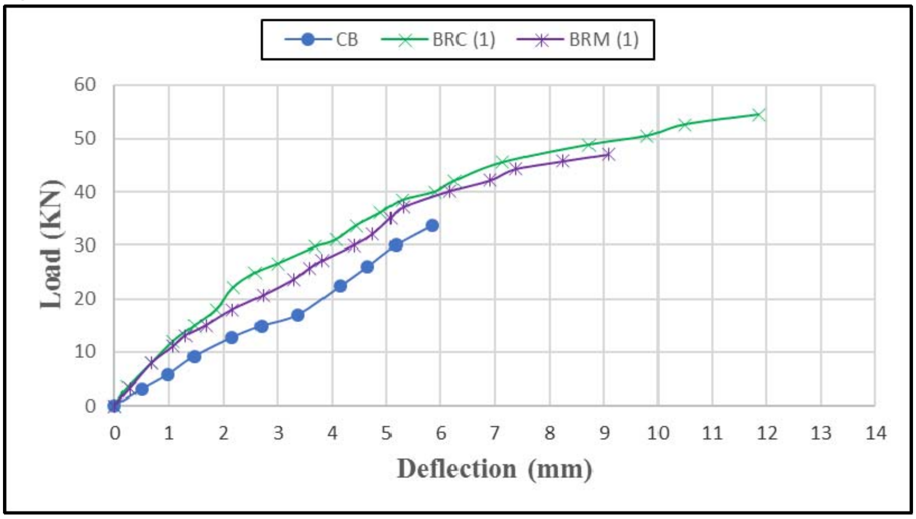

Fig. 9 Load–deflection curves of beams of group 1

Table 3. **Load, mid-span deflection and ductility index values of all beams and its gains relative to the control beam**

Beam code	*Control beams*			*Strengthened beams*					
	Load f_u *(KN)*	*Deflection* δ_u *(mm)*	*Ductility index* μ_E *(%)*	*Load* f_{us}*(KN)*	*Deflection* δ_{us} *(mm)*	*Ductility index* μ_{Es} *(%)*	$\frac{f_{us}-f_u}{f_u}$ (%)	$\frac{\delta_{us}-\delta_u}{\delta_u}$ (%)	$\frac{\mu_{Es}-\mu_E}{\mu_E}$ (%)
CB	33.71	5.84	4.45	/	/	/	/	/	/
BRMBL (1)	/	/	/	47.05	9.08	7.97	+40	+55	+79
BRCBL (1)	/	/	/	54.58	11.85	9.56	+62	+103	+115
BRM (2)	/	/	/	50.10	10.87	9.42	+49	+86	+112
BRC (2)	/	/	/	57.14	12.95	14.21	+70	+122	+219
BRCM (3)	/	/	/	36.88	8.66	6.02	+9	+48	+35

The strengthening beams of group 1 show an interesting improvement in terms of ultimate loads, midspan deflection and ductility index. The increase in the load is from 40% and 62%, the mid-span deflection is improved from 55% and 103%, for the ductility value the improvement is of 79% and 115% compared to the control beam, for the bemas strengthened by the metallic grids (beam BRM (1)) and CFRP grids (beam BRC (1)), respectively compared to the control beam. These results clearly indicate the effectiveness of strengthening beam by CFRP grids and metallic grids in improving the load capacity and the mid-span deflection.

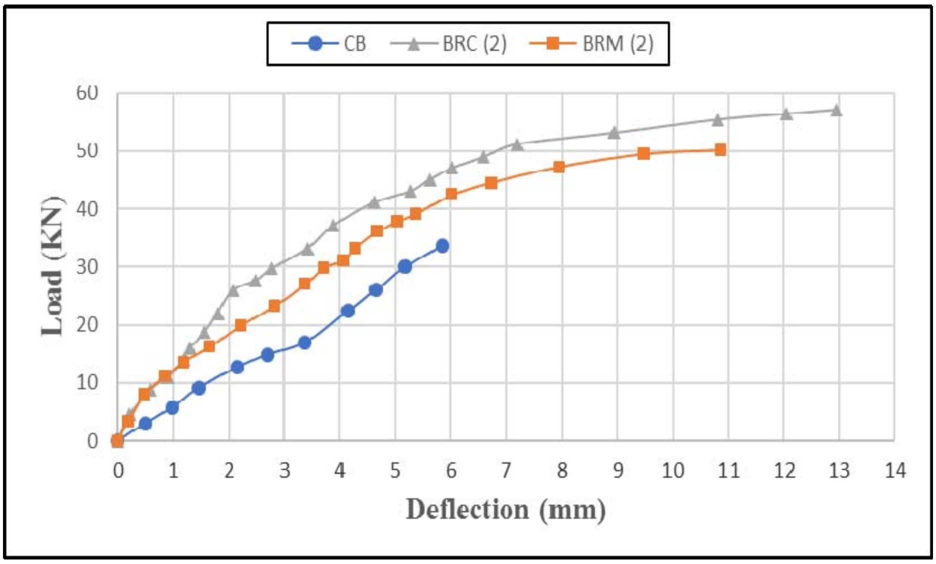

Fig. 10 Load–deflection curves of beams of group 2

In the strengthening beams of group 2, we have registered the best improvements in terms of ultimate loads, midspan deflection and ductility values despite that we have increased the spacing of the stirrups at the influence zone of shear, (see Fig. 2), the increase in the load varies from 49% and 70%, the mid-span deflection is improved from 86% and 122%, for the ductility value the improvement is of 112% and 219%, for the bemas strengthened by the metallic grids (beam BRM (2)) and CFRP grids (beam BRC (2)), respectively, with a gain of 5 stirrups per linear meter of the beam compared to the control beams. These interesting results provided by the strengthening with metallic and CFRP grids are attributable to their high mechanical properties values, especially for beams strengthening by CFRP grids, these have a high value of the tensile load at failure and elastic modulus in tension compared to that corresponding to the metallic grids.

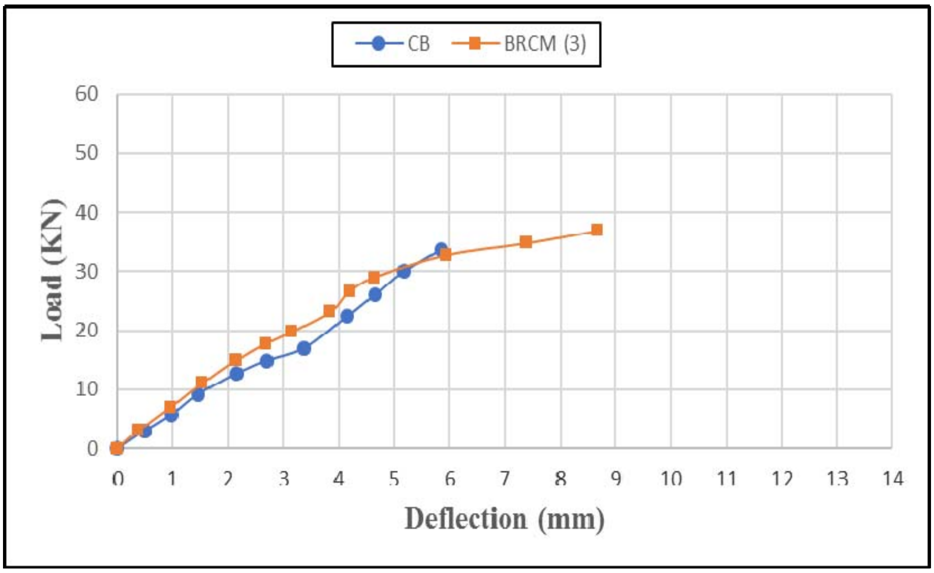

Fig. 11 Load–deflection curves of beams of group 3

For the beams of group 3 (beam BRCM (3)) strengthened by the hybrid reinforcement system with one layer of CFRP grid and one layer of metallic grids (see Fig. 3.c), the spacing between the stirrups is 30 cm on full-length of the beam with a reduce of the diameter of the bottom reinforcement bars compared to control beam (see Fig. 2), the ultimate loads, midspan deflection and ductility value have all been improved compared to the control beams, the increase in the load is 9%, the mid-span deflection is improved from 48% and the ductility value has been improved of 35%, with a gain of 11 stirrups per linear meter of the beam and a reduction in the longitudinal rebar section area equal to 39% which therefore generates a significant gain in the weight of the beam compared to the control beams. As the load increased, the size of the flexural increased leading to a flexural failure at the mid-span region. The cracks for the BRCM (3) beam were narrower compared to the control beam, the grids prevent the distribution of cracks around the shear zone in particular, and the cracks were taken up by the grids so make a less brittle material; more ductile, it takes more energy to advance the crack.

4. Conclusion

This experimental investigation focuses on the effect of strengthening beams under flexural test, using metallic and CFRP grids embedded in the beams. The results obtained show that the strengthened beams have higher mecanical properties than that of the CB, the improvement of flexural load varies from 9% to 70%, from 48% to 122% for the midspan deflection, and 35% to 219% for the ductility index depending on the type of strengthening (CFRP grids or metallic grids) and the reinforcement details. The composite grids have a significant capacity in the improving of the mechanical properties of the beams and in the reduction of construction labor costs. The tying of steel rebar is a tedious and labor-intensive process. the lightweight grids would can easily replace the steel rebar. Transportation costs would also be lower due to the reduced weight. The inherent corrosion resistance of polymers would significantly increase the life of the structure and reduce the maintenance costs. The higher raw material costs would be partially offset by these other cost reductions. The corrosion-resistant nature, high specific strength, high specific stiffness, and moldability make the metallic and CFRP grids a natural choice for critical applications where corrosion is a concern.

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