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Mechanical performance of a confined reinforced concrete beam

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Abstract

This study focused on the four-point bending behavior of the concrete beam subjected to an innovative internal axial confinement process. An experimental study was carried out to validate the effectiveness of this technique. The four-point bending tests was carried out on confined concrete beams by this technique which makes it possible to produce an induced a compression stress induced by the normal component of the tensile effort developed in the resistance reinforcement at the level of the anchoring of steel bars. The results show the increasing of the ultimate bending strength compared to the control beam. Two opposing half-cylindrical plates are welded to the level of the curvatures of the steel bars. Each bar has a hook at one end only. The two hooks are arranged in the taut area of the beam and diametrically opposite. This technique allows us to mobilize the confining stresses from the beginning of loading of the beam, contrary to the existing methods, without using other materials as a composite FRP. Furthermore, a theoretical study was proposed to predict the equivalent load to be applied to the reference concrete beam when it is subjected to an ultimate bending moment determinate in the confined concrete beam. The experimental and theoretical results confrontation shows a good agreement.

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Keywords: Beam, Concrete, Axial Confinement, Mechanical testing, Strength; ;

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1. Introduction

The development of construction is intimately linked to the actual development of design, implementation and realization techniques. Following the development of new materials, the designers have posed a new challenge, the first concern of which is to extend the life of the structures, while respecting the increasingly stringent safety and mechanical performance standards.

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The behavior of reinforced concrete beams is very complex: several parameters influence its behavior (deep or slender beam, steel ratio, size, etc.) [1,7,12] .Various reinforcements have been made in order to curb diagonal cracks in order to avoid any catastrophe leading to the rupture of the structural elements or even the whole structure as a whole. There are many reasons for reinforcements / repairs such as structural changes, changes in use or even repairs after earthquakes or other phenomena [2,3,4,5].

For concrete beams, the confining of the concrete is ensured by the transverse reinforcement, generally in the form of closely spaced turns or steel frames [6,7]. For low stresses in concrete, the intervention of the transverse reinforcement (Frames and stirrups) as a confinement reinforcement is not significant therefore the concrete is considered as unconfined. The concrete becomes effectively confined when the stresses developed by the core of the concrete approach the limiting strength [10]. The transverse deformations become very important due to the progressive internal cracking in the concrete which relies on the transverse reinforcement, which in turn responds by a confinement reaction on the concrete [4,8, 9,10,11].

The reinforcement of the reinforced concrete beams is mainly aimed at the recovery of bending forces and shear forces. Several authors have proposed a lot of solutions of reinforcements with experimental arguments. Two techniques of reinforcement in the recovery of the bending force in the beams are used, such as: bonding plates or bonding strips to the external lower and lateral faces of beams [2, 9, 12, ,13,14]. In the late 1980s, a similar bonding technique was proposed, with the only difference being that the glued element is presented in the form of strips, adjustable to the reinforced structure [2, 15,16].

Initially, steel plates glued under the concrete elements were used as reinforcing elements, but they were gradually replaced by other innovative materials such as composite materials, which are a very attractive solution to meet the need for reinforcement Buildings and structures due to their mechanical performance such as strength, ductility and lightness. The work on confinement was developed more for the concrete columns subjected to an axial load of compression. Generally, the confinement or reinforcement of the concrete beams is achieved by bonding the composites 'FRP'. The reinforcement, using "PRF" composites is generally achieved by external bonding of the "PRF" lamellas glued to the support of the beam in question [8,9,13,16]. The majority of the researchers observed an increase in bearing capacity and ductility, accompanied by a change in the mode of rupture [2,8, 16].

The development of new, cost-effective reinforcement technologies is a topical issue. The proposed techniques for reinforced concrete reinforcement elements such as: beams, posts, column, slabs, .., must provide them with a clear improvement in terms of durability, rigidity and stability with a consequent carrying capacity [11,17,18, 19].

The critical analysis of the existing work led us to ask the following question: Is it possible to confine a reinforced concrete beam without using additional materials, such as 'FRP' composites, in order to improve its strength, rigidity and ductility under a bending load?

To answer this question, based on the theory of bar curvature and confinement studies, we propose, in this research work, an innovative method of internal axial confinement of the tensile concrete zone of the beam, based on the idea of the compression induced at the level of the anchorage due to the normal component of the tensile force acting on the traction metallic bars. This study focused on the four-point bending behavior of the concrete beam subjected to an innovative internal axial confinement process. This technique allows us to mobilize the confining stresses from the beginning of loading of the beam, contrary to the existing methods, without using other materials as a composite FRP.

In order to thoroughly understand the strengthening behavior of the proposed beams, the results of the theoretical study and 4-point bending tests carried out have made it possible to formulate comprehensible conclusions and to quantify the contribution in terms of increased strentgh and ductility compared to the reference beams. The experimental and theoretical comparison of the results shows a good agreement.

2. Experimental

2.1. Materials used and manufacture of test specimens

The specimens have been made according to Eurocode 2. Mix proportions of the components (cement/water ration, gravel, and sand) of the used concrete are depicted in table 1. Before filling the cast iron cylindrical moulds, slump tests have been carried according to EN 12350-2 standards. The filling of the cylindrical moulds was carried out in two phases, a vibrating needle of 40 mm diameter was used for vibration and consolidation. After 24 h, the cylindrical specimens were demoulded, and then were cured in saturated limewater for 28 days until testing. Three standard cylinders with a diameter of 160 mm and a height of 320 mm were casted from each batch. The cylinders specimens were tested under compression load to evaluate the ultimate strength and the corresponding strain. The specified average compressive strength of the concrete at 28 days is 30.6 MPa. Using the mix proportions of the components, six beams with a width of 80 mm, a height of 160 mm and a length of 1100 mm, were casted for the 4-bending tests. Two series of beams are considered, series 1: 03 reference reinforced concrete beams (RCB) and series 2: 03 confined reinforced concrete beams (CRCB). The steel reinforcement used was Ø 6 Fe240. The CRCB beams are reinforced by two steel bars reinforcement of diameter Ø6 each bar have half-cylindrical steel plates welded to the level of the curvatures of the steel bars. Each bar has a hook at 180 ° at one end only. The two hooks are arranged in the taut area of the beam and diametrically opposed. The central distance between the plates is 600 mm. The mechanical strength characteristics are given as follows: yield strength of the used steel bars diameter (ϕ6) is f_e = 240 MPa and a tensile strength is fr ≥ 400 MPa. The mechanical properties of the concrete are depicted in Table 2.

Table 1. Mix proportions of the used concrete

Component	amount (Kg/m^3)
Cement CPJ 42.5	425
Sand	750
Gravel 3/8	253
Gravel 8/15	572
Water / cement ratio	0,54
Super plastizer	5,1L

Table2: Mechanical properties of the used concrete

Properties		Values
	Uni axial loading	
Maximum compressive stress	fc [Mpa]	30.6
Déformation axiale de rupture	ε (‰)	3.4
Ultimate tensile stress	ft [Mpa]	3,1
Young Modulus	Ec [Mpa]	29120
Poisson's ration	υ	0,196

2.2. Presentation of the proposed process

The proposed process is developed based on the analysis of the curvatures of the steel bars and the concepts of confinement of concrete. Indeed, at the level of the curved anchoring of the resistance reinforcement, a semi-cylindrical plate is welded to the bar inside the curvature. To ensure a uniform geometry of the metal plates, we used a metal tube of diameter 6cm. This tube was sawn every 5 cm in length. Thereafter, each cylindrical element was cut into two equal parts, thus half-cylinders of identical dimensions were obtained. These two plates are welded to the steel bars in order to ensure a good adhesion which in turn allows to fully transfer the tensile force developed in the metal reinforcement to the steel plate, which will generate compression forces produced by the A normal component of the tensile force acting on the reinforcement of the reinforcement in the concrete of the taut area of the beam.
In fact, an axial compression pressure exerted on the cross-section of the taut area of the beam is mobilized by virtue

of the tensile force acting on the resistance bars and transmitted to the volume of the concrete trapped between the two half-cylindrical metal plates. Bending cracks are hampered and slowed down by the mobilization of this concrete confinement pressure. To this end, this innovative process makes it possible to oppose the opening of the cracks and to reduce the speed of propagation and development of the initial bending cracks in the proposed beam. The use of metal plates is justified by the need to distribute the confinement force over the entire width of the cross-section; This makes it possible to completely confine the cross-section of the beam and to avoid the crushing of the concrete at the points of contact of the reinforcement in the case of the bends without plates. The originality of this process consists in ensuring confinement at the beginning of the loading, as a function of the tensile force developed in the reinforcement in a bending test, in contrast to the various existing processes. The characteristics of the reinforcements used in the different beams are shown in table 3.The details of the proposed internal axial confinement process of the concrete beams are illustrated in Figure 1.

Table3: Characteristics of the reinforcements used in the different beams

Beam reference	Number of bars	Diameter (mm)	Mass (g)	Total length developed (cm)
Series				
N°1 : **RCB**	**2**	**φ6**	**498**	**220**
N°2: **CRCB**	**2**	**φ6**	**339**	**150**
half-cylindrical plate	Number	Thickness (mm)	Mass (g)	area developed (mm^2)
	2	**1**	**84**	**60*50**

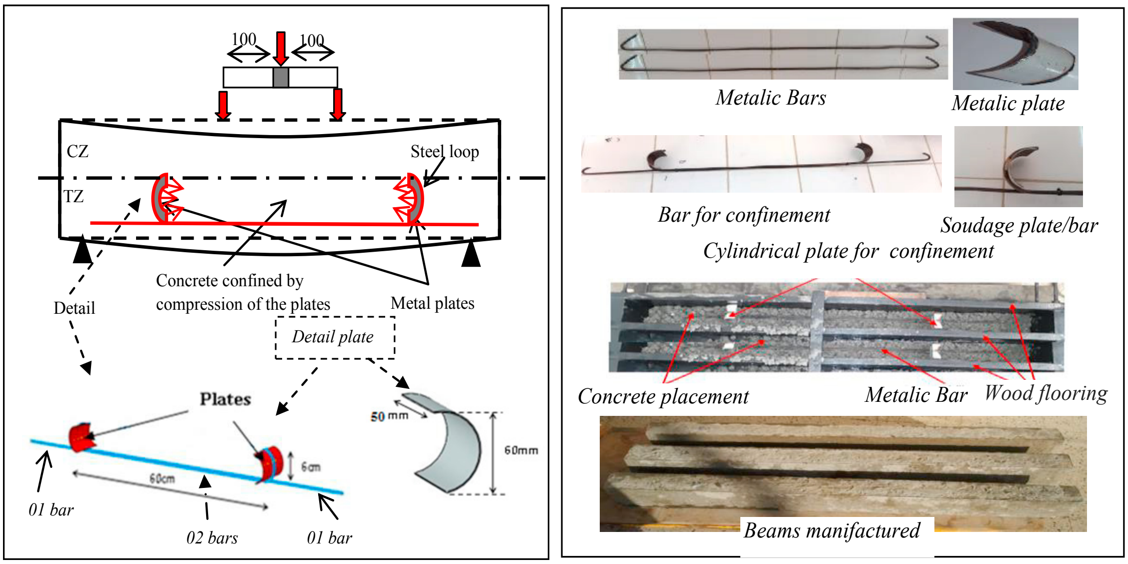

Figure1- Detail of process proposed and beams manufacturing

After 28 days, all the beams were subjected to 4-bending test using a universal ELE IBERTEST machine of 200 kN capacity, equipped with a digital software. The effective span of the beams was 1000 mm and the distance between the loads was 200 mm. All the beams were loaded at the constant rate of 1 kN/min.. The cracks developments and the mid-span deflection under loading were observed at every 5 kN. The values of the ultimate strength to the peak and of the corresponding arrow are recorded automatically. Tests were conducted until rupture of the beam.

3. Experimental results comparison

The experimental behaviors of the proposed beams were studied under static four -point bending test. The obtained load-deflection curves of the beams plotted in figure 2 and the depiction of failure modes and damages evolution allows us to measure the differences in ultimate strengths and the effect of the confinement for each rate of loading until rupture of the beam. Table 4 summarizes the average test results obtained from the different beams specimens in terms of flexural load capacity, and mid-span deflection.

Table 4.The average test results

Specimens / Parameters	**Type of Beam**	
	RCB	**CRCB**
Ultimate load (kN)	10,77	16,67
Displacement at the peak (mm)	2,4	3,40
Displacement at the rupture (mm)	5.98	7.23
Reduction of the mass of steel bars used (%)	0	32%
Increase in ultimate strength (%)	0	+54,8

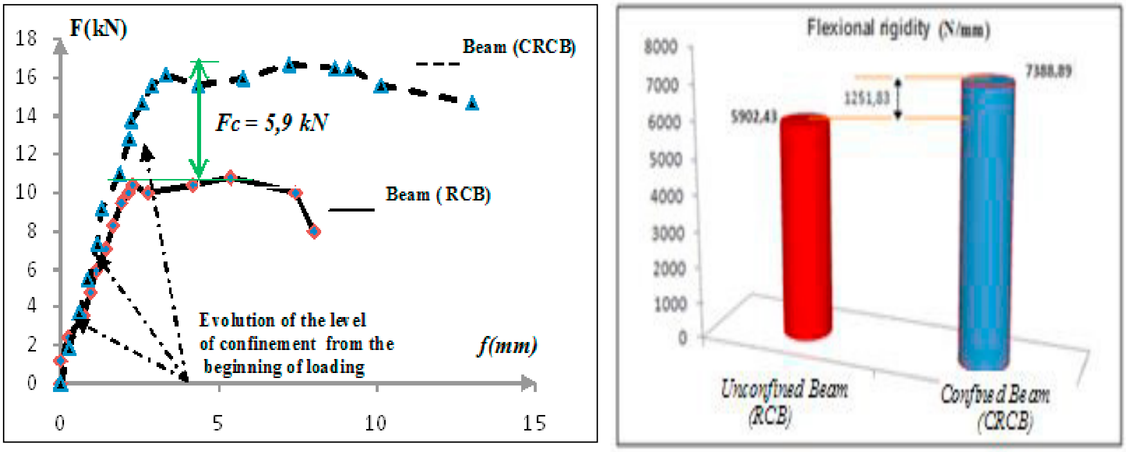

Figure2- Average test load – mid span deflection curves confrontation and flexional rigidities of beams

In the first branch of the curves, the effect of the confinement is weak, because the reinforcements are not very stressed, so the mobilization of the confinement stresses generated by the compression induced as a function of the tensile force developed in the reinforcements is very weak. Note that a slight improvement in stiffness is observed. The ultimate strength to the peak of the confined concrete beam 'CRCB' is of the order of 16.67 kN, with a corresponding vertical displacement of 3.40 mm. The reference unconfined concrete beam 'RCB' has a fairly ductile behavior with maximum peak strength of 10.77 kN and a corresponding displacement of 2.4 mm. The comparison of the results shows that for the confined beams 'CRCB' the breaking load increases considerably by approximately 55%, the displacement increases by approximately 20%, the flexural rigidity is improved by 54.78% and the reinforcement mass is reduced by 32%, (excluding plate mass).

In conclusion, the confinement stresses is a function of the tensile force developed in the reinforcements steel bars, In conclusion, the confinement stress is a function of the tensile force developed in the reinforcements. The increase in the tensile force acting on the bar induces an increase in the mobilization of the confinement pressure of the tensile area of the beam subjected to bending.

4. Theoretical analysis

The aim of the theoretical study consists in taking into consideration the stresses induced by the compression force transmitted by the metal plate to the tensioned concrete zone of the beam, which is between the two half-cylindrical plates welded to the reinforcement steel bars, at the level of the anchorages by curvature and to evaluate the bearing capacity of the proposed confined beam subjected to a four-point bending load. On the basis of the notion of equilibrium of the sections, a flowchart for calculating the equivalent load is developed. The proposed approach makes it possible to establish a flowchart for calculating the equivalent ultimate load developed by the confined beam when it is subjected to a developed moment in the reference unconfined concrete beam and to deduce the confining force. The different results can be used to optimize the design parameters, ie plate size and shape, plate radius, grade of steel used, characteristic strength of the concrete, ..

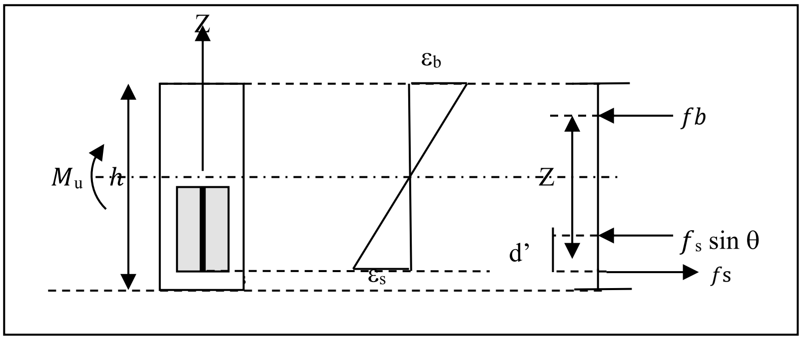

Figure3- Equilibrium state of the middle cross-section of the confined beam

Considering the state of equilibrium of an element of curvature, we can write:

$$dN = 2\,F \sin d\theta/2 + dF \,.\, \mathrm{Sin}\, d\theta/2 \quad (1)$$

Where **θ** : Angle at the center of the curvature of the bar in radian, , **F**: Axial tensile effort and **dN**: Normal component of the contact action of the concrete on the bar welded to the metal plate

dθ is very small, the sinus are approximated to the value of the angle in radian and dF.dθ is an infinitely small of the second order which one neglects before the other terms of the equation, by simplification, we can write:

$$N = fs \sin\theta \quad (2)$$

Based on the equilibrium state of the section, the ultimate bending moment of the confined beam is determined by the force equilibrium from Figure 3.

$$Mr = fs.z - fs.\sin\theta.(z - d') \quad (3)$$

Confinement stresses are determined by dividing the normal component on the surface of the metal plate:

$$\sigma_c = \frac{2.F_S \sin\theta.}{\pi.L.R} \quad (4)$$

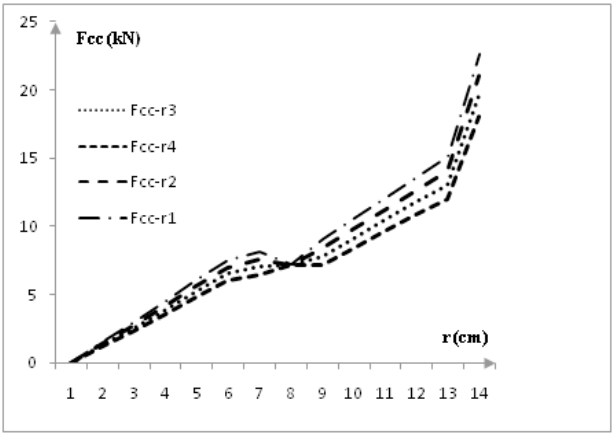

Figure4- *Variation of c*onfining force Fcc according to radius 'r' of the plate curves

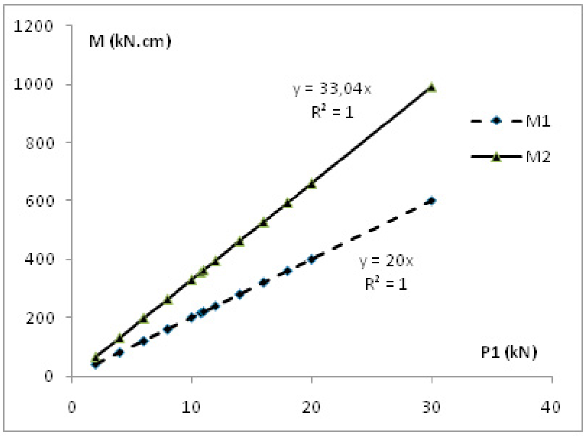

Figure5-Variation of the bending moment 'M_r 'of' CRCB and RCB beams under load ' P1'

The Variation of confining force Fcc according to the radius 'r' of the plate and the bending moment 'Mr 'of' CRCB and RCB beams according to load ' P1' are shown by figure 4 and 5. It can be observed that the confinement effect varies as a function of the radius of the plate.

- The theoretical values of the ultimate rupture loads are equal to 10.77 kN for the RCB beam and 17.7 kN for the CRCB beam, respectively. While those determined experimentally are 10.77 kN for the RCB beam and 16.67 kN for the CRCB beam. The error is about 6.7%;

- The confinement force is equal to 7.02 kN, which represents a very appreciable contribution of 65.2%. This improvement in strength and stiffness highlights the effectiveness of the proposed confinement process. The plate plays an important role in maintaining the anchoring of the resistance bar, avoiding it's unfolding and above all allows a better distribution of the confinement stresses on the section of the tensioned concrete zone of the beam without exceeding the limit value of the compression resistance of the concrete.

5. Conclusion

The different results presented in this study validate the feasibility of the proposed process of the internal confinement of tensile zone of the reinforced concrete beam and highlight the contribution in terms of strength and rigidity provided by the confinement.

When the tensile force is exerted on the element of the curved anchor of the bar sealed in the concrete, the normal component of this force produces a confining force on the concrete situated inside the hook. The proposed method of internal axial confinement of the concrete of the tensioned zone of the beam by induced compression without the use of additional materials makes it possible to mobilize the confinement pressure at the beginning of the loading, contrary to the traditional methods and techniques of confinement which require much more complex procedures and reduce the total weight of the bars used in reinforcement of the concrete beam.

The results obtained are very encouraging, although this process may be very competitive in the face of traditional confinement methods. The use of plates to ensure confinement can be considered as a disadvantage due to their masses, although the beam must have only two plates, whatever the number of reinforcing bars.

Finally, In order to better understand the flexural mechanical behavior until rupture of the beams confined by the proposed technique, it is necessary to realize and test beams on a real scale, considering reinforcement with a high adhesion steel bars 'HA' type and Cross-sectional frameworks.

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