Structural Behavior of Normal R.C Rectangular Short Columns Strengthened Using Ferrocement System

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Abstract - **The main objective of the current research is to study the behavior of reinforced concrete R.C columns strengthened with ferrocement jacket and subjected to axial load. The experimental program includes ten R.C columns. Three columns were used (C1, C2, and C3) with an aspect ratio of (1, 1.56, and 2.04), respectively as a control column, and the remainder of the columns were strengthened with a ferrocement jacket. The parameters studied were the thickness of the ferrocement jacket, the number of wire mesh layers, and the aspect ratio of the cross-section of the column. The obtained results showed that as the wire mesh layers increase, a significant increase in the nominal compressive strength of the strengthened columns was satisfied. Moreover, a similar trend of the effect of the number of wire mesh layers was obtained due to increasing the ferrocement thickness. On the contrary, increasing the aspect ratio of the columns resulted in decreasing the nominal compressive strength of the strengthened columns. Furthermore, the ductility, toughness, and stiffness of the strengthened columns are improved by increasing both the number of wire mesh layers and the ferrocement thickness. However, the ductility, toughness, and stiffness of the strengthened columns decrease as the aspect ratio of the strengthened columns increase.**

keywords - **Columns, Ferrocement, Reinforced Concrete, Strengthening, Wire Mesh.**

I. Introduction and literature review

No doubt that the reinforced concrete column is one of the most important elements in the reinforced structure. The failure of the column may lead to a total collapse of the building. The column could lose its strength due to a change of service load, retrofitting is the solution to increase the load-carrying capacity of the columns. There are most techniques of retrofitting such as Confinement with fiber-reinforced polymers (FRP), with an external steel jacket, and with ferrocement. The current research studies the technique of retrofitting using ferrocement Confinement for RC columns. Ferrocement is a type of thin reinforced wall commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh (ACI Committee 549-R97, 1997) [1]. (see **Figure1**). This material has many advantages such as it locally available, doesn't need high skill it easy to apply, has the features of fire and corrosion protection, and low-cost compared with steel jacket or FRP. Many studies pointed out the ferrocement technique such as (Singh et al. [2]; Mansur et al. [3]; Walliuidin et al. [4]; Singh et al. [5]; Seshu et al.[6]; Kondraivendhan et al.[7]; Xiong et al. [8]) they study the effect of ferrocement confinement on the plain and reinforced concrete under concentric compressive loading. (Takiguchi et al. [9]; Takiguchi et al, Abdullah et al. [10]; Kazemi et al. [11]; Rathish Kumar et al. [12]) these researches investigate the Shear capacity of the reinforced concrete column strengthened with ferrocement. It was found that the control columns suffered from shear failure with low deformation and ductility, but the strengthened columns' deformation and ductility were greatly improved. Kaishet. al. [13] study three techniques to improve the ferrocement jacketing for the square RC short column. The dimensions of the specimens used in this investigation were (L=600mm length, b=100mm breadth, and with L: b=6:1). In the first phase, the corners of the specimens were rounded and strengthened with single layer wire mesh. In the second phase, it was used shear keys at the center of each face of the specimens to fix the single layer wire mesh. In the third phase, the corners of the specimens were left sharp and strengthened with single layer wire mesh, and with two extra layers of wire mesh at each corner, the thickness of the ferrocement jacket was (12mm) for each phase. It was noticed that all the previous techniques were effective to overcome the drawbacks of conventional square ferrocement jacketing of square RC column. The third technique shows the highest load-carrying capacity as well as good ductility comper with other techniques. B. J. AL-Sulyfani et al [14] carried out research work, to investigate the efficiency of strengthening reinforced concrete columns using ferrocement jacket with different numbers of chicken wire meshes (2, 3, and 5) layers and with different ferrocement thickness (20 and 30mm). It was tested seven columns, with a cross-section of 250 mm depth, 150mm width and 2350 mm overall height, with a hunch at each end. All the columns were reinforced with 4Ø12mm diameter main reinforcement and Ø10 ties spaced at 150mm c/c. One of these columns was used as a reference column. It was found that increasing wire mesh from 2 to 5 layers, for both 20 and 30mm ferrocement thickness resulted in increasing the ultimate load of the tested strengthened columns by 20% to 48%, respectively. Also, It was noticed that that increasing the ferrocement thickness from 20mm to 30mm causes an increase in the ultimate load of the strengthened columns by 6.4% to 17.4% for 3 and 5 wire mesh layers, respectively. Yamen Ali [15] and N.Karthik, N.Mohamed Azhar [16] study the effect of strengthening the pre-loading reinforced concrete square columns using ferrocement. It was noticed that all the strengthened specimens have a ductile failure. By increasing the value of the pre-loading for the tested specimens before strengthened them the ultimate load of the strengthened specimens is slightly increase compares with the reference specimens. This paper verifies from the effect of increasing the number of the wire mesh layer and the thickness of the ferrocement jacket on the ultimate load-carrying capacity, stiffness, ductility, and toughness the results were satisfied when compared with the previous researches. The previous researches didn't study the effect of increasing the aspect ratio of the cross-section of the column on the behavior of reinforced concrete columns strengthened with ferrocement jackets. The current research studies this point to overcome these shortcomings.

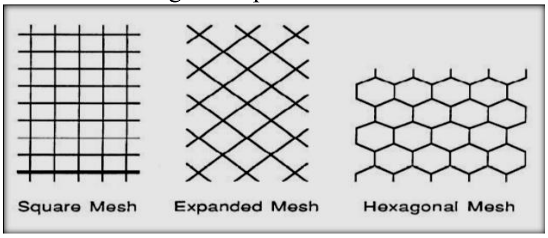


Fig 1. Example of steel wire mesh [17]

II. Materials and Experimental Program

The experimental program consisted of testing ten R.C columns, including, three control columns (unstrengthened columns), and seven strengthened columns, as given in **Tables 1 and 2**.

Table 1. The control columns used in the experimental work

Col. designation	Cross section dimension (mm)	t/b	H (mm)	μ_s%	μ' %
C_1	200*200	1	1200	6 bars 12 dia. (1.69%)	1Ø6@11.2 cm (0.35%)
C_2	160*250	1.56	960		1Ø6@11.6 cm (0.35%)
C_3	140*286	2.04	840		1Ø6@12.3 cm (0.35%)

* H/b =6, μs % and μ' % were constant in the experimental work,
Where: -
(μs %) is the percentage of longitudinal steel reinforcement,
(μ' %) is the percentage of lateral steel (stirrups),
(t/b) is the cross-sectional aspect ratio.

Table 2. The strengthened columns used in the experimental work

Col. designation	t/b	Number of wire meshes	Ferrocement thickness (mm)
C_{1-2-2}	1	2	20
C_{1-2-3}	1	2	30
C_{1-2-4}	1	2	40
C_{1-3-3}	1	3	30
C_{1-4-3}	1	4	30
C_{2-2-2}	1.56	2	20
C_{3-2-2}	2.04	2	20

Testing of Materials

Properties of materials used for this investigation are evaluated by testing of cement, fine aggregate, coarse aggregate, and the details of the test results are given in **Table 3**.

Table 3. Properties of concrete components

Content	Water	Cement	Fine Aggregate	Coarse Aggregate
Size/ Grade	Ordinary potable water free from impurities.	OPC 42.5	Passing through 4.75mm and retaining on 0.75 micron	Passing through 20mm and retaining on 10mm sieve
Specific Gravity		3.05	2.5	2.74
Mix design	The mix proportion of cement: sand: gravel of ratio (1: 1.76: 3.23) at 0.56 water-cement ratio was used. The concrete mix proportion was designed to achieve the strength of 25 N/mm^2.			

Mortar mix	The mortar mix proportion of cement sand mortar of ratio1:2 was used and the water-cement ratio of 0.5 was used [18].

REINFORCEMENT DETAILS

Six bars of 12mm diameter (High tensile steel), having a yield strength of 427.52 MPa and ultimate strength of 585.23 MPa were used as longitudinal reinforcement, and 6mm diameter (Mild steel) was used for stirrups with a nominal yield strength of 291.46 MPa and ultimate strength of 397.75 MPa, as shown in **Figure 2**.

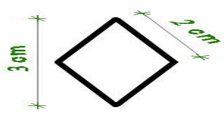
Fig 2.The details of the reinforcement used in the experimental work

WIRE MESH

Steel wire mesh of 1 mm diameter wires woven in the expanded pattern was used for the confinement of the specimens. Three specimens of the wire mesh were used to carry out the tensile test as shown in **Figure 3**. The mechanical properties of the wire mesh are given in **Table 4**.

Fig 3.The specimens of the wire mesh and the tensile test

Table 4. Properties of Wire Mesh

Diameter of wire	1mm
Ultimate Tensile Strength of wire kg/cm²	26.78 (from the tensile test)
Mesh opening size	expanded pattern 

THE CASTING OF REINFORCED CONCRETE COLUMNS SPECIMENS

All the ingredients were first mixed in dry condition. According to the dry mix calculated, the quantity of water was added and thoroughly mixed to get a uniform mix. Oil was applied on the inner surface of the mold and the reinforcement cage was placed in position. Concrete was poured into two layers and each layer was compacted. The molds were stripped off after 24 hours and the columns are moist cured for (28) days until being tested.

CONFINEMENT OF COLUMNS SAMPLES WITH FERROCEMENT JACKET

The wire meshes were wrapped after the concrete had reached an age of 28 days. The wrapping procedure was applied as follows:

- The surface of the samples was roughed and any dust or loose particles were removed with washing and allowed to air dry as shown in **Figure 4.**

- The steel nails with lengths 3cm and 0. 5 mm diameter were fixed with epoxy 165 at the top, bottom, and the middle of specimens at a spacing of 10cm as shown in **Figure 5.**
- The wire mesh was wrapped around the column specimens with the help of the nails and the wire bond. The wire mesh overlapping was 75 mm in the lateral direction [18], as shown in **Figure 6.**
- A small gap of 5 mm was kept between R.C column specimens and ferrocement jacket and a small gap of 10mmwas kept at both the top and bottom of the specimens [18] to avoid direct compression on the ferrocement jacket as shown in **Figure 7.**
- After wrapping all column specimens with the wire mesh, plastering of cement mortar was put around the specimens as shown in **Figure 8.**
- The specimens were cured with wet burlap rolls for (28) days until testing.

Fig 4. The roughness of the surface of the column

Fig5.The fixation of the nails at the column's surface.

Fig 6.The wrapping procedure

(a) *(b)*

Fig 7. (a) The gap of 5mm between the wire mesh and the specimen

(b)The gap of 10 mm at the top and the bottom of the specimen
Fig 8. Columns Confined with mortar Layer

TEST PROCEDURE

The test procedure was divided into three groups: -

- The first group (t/b=1): the column specimens were wrapped with constant wire mesh layers (2 layers) and variable thickness of ferrocement jackets (20, 30, and 40) mm.
- The second group (t/b=1): the column specimens were wrapped with a constant thickness of ferrocement jacket (30 mm) and variable wire mesh layers (2, 3, and 4).
- The third group: the column specimens were wrapped with constant wire mesh layers (2 layers), the constant thickness of ferrocement jacket (20 mm), and the aspect ratio of the cross-section of the columns was variable (1, 1.56, and 2.04).

The tested columns were first loaded axially by minimum load representing the weight of the machine tare (1.5 ton), then the reading of (LVDT) and strain gauges were recorded. The rate of loading of the machine was constant as 140 kg/cm^2/minute up to failure.

TESTING MACHINE AND MEASURING DEVICES

The specimens were instrumented to record the axial strain of the concrete, as well as the transverse strain of the ferrocement jacket. The axial strain of specimens was measured using Liner Variable Distance Transducers, (LVDT) which attached to the base of the testing machine and the top of specimens. Two electrical strain gages were installed at the mid spans of the wrapped columns for both directions (short side and long side). The data from strain gages, LVDT, and Load Cell were collected by using the Data Logger system as shown in **Fig 9**.

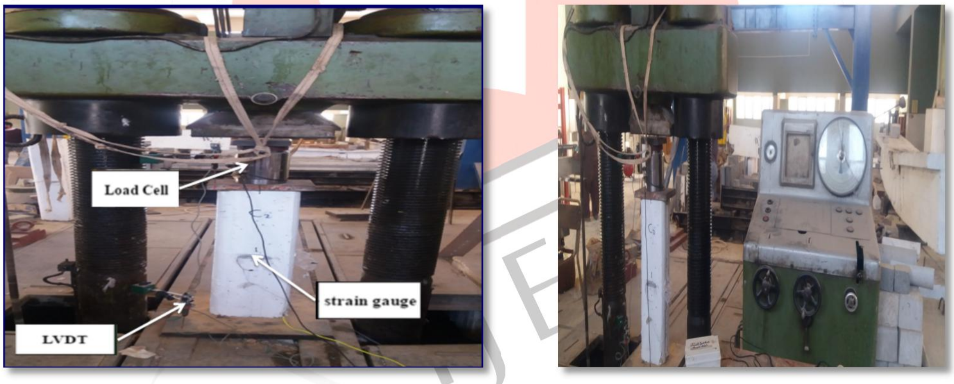


Fig 9. Test setup, instrumentation, and the location of LVDTs and strain gauges on the concrete surface.

III. TEST RESULTS AND DISCUSSION

Un-strengthened Columns Behavior:-

The failure mode was a brittle failure. During loading, the sound of aggregate sliding was heard then by continuing loading, an inclined crack occurred followed by concrete crushing at the middle third of the column height as shown in **Fig 10**. By analyzing **Fig 11**. It was observed that the square specimen has a higher initial stiffness. Also, the control square R.C column has the highest value of compressive strength (F_{cc}).

Fig 10. Cracking pattern at failure for control columns (C_1, t/b =1- C_2, t/b =1.56 - C_3, t/b = 2.04).

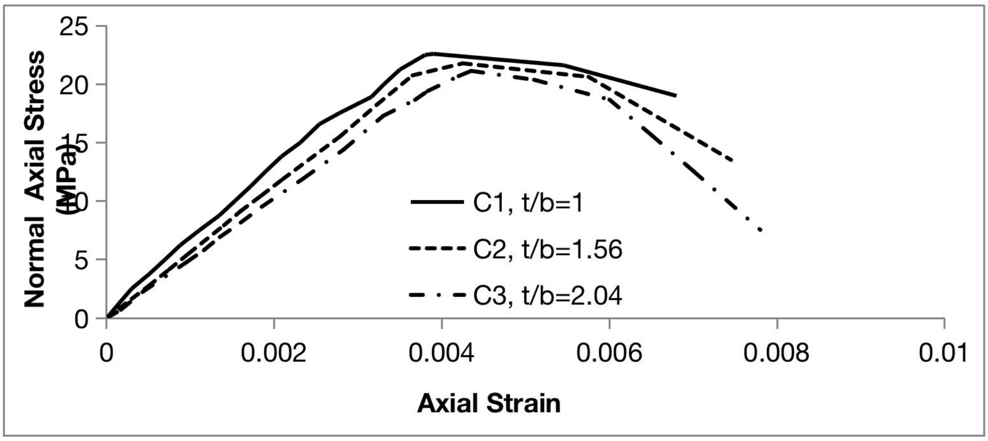


Fig 11. Stress-Axial strain response for all control columns (C_1- C_2 - C_3)

The strengthened Columns Behavior:-

The failure mode was a ductile failure. During loading, the cracks spread along the entire length of the column. Cracking occurs at both the corner and the middle of each face. All jacketed columns start to fail from the ferrocement jacket as shown in **Fig 12**. By comparing the failure results with the previous researches it was noticed that [9], [10], [11], and [12] mentioned the same results for the strengthened and Un-strengthened Columns.

Fig 12. Cracking pattern at failure for the strengthened columns

By analyzing **Fig 13**. It was observed that confinement with a ferrocement jacket can enhance the performance of concrete and increase the compressive strength (F_{cc}) of the concrete. **Figs 14** and **15** show that increasing the wire mesh layer and the ferrocement thickness resulted in increasing the compressive strength of the strengthened columns, these obtained results agree with [14]. On the contrary, increasing the aspect ratio of the columns caused a decrease in the compressive strength of the strengthened columns. It was noticed that the stiffness of the strengthened columns is improved by increasing both the number of wire mesh layers and the ferrocement thickness. However, it decreases as the aspect ratio of the strengthened columns increase as shown in **Fig 16**. **Table. 5** summarizes the test results of all the tested specimens.

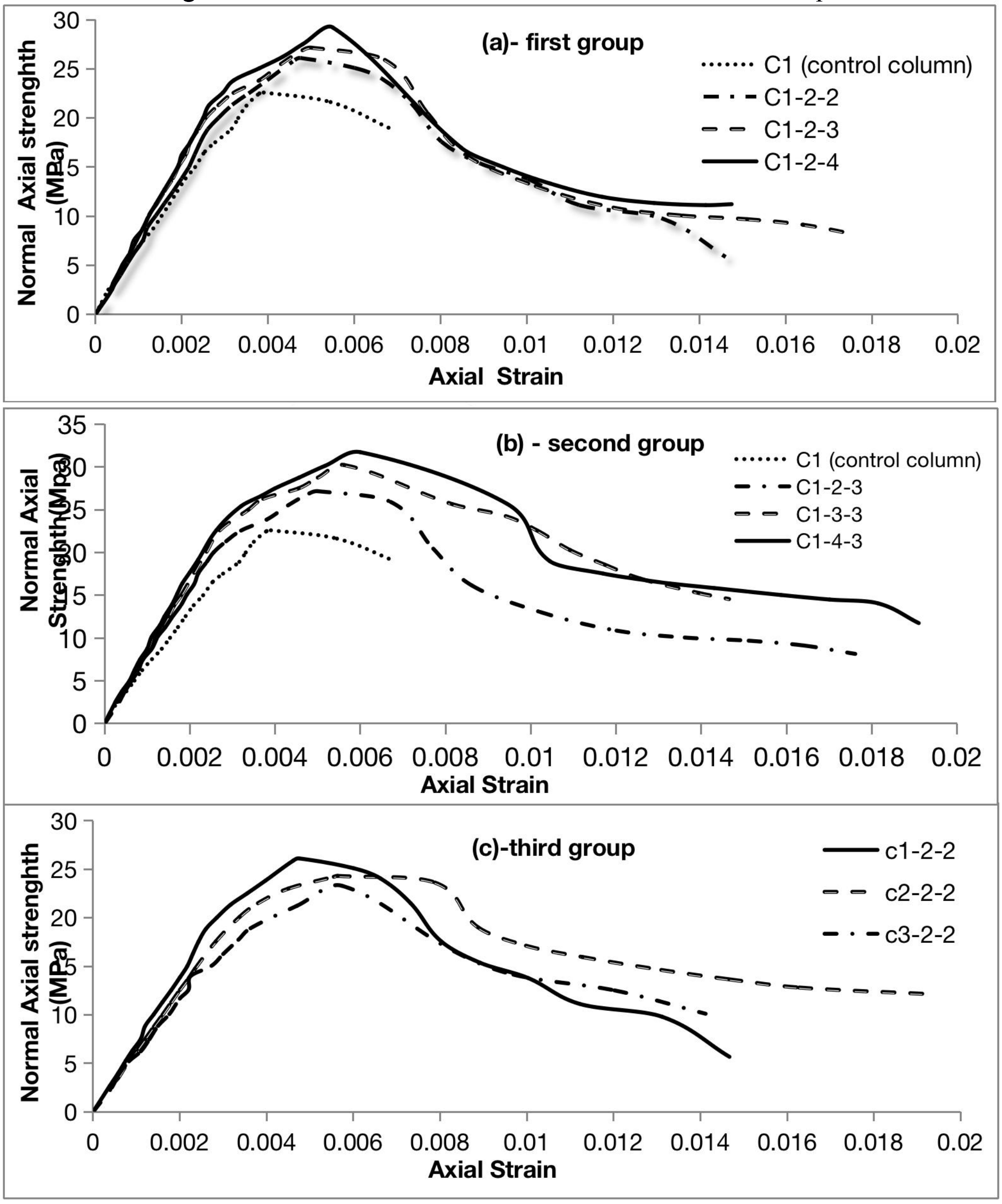


Fig 13. (a), (b), and (c) Stress - Axial strain response for the strengthened columns for the first, second, and third groups

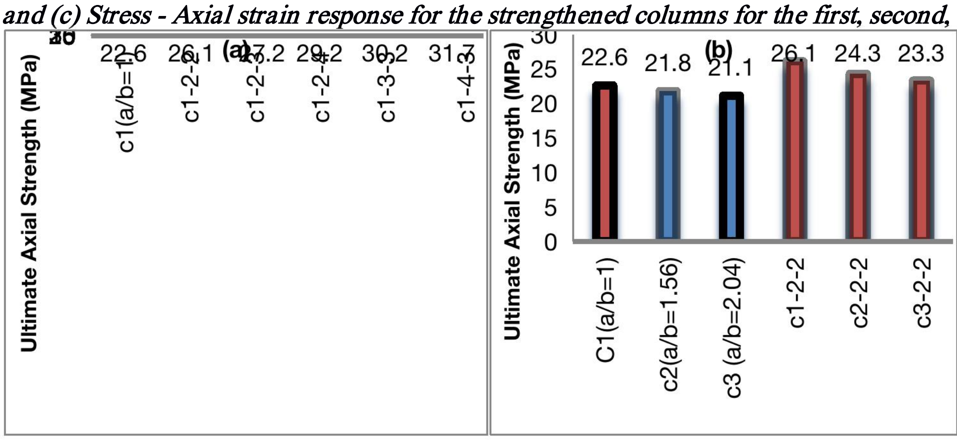


Fig 14. (a) The ultimate axial strength for the first and second group - (b) The ultimate axial strength for the third group.

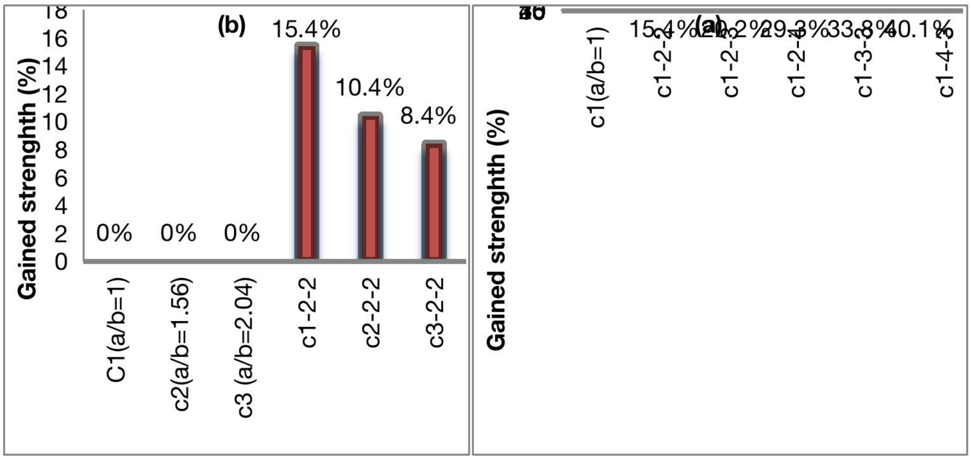


Fig 15. (a)The gained strength for the first and second group - (b)The gained strength for the third group

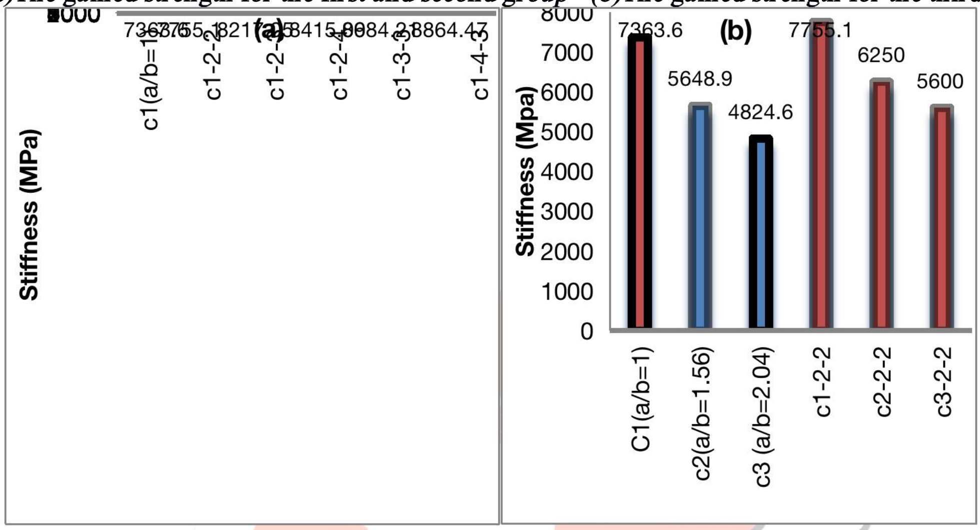


Fig 16. (a)The stiffness for the first and second groups, (b)The stiffness for the third group.

Table 5. Effect of strengthening on the carrying capacity

Group	Specimen ID	t/b	Number of wire meshes	Ferrocement thickness (mm)	F_c (MPa)	p_u (kN)	F'_{cc} (MPa)	F'_{cc} / F_c	% Gained strength
Control columns	C_1	1	……	……	25.5	904	22.6	0.89	-----
	C_2	1.56	……	……	25.1	871	21.8	0.87	-----
	C_3	2.04	……	……	25.0	846	21.1	0.84	-----
1	C_{1-2-2}	1	2	20	25.5	1043	26.1	1.02	15.4%
	C_{1-2-3}	1	2	30	25.72	1086	27.2	1.06	20.2 %
	C_{1-2-4}	1	2	40	25.72	1169	29.2	1.14	29.3%
2	C_{1-2-3}	1	2	30	25.3	1087	27.2	1.08	20.2 %
	C_{1-3-3}	1	3	30	25.3	1209	30.2	1.19	33.8 %
	C_{1-4-3}	1	4	30	26.3	1268	31.7	1.21	40.1 %
3	C_{1-2-2}	1	2	20	25.5	1043	26.1	1.02	15.4 %
	C_{2-2-2}	1.56	2	20	25.4	973	24.3	0.96	10.4 %
	C_{3-2-2}	2.04	2	20	25.85	924	23.3	0.90	8.4 %

*where; F_c: the ultimate axial strength for the standard cube, F'_{cc}: the ultimate axial strength of the specimens confined with ferrocement jacket and control specimens,

$$** \ \% \text{ Gained strength} = \frac{F'_{cc\,(confined\ column)} - F'_{cc\,(control\ column)}}{F'_{cc\,(control\ column)}} \ X100$$

By analyzing **Figures 17** and **18**. It was observed that the ductility and The toughness of the strengthened columns are improved by increasing both the number of wire mesh layers and the ferrocement thickness. However, they decrease as the aspect ratio of the strengthened columns increase.

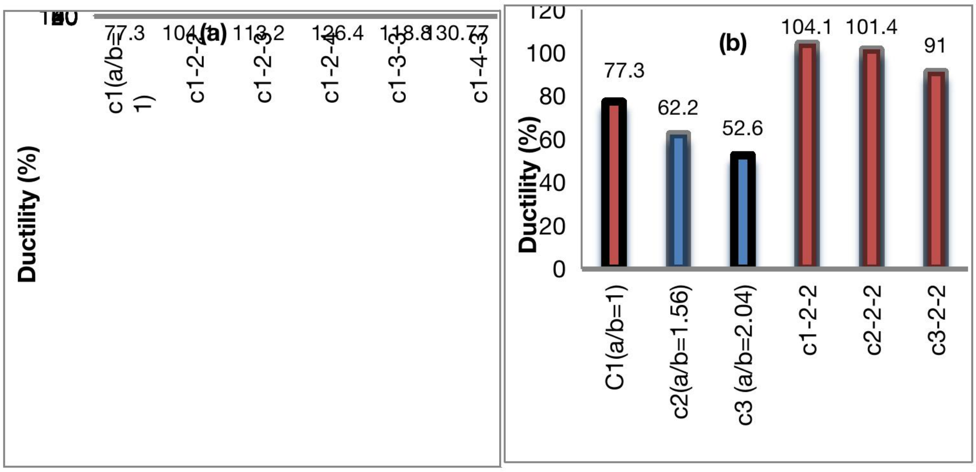


Fig 17. (a)The ductility for the first and second groups - (b) The ductility for the third group.

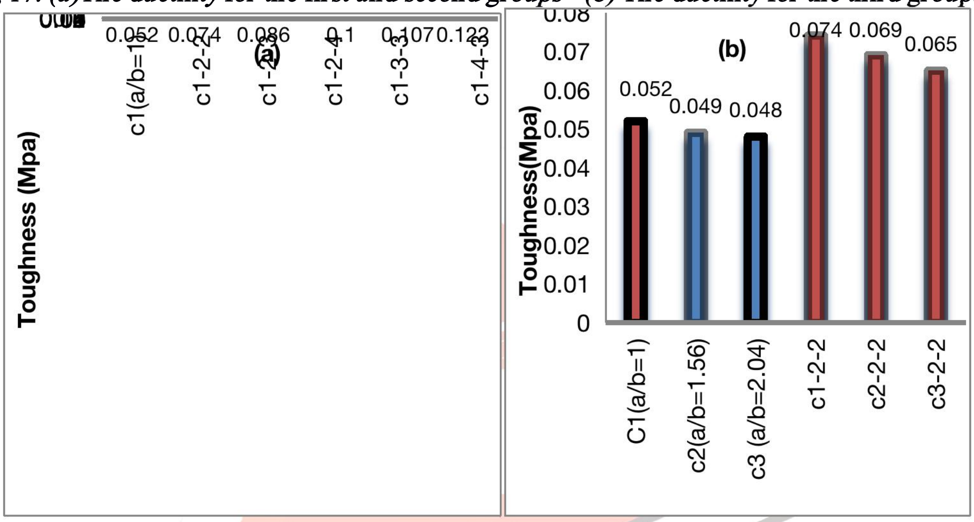


Fig 18. (a) The toughness for the first and second groups - (b) The toughness for the third group.

IV. CONCLUSIONS

This experimental study is carried out to analyze the behavior of RC rectangular short columns strengthened using ferrocement. Based on test results, the following conclusions are obtained:

1. Ferrocement jacketing improves the ultimate load-carrying capacity, stiffness, ductility, toughness, and increases the ultimate axial deformation of R.C columns.
2. Increasing the thickness of the ferrocement jacket from 20 to 40 mm resulted in increasing the gained strength by 15.4 % to 29.3%, using two-wire mesh layers.
3. The experimental results have shown that increasing wire mesh from 2 to 4 layers, for 30 mm ferrocement thickness helps in increasing the gained strength of confined concrete columns by 20.2% to 40.1%.
4. It was observed that increasing the aspect ratio of the cross-section of the tested strengthened columns from 1 to 2.04 for 20mm ferrocement thickness and two-wire mesh layers decrease the gained strength of confined concrete columns by 15.4 % to 8.4 %.
5. The ferrocement jacket is more effective in square sections rather than in rectangular sections.

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