Experimental and Theoretical Behavior of Reinforced Concrete Two Way Slabs Strengthened by Steel Fiber Ferrocement Layers at Tension Zone

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Abstract

An experimental and analytical behavior of strengthened reinforced concrete two way slabs by steel fiber ferrocement layers ,this study included testing 14 simply supported two way slabs, which include 1 control slab, 13 strengthened slabs. In the strengthened slabs the effect of the ferrocement layers with; steel fiber content in the ferrocement mortar of (0.25,0.5,0.75.1.1.25%), thickness of ferrocement layers, the compressive strength for ferrocement mortar and wire mesh layers number of ferrocement was investigated. The mid span deflection at ultimate load and cracks pattern were discussed. All the reinforced concrete slab specimens were designed of the same dimensions and reinforced identically to fail in flexure. Simply supported conditions for all slabs has bean tested under central concentrated load. The experimental results show that; the ultimate loads and mid span deflection of strengthened reinforced concrete slabs were more effected by using the steel fiber on the ferrocement mortar, increasing the thickness of ferrocement and the compressive strength of ferrocement. Three-dimensional nonlinear finite element analysis has been used to conduct the analytical investigation, ANSYS (Version 16.0) computer program was used in this study. The analytical result from modeling in ANSYS program exhibited a good agreement with experimental results.

Keywords: Concrete, Ferrocement, Repair, Slab, Strengthening.

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الخلاصة

تناول هذا البحث دراسة عملية ونظرية لخواص البلطات الخرسانية المسلحة ذات الاتجاهين و المقواة بالفيروسمنت حيث اجريت مجموعة من الاختبارات لدراسة تاثير: تعدد الطبقات للمشبكات الحديدية حيث تم استخدام (1و2و3) طبقات من المشبكات الحديدية ، سمك طبقة الفيروسمنت ، و مقاومة الانضغاط للفيروسمنت على زيادة مقاومة الاثناء للعتبات و مراقبة سلوك الحمل – الهطول بعد التقوية بالإضافة إلى تأثيرها على عرض التشققات. يتضمن الجزء العملي فحص اربعة عشر بلاطة، تم تقوية ثلاثة عشر منها بالفيرو سمنت و تركت بلاطة واحدة بدون تقوية كبلاطة مرجعية. صممت جميع البلاطات الخرسانية المستخدمة في هذا البحث بنفس الابعاد وتم تسليحها بشكل يضمن فشلها بالانحناء، تم فحص جميع البلاطات في فضاء بسيط الاسناد وبتسليط حمل مركز في منتصف هذه البلاطات. أظهرت النتائج العملية التي تم الحصول عليها من النتائج المختبرية أن عملية تقوية البلاطات الخرسانية باستخدام لفيروسمنت ادت الى زيادة في قيمة التحمل الاقصى للانحناء للبلاطات (Ultimate Loads) يصل مقدارها بين (11−22%) مقارنة بالبلاطات الخرسانية غير المقواة باستخدام لفيروسمنت. تم أستعمال التحليل اللاخطي بواسطة العناصر المحددة (Finite Elements) ثلاثية الأبعاد كوسيلة عددية للدراسة والتحري عن سلوك وتصرف هذه البلاطات باستخدام البرنامج (ANSYS الاصدار السادس عشر) حيث تم في هذا البرنامج تمثيل الاجزاء الخرسانية باستخدام العناصر الطابوقية ذات الثمانية عقد (Solid 65).

الكلمات المفتاحية : الخرسانهه ، الفيروسمنت ، تصليح ، السقوف ، التقوية .

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1. Introduction:

Ferrocement was invented by a Frenchman, Joseph Louis Lambot, in 1848 it was a form of reinforced concrete, and it was used for the first time in making boats. Since the 1940s its application in the civil engineering field has widened [Thandavamoorty]. Definition of ferrocement reported by ACI Committee 549 [ACI committee 549-1R-88] is a form of thin reinforced concrete structure in which a brittle cement-sand mortar matrix is reinforced with closely spaced multiple layers of thin wire mesh and /or small diameter rods, uniformly dispersed throughout the matrix of the composite.

2. Fibre reinforced concrete (FRC)

Fibre reinforce may be defined as a composite materials made with Portland cement, aggregate, and incorporating discrete discontinuous fibres. Now, why would we wish to add such fibres to concrete? Plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capcity. The role of randomly distributes discontinuous fibres is to bridge across the cracks that develop provides some post-cracking "ductility". If the fibres are sufficiently strong, sufficiently bonded to material, and permit the FRC to carry significant stresses over a relatively large strain capacity in the post-cracking stage. There are, of course, other (and probably cheaper) ways of increasing the strength of concrete. The real contribution of the fibres is to increase the toughness of the concrete, the strain at peak load, and provide a great deal of energy absorption in post-peak portion of the load deflection curve.

3. Test Program

Fourteen slabs were tested. Slabs which casted as rectangular shape with 800mm width, 80 mm total depth. Each reinforced concrete slab is reinforced with 6Ø10 as a main reinforcement in each way and the six groups were casted; (A-F) as follow:-

• **Group A(Control)**

This group consisted of one specimen; this specimen was the control specimen with normal concrete cover and tested up to failure (SA).

• **Group B**

This group includes five reinforced concrete slabs strengthened with one layer of ferrocement(20mm) thickness and 40Mpa compressive strength (SB1,SB2,SB3,SB4 and SB5), in this group is to study: the different content of the steel fiber on ferrocement mortar(0.25, 0.5, 0.75,1 and 1.25%) .

• **Group C**

This group consisted of two reinforced concrete slabs (SC1 and SC2) with one layer of ferrocement, 40Mpa compressive strength for ferrocement and steel fiber content (0.75%) , this group is to study : the varying of thickness of ferrocement (30 and 40mm) respectively.

• **D Group**

This group consisted of two reinforced concrete slabs(SD1 and SD2) with ferrocement thickness (20mm), steel fiber content (0.75%) and the compressive strength of ferrocement (20 and 30Mpa) respectively.

• **Group E**

This group consisted of two reinforced concrete slabs(SE1 and SE2) with ferrocement thickness (20mm), 40Mpa compressive strength for ferrocement and steel fiber content (0.75%), this group is to study: the varying of the number of ferrocement layers (two layer and three layer) respectively.

• **Group F**

This group consisted of one reinforced concrete slabs (SF1) with ferrocement thickness (20mm), 40Mpa compressive strength for ferrocement and steel fiber content (0%). Fig. 1 &Table 1 show the details of tested specimens.
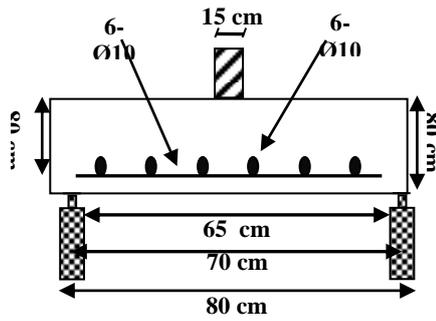
Figure 1.1 Cross section of specimens
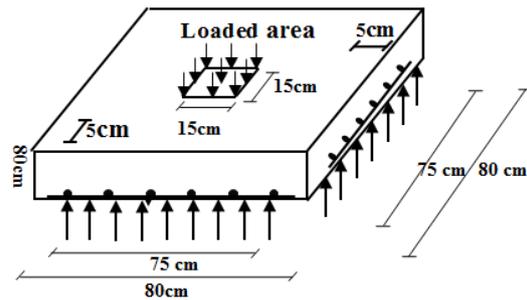
Figure 1.2 Geometry of specimens

Fig. 1 Details of test specimens

Table 1: details of specimen

Group	No. of specimens	Ferrocement thickness (mm)	Total slab thickness (mm)	No. of wire mesh	Fiber content %	Compressive strength of ferrocement mortar
A	A	-----	800	----	-----	
B	SB1	20	800	1	0.25	40.4
	SB2	20	800	1	0.5	40.4
	SB3	20	800	1	0.75	40.4
	SB4	20	800	1	1	40.4
	SB5	20	800	1	1.25	40.4
C	SC1	30	800	1	0.75	40.4
	SC2	40	800	1	0.75	40.4
D	SD1	20	800	1	0.75	20.3
	SD2	20	800	1	0.75	30.5
E	SE1	20	800	2	0.75	40.4
	SE2	20	800	3	0.75	40.4
F	SF1	20	800	1	0	40.4

4. Materials

Maprok Portland cement satisfied the specification (IQS:5/1984)[6 IQS (5)] (Table 2 and Table 3 contain the chemical and physical properties of cement respectively), natural sand and aggregate with the (10 mm) maximum aggregate size that satisfied the specification [ASTM C33-03](see Table 4 and Table 5)are used for the concrete (cement: sand: gravel/water) in the ratio of (1:1.4:2.6/0.47 by weight). The concrete mix was design to give 28-days cylinder strength of 35 MPa [ACI 211]. All slabs were reinforced with six (10mm diameter) tensile steel bars in each direction with yield strength of 551 MPa. For ferrocement mortar (cement: sand /water, super plasticizer, steel fiber), Portland cement and natural sand [ACI Committee 549R-97] were used in the ratio of 1:1.6/0.4by weight. This mortar gives 28-days strength of (40Mpa) with the aid of using super plasticizer (Sika Viscocrete-5W) with a dosage of (0.08% and 0.09 of cement weight). The steel fiber ratios of 0, 0.25, 0.5, 0.75, 1 and 1.25%. of the ferrocement weight were used on the ferrocement mortar. The ferrocement chicken wire of (0.6 mm) diameter was a galvanized welded square mesh of (12.5 mm) openings, the choice square mesh was related to many studies stated that the type of mesh with square opening is better than any other types of mesh (Alniaeeme , 2006). The mesh tested according to the method described in reference (Naaman , 2000) to get its yield strength and it was found to be 360 MPa.

5. Preparation of Test Specimen and Casting

The molds made of plywood were used for casting slabs specimens. For strengthened slabs the ferrocement cover was first placed at the bottom with the required layers of wire mesh and with specific content of steel fiber followed by placing steel reinforcement on the top layers of the ferrocement and then concrete instantaneously placed (see Fig 2). With each specimen, three cylinders (150mm diameter and 300mm height) casted to fined compressive strength of concrete and three (50×50×50mm) cubes casted to fined the compressive strength of mortar, Table (6) includes the concrete compressive strength and mortar for all slabs. All of these tests are conducted in the Structure Laboratories for the College of Engineering in Basrah University.

Table 2: Chemical properties of cement Iraqi specification number (5/1984) .

Composition of cement	(%)	Specification limit
(CaO)	62.83	
AL2O3	5.5	
SiO	22.54	
Fe2O3	2.6	
SO	2.4	2
MgO	3.2	5
(K$_2$O)	0.61	
(Na$_2$O)	0.23	
(L.O.I)	0.73	4.00 (Max.)
(I.R)	0.58	1.50 (Max.)
(L.S.F)	0.91	0.66-1.02
compound of cement		
C3	38.51	31.03- 41.05
C2	33.65	28.61 – 37.9
C3A	10.21	11.96-12.3
C4AF	7.93	7.72-8.02

Table 4: specification of used sand

Sieve size	Passing %	Standard
No. 8	100	100
No. 4	96	95-100
No. 8	85	80-100
No.16	62	50-85
No. 30	46	25-60
No. 50	18	5-30
No. 100	8	2-10
F.M.	2.7	
M.A.S	No.4	
A.S.S.	No.30	
Sp. gr.	2.61	

Table 3: physical properties of cement Finesse Iraqi specification number (5/1984) .

Physical property	Test results	Limit of I.Q.S No. 5/1984
Setting time (Vicat apparatus), hr:min Initial Final	1.43 3.9	00:45 (Min.) 10:00 (Max.)
Compressive strength (70.7mm cube), MPa 3-day 7-day	19.9 25	15 (Min.) 23 (Min.)

Table 5: specification of used gravel

Sieve size In.	Passing %	Standard %
2	100	100
1.5	97	95-100
3/4	66	35-70
3/8	13	10-30
3/16	2	0-5
Pan	0	
F.M.	7.1	
M.A.S	1.5 in	
Sp.gr.	2.64	

Table 6: Properties of concrete and mortar

Properties Slabs	Fc(concrete compressive strength) (MPa)	Fcm (mortar compressive strength) (MPa)
A	32	-----
SB1	33	40.4
SB2	32	40.4
SB3	29	40.4
SB4	30	40.4
SB5	32	40.4
SC1	29	40.4
SC2	33	40.4
SC3	29	20.3
SD1	29	30.5
SD2	30	40.4
SE1	33	40.4
SE2	33	40.4
SF1	32	40.4

Plate. 2: Concrete casting

6. Test Set-up and Instruments:

Fourteen simply supported slabs with a dimension of (800mmx800mmx80mm) and reinforced with 10mm diameter deformed steel bare in each way as shown in plate (2). The machine of 2000 kN capacity was used. The slab was loaded from top at the mid-span. Load was applied in increments, with approximately fifteen load steps to the failure. At each load increment, the total applied load on the slab, mid-span deflection, and crack width were measured. The cracks were plotted and marked. A test was terminated when the total load on the specimen started to drop off. The total time to failure in a test was approximately one hours. Plate. 3 and Plate(4) show the position of transducer, loading point on the slabs. All the slabs were tested using an incremental loading procedure. The mid span deflection of the slab was measured by using dial gauge .
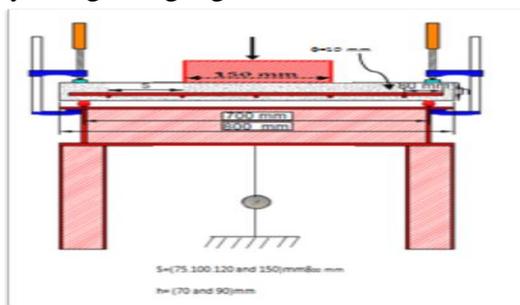
Fig. 3: position of transducer, loading

Fig. 4 : Test procedure

The initial values for deflections, loads were zeroed on the measuring device and the loading system was the assembled in position. These conditions were then considered to represent the initial state of the slabs. Out of these fourteen slabs one are control slabs which are tested after 28 days of curing to find out the load carrying capacity, thirteen strengthened slabs were tested to failure after 28 days of curing to find out the load carrying capacity.

7. Results and discussion
A. Strengthened & Slabs

From Fig.(5.1) to Fig.(5.4) shows the load-deflection curves for strengthened slabs and Table (7) shows the results of the ultimate load for strengthened slabs. In general, slabs with ferrocement mortar content steel fiber exhibited greater stiffness, ductility and ultimate load than the control specimens and specimens without steel fiber content on the ferrocement mortar. This ultimate load increased with: the increase of steel fiber content (7.6,12.9, 14.2, 16.7, 19.6 and 21.2%) when using (0,0.25, 0.5, 0.75, 1 and 1.25%) fiber content, the wire mesh layers (16.7, 19.2 and 22.6%) when using (one layer, two layers and three layers), the ferrocement thickness (16.7, 17.5 and 17.8%) when using (20, 30 and 40mm) ferrocement thickness, the increase of compressive strength of ferrocement (12.1, 14.2 and 16.7%) when using (20, 30 and 40Mpa) compressive strength of ferrocement. From the load deflection curves it can be noticed that the: Increase of , ferrocement thickness has a little effect on the reducing the total deflection as shown in Fig.(5.2) and the deflection decreases due to the instruction of slab was increase than the deflection at ultimate load in control slab. The steel fiber content, the ferrocemen compressive strength, wire measure layers of ferrocement respectively did a significantly reduce the total deflection. The use of steel fiber in ferrocement is very effective in increasing the ultimate load and decreasing the made span deflection.

Table 7: Results of strengthened slabs

Specimen	Ultimate load(KN)	Deflection at ultimate load(mm)
A	47	6.4
SB1	53.06	7.2
SB2	53.67	6.1
SB3	54.84	5.6
SB4	56.21	3.3
SB5	56.09	3.1
SC1	55.22	5.3
SC2	55.36	4.7
SD1	52.68	6.7
SD2	53.67	6.1
SE1	56.02	4.1
SE2	57.62	3.2
SF1	52.31	8.1
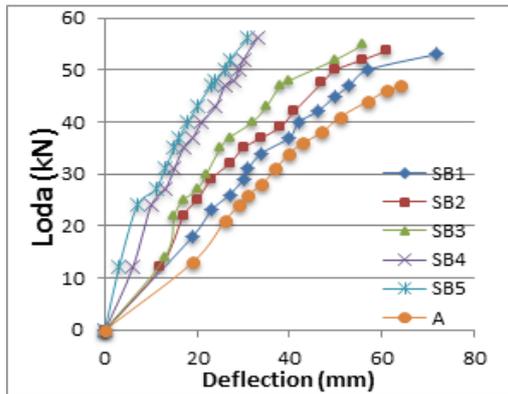
Fig. 5.1 Load mid-span deflection
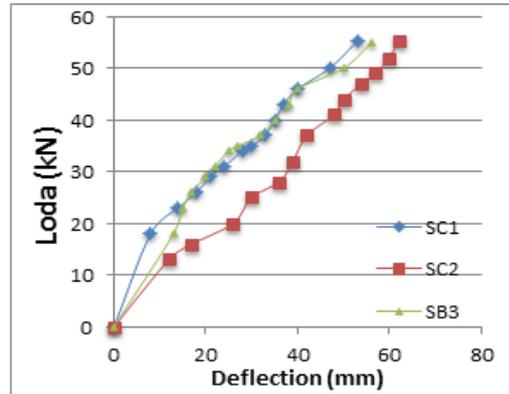
Fig. 5.2 Load mid-span deflection
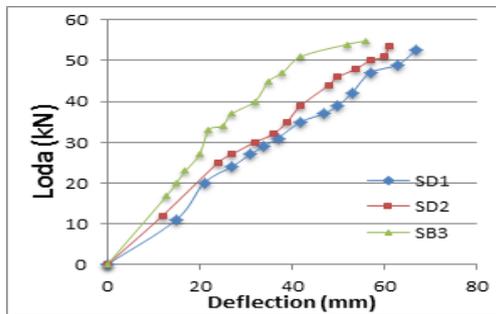
Fig. 5.3 Load mid-span deflection
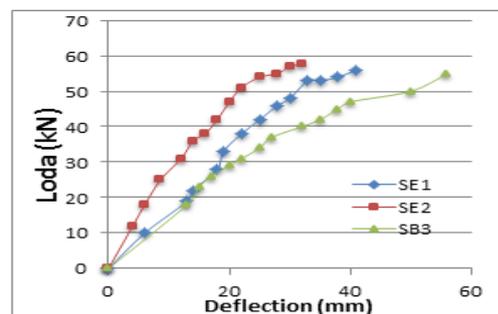
Fig. 5.4 Load mid-span deflection

B. Ultimate load

The ultimate load of strengthen and repaired slabs are given in Table (8).

Table8: Ultimate load of repaired slabs

group No.	Specimen	Ultimate load (kN)	% increase of ultimate load
A	SA	47	----------
	SB1	53.06	12.9
	SB2	53.67 54.534	14.2
	SB3	54.84	16.7
	SB4	56.21	19.6
	SB5	56.09	21.2
C	SC1	55.22	17.5
	SC2	55.36	17.8
D	SD1	52.68	12.1
	SD2	53.67	14.2
	SE1	56.02	19.2
E	SE2	57.62	22.6
F	SF	52.31	11.3

The results above show that the addition of ferrocement caused to increase the ultimate load as shown in Fig. (6). The table shows that the increase of ultimate load compared with the control specimens (SA) is mainly affected by the number of wire mesh layers, steel fiber content on Ferrocement mortar, compressive strength of ferrocement mortar and the thickness of ferrocement. By comparing the results of groups B, C, E and F it may be noted that by using steel fiber on the ferrocement mortar and increasing the number of wire mesh layers a r e more effect than other factors for increasing the ultimate load.
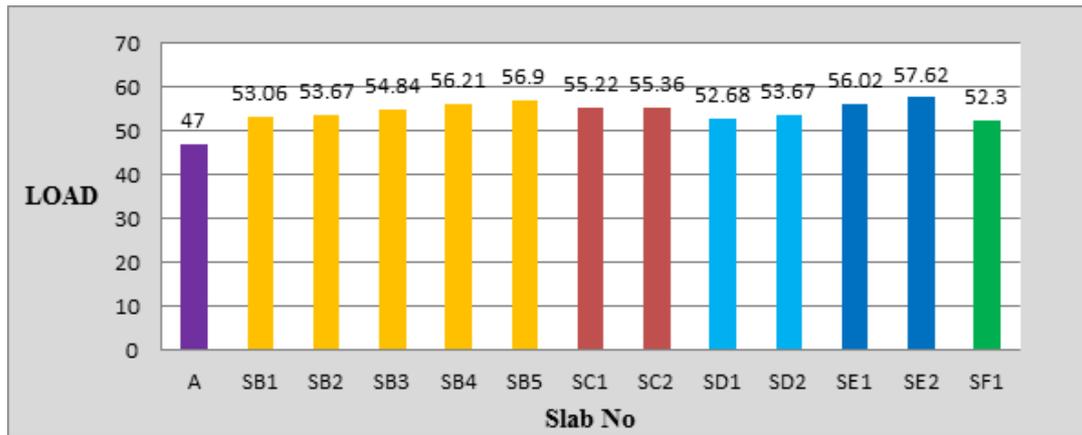
Fig.(6): shows the percentage increase of ultimate load compared to control slab.

C. Crack pattern

For each load increment, the crack width of the slabs at mid span of the slab was measured by means of crack detection pocket microscope. plate (8) shows the crack pattern in all slabs. Where the slabs without ferrocement exhibited considerably larger crack width. From the curves Fig. (9.1) it can be found that the maximum width of the flexural crack at ultimate load level was (0.78 mm) for slab SB1 and the minimum width of the flexural crack at ultimate load level was (0.62 mm) for slab SB1 strengthening with ferrocement strips. Also it can be noted that the presence of ferrocement tends to reduce cracks width even at the same loads compared with reference slab.

It is clear from Table (9) the results that wire mesh layers number, used the steel fiber on ferrocement mortar, compressive strength of ferrocement mortar and the thickness of ferrocement, caused a significant reduce in the cracks width. And this due to the increase in surface of ferrocement reinforcement (interface area) and the increase of compressive strength of mortar led to increase on the stiffness's .On the other hand; increasing of ferrocement thickness from 20mm to 40 mm caused a reduction in the crack width due to the reduction in specific surface of ferrocement reinforcement caused by increasing ferrocement volume and that can be clearly noticed by comparing between (SB3,SC1 and SC2). The use of steel fiber in ferrocement mortar is very effective in decreasing the cracks width plate.(8) shows the crack pattern in all slabs.

Table (9) First cracking loads of the tested slabs

Croup	No. of specimens	First cracking load (kN)	Increase in cracking load(%)
A	SA	14.3	N/A
B	SB1	20.8	31.0
	SB2	22.5	36.0
	SB3	22.7	37.0
	SB4	23.7	39.6
	SB5	24.2	40.9
C	SC1	23.8	39.9
	SC2	24.3	41.1
D	SD1	22.4	36.1
	SD2	22.3	35.8

Slab (A)   Slab (SB1)   Slab (SB2)   Slab (SB3)

Slab (SB4)   Slab (SB5)   Slab (SC1)   Slab (SC2)

Plate 8: Cracks Pattern of Slabs

Slab (SD1)   Slab (SD2)   Slab (SE1)   Slab (SE2)

SF1
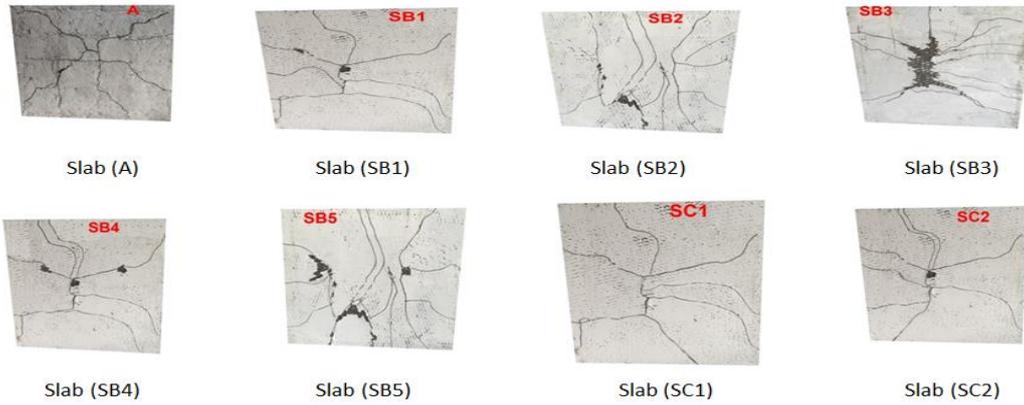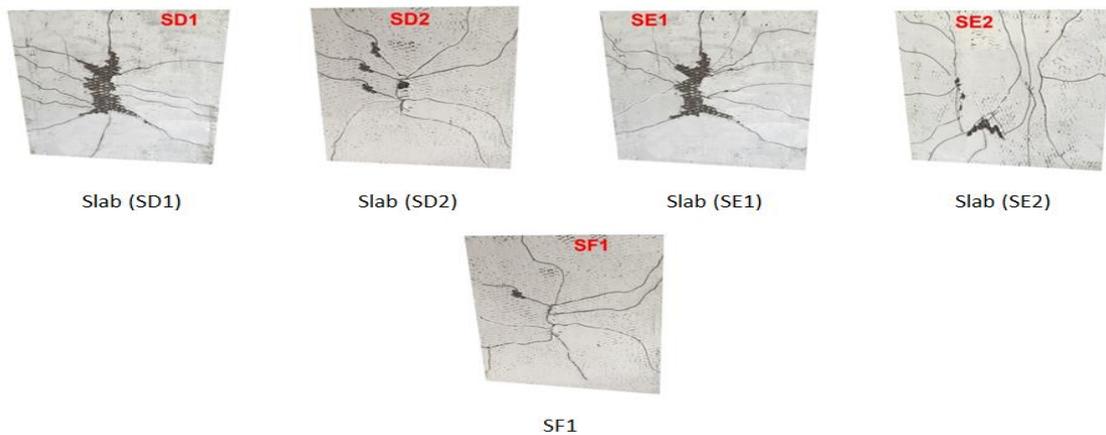
Plate 8: Cracks Pattern of Slabs
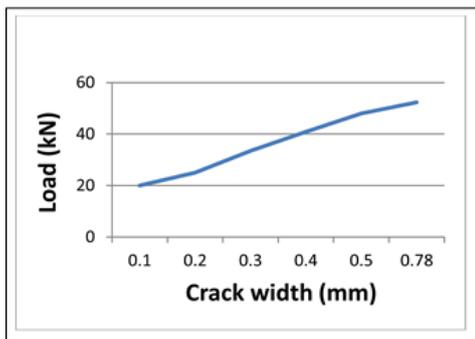
| Fig 9. 1 Crack width versus applied load for slab SB1 | Fig 9. 2 Crack width versus applied load for slab SB5 |
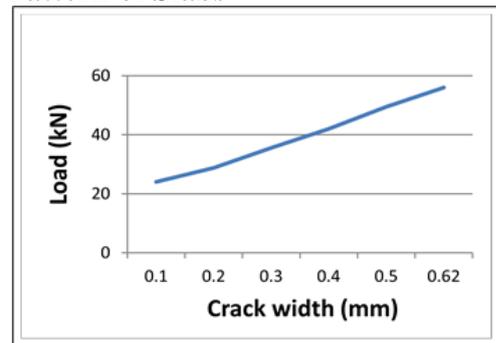
8. Numerical Applications

In parallel with the experimental work , finite element (FE) models were constructed in the ANSYS Version 16.0 program for each of the tested slabs. Material properties which have been used in experimental work for all slabs are adopted in this analysis. The support and loading condition of experimental slabs were simulated in the analytical model by restraining the appropriate degrees of freedom. The displacement in x and y direction are equated to zero for all the nodes at the plane of base of the slab. The concrete of slab was modeled using SOLD 65 element , which is

defined by eight nodes with three degree of freedom at each node –translation in the nodal x,y and z directions and the isotropic material properties . A LINK180 element is used to model the steel reinforcement two nodes. A solid element, SOLID45 is used to model the loading and support plates [SAS2016]. Fine mesh (10mm*10 mm) was provided to simulate the geometry of the analyzed models and to satisfy the requirement of used aliments' aspect ratio. Fig.(10.1) to Fig.(10.4) shows atypical model for one of the analyzed slabs .

A summary of experimental and the finite element is presented in Table 5. Fig 11shows crack patterns for slab specimen and Fig (12.1) to Fig.(12.4) represents the typical load –deflection plot from finite element analysis and experimental results for all slabs**.**

Table (10) : The ultimate load of strength

Series	Specimens designation	P_{ult} Numerical KN	P_{ult} Experimental KN	P_{ult} Numerical/ P_{ult} Experimental
A	SA	51.32	47	1.092
B	SB1	55.34	53.06	1.042
	SB2	56.08	53.67	1.044
	SB3	57.41	54.84	1.046
	SB4	59.02	56.21	1.049
	SB5	59.45	56.09	1.059
C	SC1	60.18	55.22	1.089
	SC2	59.78	55.36	1.079
D	SD1	54.78	52.68	1.039
	SD2	57.05	53.67	1.063
E	SE1	58.37	56.02	1.042
	SE2	59.57	57.62	1.034
F	SF	58.06	52.31	1.11
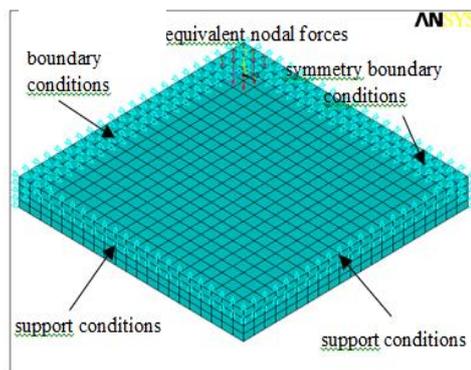
Fig. 10.1 Boundary conditions of symmetry and support
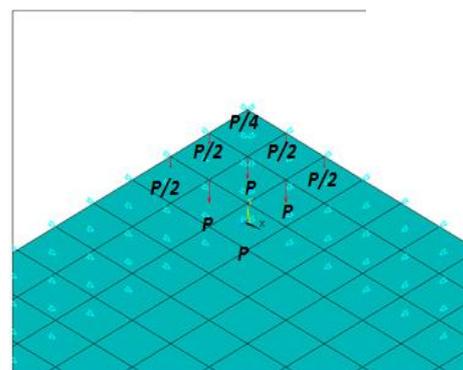
Fig. 10.2 Applied loads arrangement
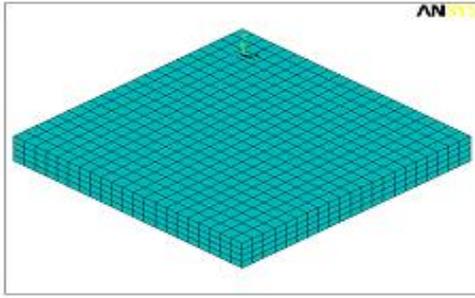
Fig. 10.3: Mesh modeling of tested concrete slab (SC)
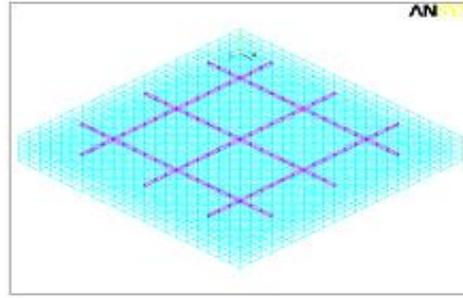
Fig. 10.4: Internal reinforcement arrangement of tested concrete slabs
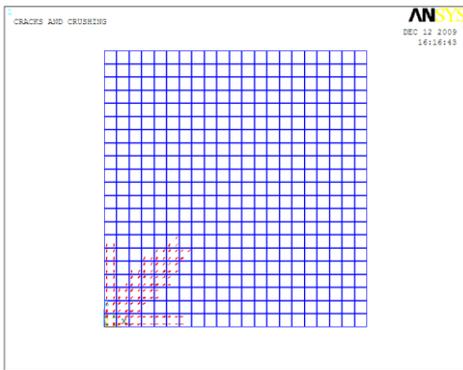
a) At load = 0.232Pu (first crack)
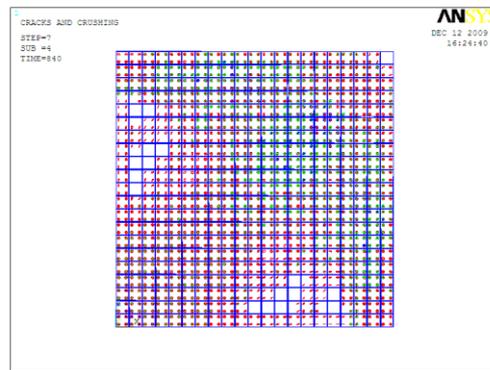
b) At load = 0.562Pu
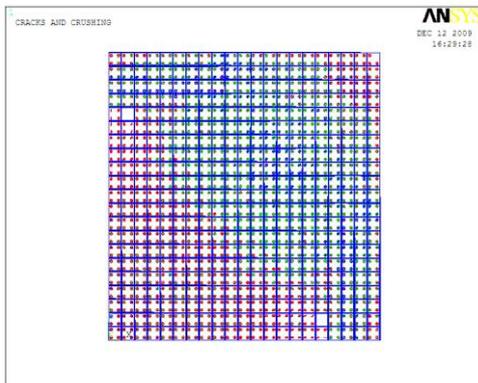
c) At load = 0.81Pu
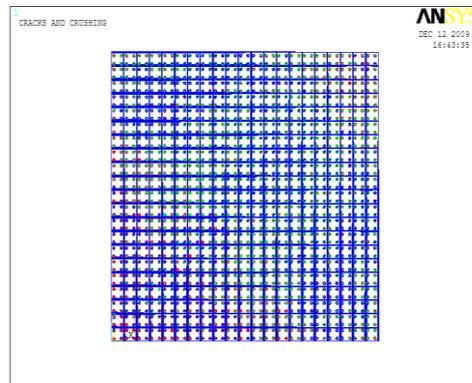
d) At load = 0.97Pu

**Fig. 11: Crack patterns for slab specimen (SA)
(bottom view)**
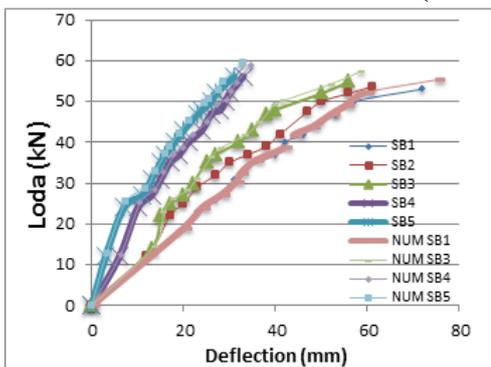
Fig. 12.1 Load mid-span deflection
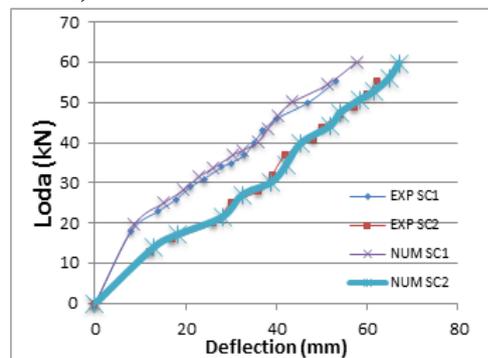
Fig. 12.2 Load mid-span deflection
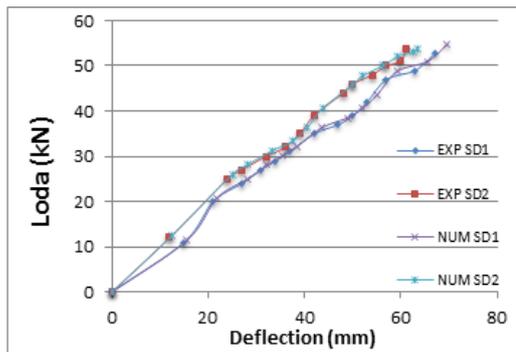
Fig. 12.3 Load mid-span deflection　　**Fig. 12.4 Load mid-span deflection**
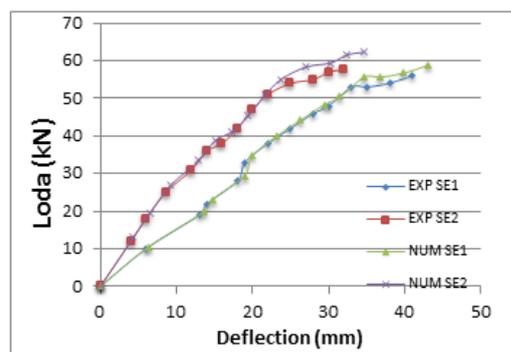
In general , the predicted ultimate load obtained by ANSYS gives a good agreement with experimental result . For the most part slabs , the finite element ultimate load was overestimates than the experimental result by (3.4%-11%) respectively .

9. Conclusion

Based on the results obtained from the experimental and theoretical study, the following conclusions may be drawn out:-
1. Slabs with ferrocement cover exhibited greater stiffness, ductility and ultimate load than the control specimens
2. The major factor that affects the strength of strengthened slabs is the steel fiber on the ferrocement mortar, the compressive strength of ferrocement, number of wire mesh layers of ferrocement and the thickness of ferrocement has only marginal effects.
3. Using the steel fiber on the ferrocement mortar is more effect than other factors for increasing the ultimate load and increasing of wire mesh layers considerably decreased the cracks intensity.
4. The analytical results from modeling in ANASYS program exhibited a good agreement with experimental results(Ultimate load, deflection)
5. The crack patterns at the final loads from the finite element models compared well with the observed crack patterns of the experimentally tested slabs.
6. The ratios of theoretical to experimental values of ultimate loads are between 1.04 to 1.11 for strengthened concrete slabs with ferrocement layers.

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