Flexural Strength of Reinforced Concrete Two way Slabs Strengthened and Repaired by High Strength Ferrocement at Tension Zone

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Abstract:
This paper presents a study of the flexural behavior of strengthened and repaired reinforced concrete two slabs by ferrocement layers. This study included testing 11 simply supported two way slabs, which include 1 control slabs, 8 strengthened slabs and 2 repaired slabs. In the strengthened slabs the effect of the thickness of ferrocement layers, the compressive strength for mortar and number of wire mesh layers of ferrocement on the ultimate load, mid span deflection at ultimate load and intensity of cracks was investigate. In the repaired part the slabs were loaded to (74 %) of measured ultimate load of control slab. The effect of connection method between repaired slabs and ferrocement jacket on the ultimate load, mid span deflection at ultimate load and intensity of cracks was examined. All reinforced concrete slab specimens were designed of the same dimensions and reinforce identically to fail in flexure. All slabs have been tested in simply supported conditions subjected to central concentrated load. The experimental results show that the ultimate loads are increased by about (4.6-19.2%) for the slabs strengthened with ferrocement with respect to the unstrengthened reinforced concrete slab (control slab).

Keywords: Concrete, ferrocement, repair, slab, strengthening.

مقاومة الانثناء للبلاطات الخرسانية المسلحة ذات الاتجاهين المقواة والمصلحة بغطاء من الفيروسمنت عالي المقاومة في منطقة الشد

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الخلاصة
يتضمن البحث الحالي دراسة مقاومة الانثناء للبلاطات المقواة والمصلحة باستخدام طبقة الفيروسمنت تضمنت الدراسة تهيئة و فحص أحدى عشر بلاطة، واحدة كبلاطة مرجعية و ثمانية منها مقواة بالفيروسمنت، اثنان لدراسة فاعلية عملية الإصلاح وبلاطة واحدة تم أخذهما كبلاطات مرجعية. إن المتغيرات التي تمت دراستها في عملية التقوية هي تأثير عدد طبقات المشبكات السلكية حيث تم استخدام (1و2) طبقات من المشبكات السلكية ، سمك الفيروسمنت ، و مقاومة الانضغاط للفيرو سمنت على الحمل الأقصى والأود المقابل له بالإضافة إلى تأثيرها كثافة الشقوق ، أما في حالة الإصلاح فقد تم تسليط (74 %) من الحمل الأقصى المأخوذ من البلاطات المرجعية على البلاطات المراد إصلاحها ودراسة تأثير كل من عدد طبقات المشبكات السلكية ،حيث تم دراسة طريقة ربط الفيروسمنت بالبلاطة ،استخدام اسلوب الربط بواسطة البراغي أو بواسطة الايبوكسي. 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 (4.6-19.2%) مقارنة بالبلاطات الخرسانية غير المقواة باستخدام الياف الكاربون البوليمرية.

1. Introduction:

Slabs are one of the most important parts of the structural construction. They are the members in which the thickness is small compared with the other dimensions and they sustain loads normal to their planes. Concrete slabs are widely used as floors not only in industrial and residential buildings but also as decks in bridges. Slabs may be supported on two opposite only, as shown in figure (1-a), in which case the structural action of the slab is essentially one-way, the loads being carried by the slab in the direction perpendicular to supporting beams. There may be beams on all four sides as shown in Fig.(1-b). On the other hand, one-way slab action may be obtained using intermediate beams, as shown in Fig.(1-c) [1]. It is well known that concrete is a building material with high compressive strength and little tensile strength. A concrete slab without any form of reinforcement will crack and fail when subjected to a relatively small load. The failure occurs suddenly in most cases, and in a brittle manner. The most common way to reinforce a concrete structure is to use steel reinforcing bars that are placed in the structure before the concrete is cast. Since a concrete structure usually has a very long life, it is not unusual for the demands on the structure to change with time. The structure may have to carry larger loads at a later date, or fulfill new standards. In extreme cases a structure will have to be repaired due to an accident. A further reason can be found that errors have been made during the design or construction phase resulting in need for strengthening the structure before usage .If any of these situations will arise; it needs to be determined whether it is more economic to strengthen the existing structure or to replace it. In comparison to building a new structure, strengthening an existing one is often more complicated, since the conditions are already set [2].This study present preliminary investigations of structural behavior of strengthen and repaired concrete two way slab by ferrocement.

1- Test Program

Eleven simply supported slabs were tested. All slabs were rectangular with 800mm width, 80 mm total depth. Each reinforced concrete slab is reinforced with 6Ø10 as a main reinforcement in each way and the specimens were arranged in four groups; (A-D) 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 included six reinforced concrete slabs strengthened with one layer of wire mesh (SB1,SB2,SB3,SB4,SB5 and SB6), in this group is to investigate the effect of varying the thickness of ferrocement (20,30,40 and 50mm) and the compressive strength of ferrocement (20,30 and 40Mpa) .

• Group C

This group consisted of two reinforced concrete slabs with ferrocement (20mm) thickness and 40Mpa compressive strength for ferrocement, this group is to investigate the effect of the repaired of specimens after loaded to (73 %) of the failure load, two specimens are repaired by adding ferrocement with (20 mm) thickness. The connection method between slab and ferrocement are as follows:-:

a) In first specimen (SC1) ferrocement is connected to the bottom face of the slab by (10 mm) diameter bolts spaced at (150 mm c/c) and reinforced with (1) layers of wire mesh as shown in Fig.(1).

b)In the second specimens(SC2), ferrocement is connected to the bottom face of the slab by epoxy and the ferrocement jacket is reinforced by (1) layers of wire mesh.

• Group D

This group consisted of two reinforced concrete slabs with ferrocement (20mm) thickness and 40Mpa compressive strength for ferrocement, in this group is to investigate the effect of varying the number of layers of ferrocement(SD1 two layer, SD2 three layer). Fig. 2 &Table 1 show the details of tested specimens.

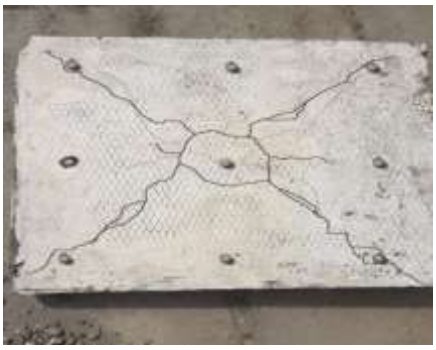

Fig.1: Bolts Connection method

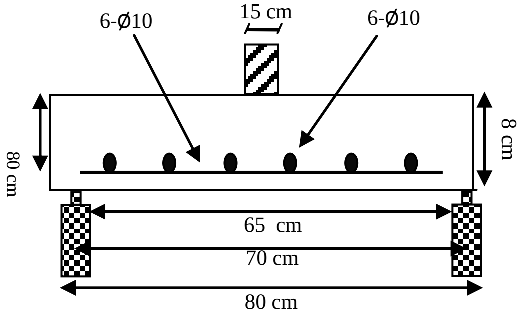

Figure 2.1 Cross section of

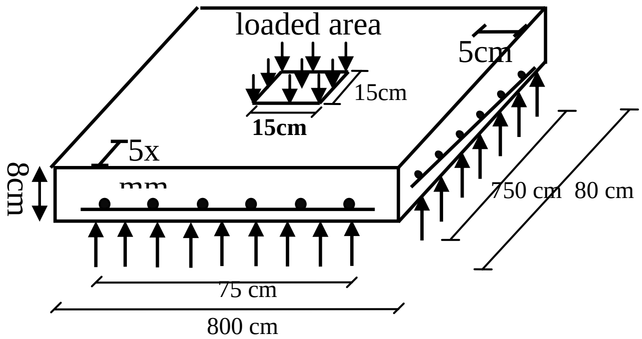

Figure2.2 Geometry of specimens

Table 1: details of specimen

Group	The purpose	No. of specimens	Ferrocement thickness (mm)	Total slab thickness (mm)	No. of wire mesh	Connection method	Compressive strength of mortar
A	Control	SA	-----	800	----	-----	
B	Strengthened	SB1	20	800	1	Epoxy	55
		SB2	30	800	1		55
		SB3	40	800	1		55
		SB4	50	800	1		55
		SB5	20	800	1		21
		SB6	20	800	1		32
C	Repaired	SC1	20	800	1	Bolts	55
		SC2	20	800	1	Epoxy	55
D	The effect of varying the number of layers	SD1	20	800	2	Epoxy	55
		SD2	20	800	3		55

3- Materials

Maprok Portland cement satisfied the specification (IQS:5/1984)[2] (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)[3](see table 4 and table 5)were 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. The main reinforcement used in all slabs consisted of six (10mm diameter) high tensile steel bars in each direction with yield strength of 551 MPa. For ferrocement mortar (cement: sand /water, super plasticizer), Portland cement and natural sand satisfied ACI 549R-97 [4] were used in the ratio of 1:2.7/0.42,1:2/0.4and 1:1.5/0.35by weight. This mortar gives 28-days strength of (21 MPa),(32Mpa) and (55Mpa) with the aid of using super plasticizer (Sika Viscocrete-5W) with a dosage of (0.08% and 0.09 of cement weight). The ferrocement chicken wire was a galvanized welded square mesh of (0.6 mm) diameter and (12.5 mm) openings, the choice of square mesh was related to many studies stated that the type of mesh with square opening is better than any other types of mesh [5]. The mesh tested according to the method described in reference [6] to get its yield strength and it was found to be 360 MPa.

4. Preparation of Test Specimen and Casting

All specimens were cast in molds made of plywood. For strengthened slabs the ferrocement cover was first placed at the bottom with the required number of wire mesh layers followed by placing the slab reinforcement on top of the ferrocement cover and then the concrete instantaneously placed (see Fig 2). For the repaired reinforced concrete slabs (without ferrocement cover), after it was loaded up to (74%) of the failure load which was predicted by the control specimens, was then repaired by epoxy resin because it has been found that roughening the face of slab was not enough to connect the ferrocement and slab tension face [7].With each specimen, three cylinders (150mm diameter and 300mm height) were cast to determine the concrete compressive strength [8] and three (50×50×50mm) cubes were cast to determine mortar compressive strength [9], Table 6 include the compressive strength of concrete and mortar for all slabs. The specimens, were kept covered with wet sacks for 28-day.

Table 2: Chemical properties of cement

Composition of cement	(%)	Specification limit (IQS,5/1984)[23]
AL_2O_3	5.5	3-8
SiO_2	22.54	17-
Fe_2O_3	2.67	0.5-6
SO_3	2.44	2.8
MgO	3.24	5%
compound of cement		
C_3	38.51	31.03- 41.05
C_2	33.65	28.61 – 37.9
C_3A	10.21	11.96-12.3
C_4AF	7.93	7.72-8.02

Table 3: physical properties of cement Finesse

Composition of cement	(%)	Specification limit (IQS,5/1984)[23]
AL_2O_3	5.5	3-8
SiO_2	22.54	17-25
Fe_2O_3	2.67	0.5-6
SO_3	2.44	2.8%
MgO	3.24	5%
compound of cement		
C_3S	38.51	31.03- 41.05
C_2S	33.65	28.61 – 37.9
C_3A	10.21	11.96-12.3
C_4AF	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 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	

Fig 3: Placing the wire mesh and casting the slabs

4- Test procedures

All slabs were tested under squar column having 15 x 15 cm loaded area in the center of slab, the clear span of all slabs is 700mm and instrumented for measuring mid span deflections. Fig. 3 and Fig. 4 show the position of transducer, loading area on the slabs. All the slabs were tested using an incremental loading procedure. Linear variable displacement dial gauge was used to measure the mid span deflection of the slab. 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 eleven slabs one are control slabs which are tested after 28 days of curing to find out the load carrying capacity, eight strengthened slabs were tested to failure, rest of eleven slabs are loaded up to 74 percent of the ultimate load obtained from testing the control slab. After failure for all slabs, the crack intensity were observed.

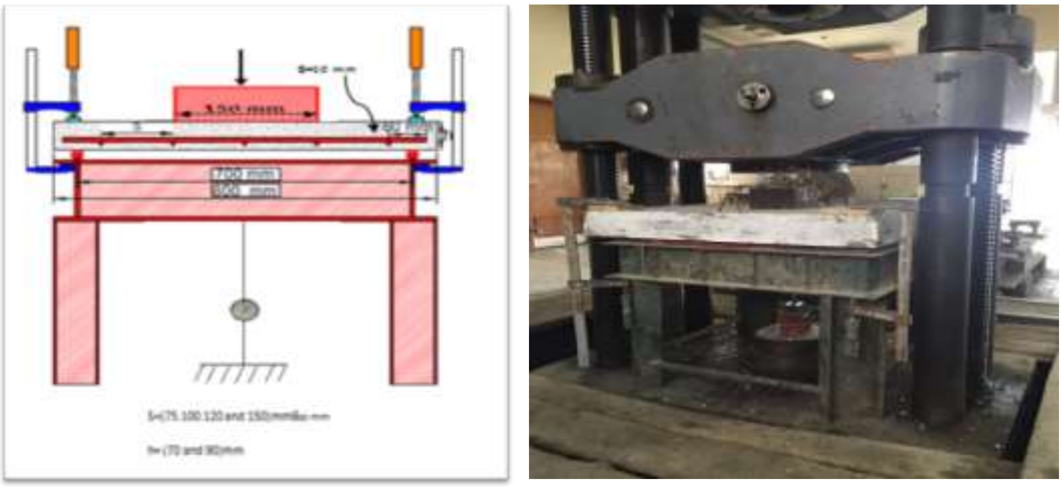

Fig. 4: Test procedure

5. Results and discussion

5.1 Strengthened & repaired slabs:

Fig.(5)shows the load-deflection curves for strengthened and repaired slabs and table (7) shows the results of the ultimate load for repaired and strengthened slabs. In general, slabs with ferrocement cover exhibited greater stiffness, ductility and ultimate load than the control specimens. This ultimate load increased with: the increase of wire mesh layers by (11.3, 17.2, 19.2%) when using (1,2 & 3) wire mesh layers respectively, the increase of ferrocement thickness by (6.5, 11.3, 13.6, 14.7%) when using (20, 30, 40, 50mm) ferrocement layer thickness ,the increase of compressive strength of ferrocement (4.6, 6.5, 11.3%) when using (21, 32, 55Mpa) compressive strength of ferrocement and the connection method between slab and ferrocement(10.3, 11.4%) when using (bolt and epoxy) connection respectively. From

Fig. (5.1) and (5.2) it can be noticed that the: The ferrocement layers thickness and the type of the ferrocement connection (bolt and epoxy) did not significantly reduce the total deflection . The deflection decrease due to the increase of wire mesh layers because the instruction of slab was increase than the deflection in control slab as shown in Fig. (5.3) and (5.4). The increase of wire measure layers and the compressive strength of ferrocement mortar did a significantly reduce the total deflection and the deflection decrease than the deflection in control slab.

Table 7: results of strengthened slabs

Specimen	Ultimate load (kN)	Deflection at ultimate load(mm)
A	47	64
SB1	53	53
SB2	54.4	52
SB3	55.1	49
SB4	55.7	47
SB5	49.3	62
SB6	50.3	58
SC1	52.4	57
SC2	53.1	54
SD1	56.8	50
SD2	58.2	44

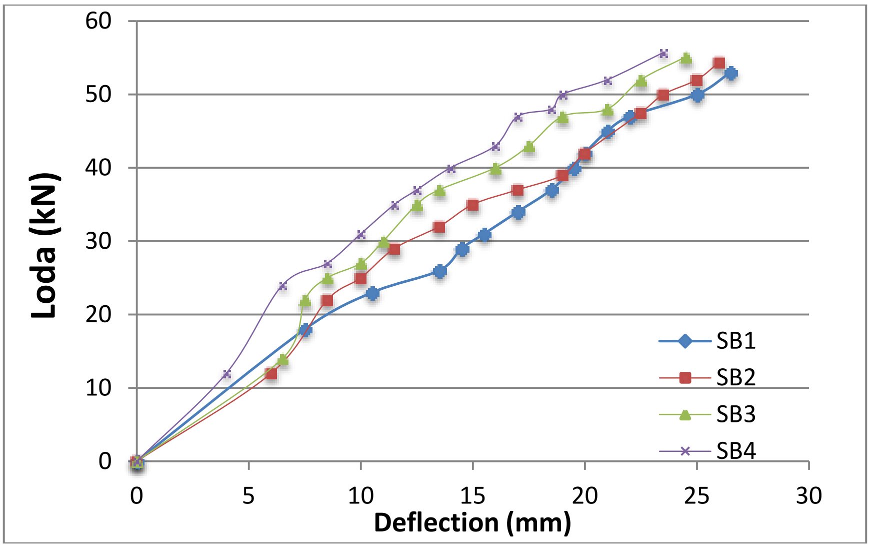

Fig.(5.1) Load versus mid-span deflection

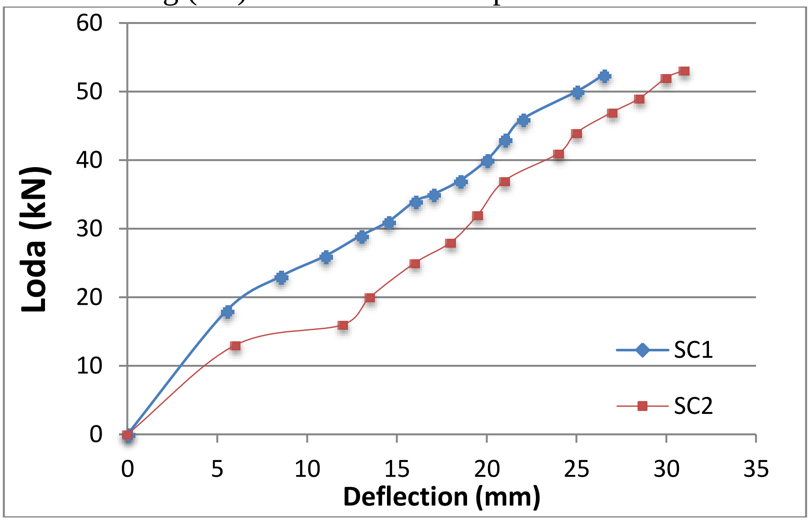

Fig.(5.2) Load versus mid-span deflection

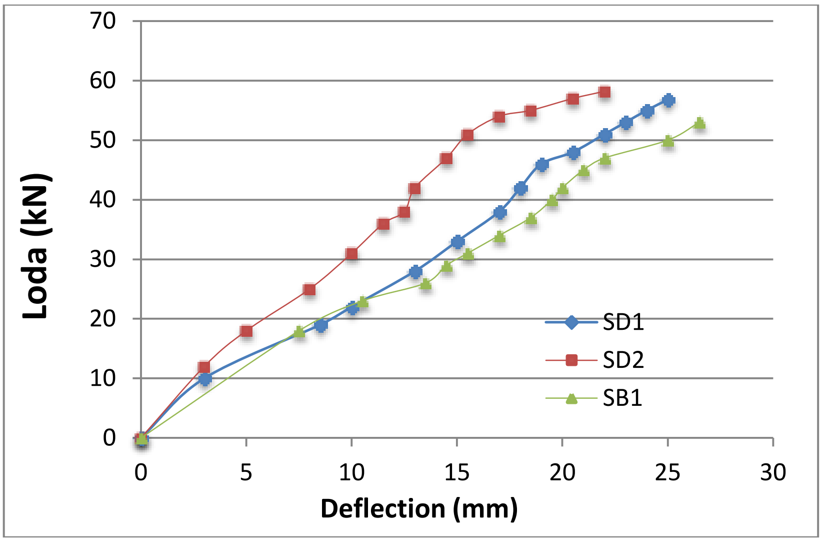

Fig.(5.3) Load versus mid-span deflection

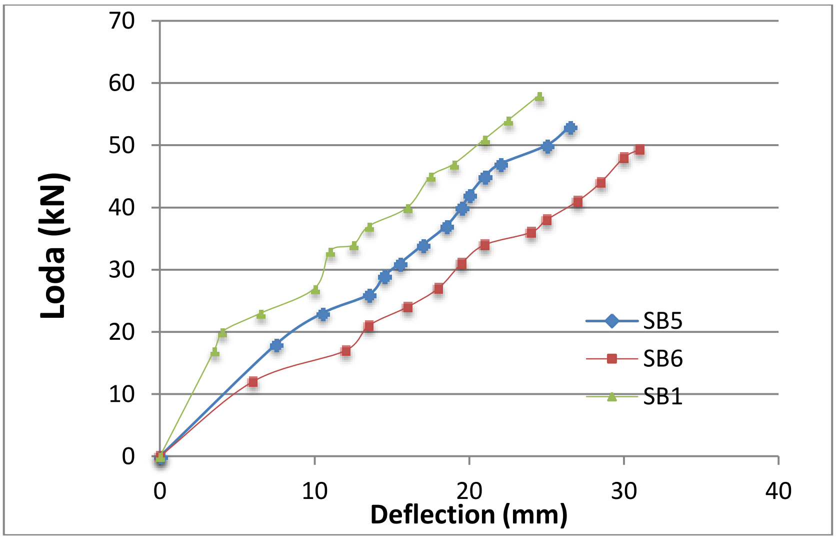

Fig.(5.4) Load versus mid-span deflection

5.2 Ultimate load

The ultimate load of strengthen and repaired slabs are given in Table 8 and fig. 6.

Table8: Ultimate load of repaired slabs

group No.	Specimen	Ultimate load (kN)	% increase of ultimate load
A	SA	47	----------
B	SB1	53	11.3
	SB2	54.4	13.6
	SB3	55.1	14.7
	SB4	55.7	15.6
	SB5	49.3	4.6
	SB6	50.3	6.5
C	SC1	52.4	10.3
	SC2	53.1	11.4
D	SD1	56.8	17.2
	SD2	58.2	19.2

The results above show that the addition of ferrocement not only restored the strength of deteriorated slab but also caused to increase its ultimate strength. 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, compressive strength of ferrocement while the thickness of ferrocement and method of connecting the ferrocement with the reinforced concrete slabs has only a marginal effect on the ultimate load of strengthen and repaired slabs. By comparing the results of group C it may be noted that using epoxy to adhere the ferrocement jacket to the bottom face of the slab gave a higher ultimate load compared with that in which the ferrocement jacket is fixed by steel bolts.

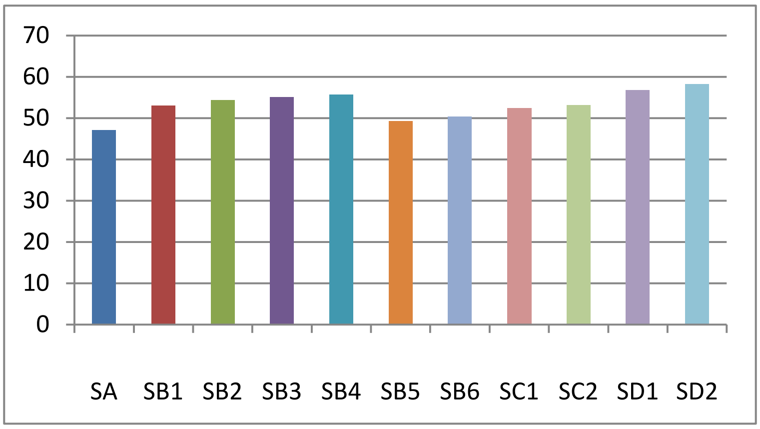

Fig.6: Ultimate load of strengthen and repaired slabs

5.3 Behavior of slab under loading

For the repair and strengthen slabs also showed similar behavior for the control slab, but when the load reached yielding of steel, the ferrocement layer contributed mainly in resisting the loads and increased the stiffness of the concrete slabs up to failure. The failure was usually recorded due to debonding of ferrocement layer sheets from bottom face of slabs specimens which was very suddenly debonding happened as shown in Fig.(7) when using epoxy and by slipping of steel bolt when using the bolts . In repaired slabs, the failure was similar to strengthened slabs, this because of the flexural strength mainly attributed to ferrocement. It is interesting to note that when increasing the numbers of layers all this slabs fail at the same behavior.

Fig.7: Debonding of ferrocement layer

5.4 Cracks intensity

Cracks intensity of slabs computed by taking a photo for slab at failure load using HD digital camera with 16 megapixels and create a diagram of cracks pattern by Photoshop 7.0 program see (Fig. 7), then the cracks intensity was computed by calculating the area of cracks using (MoticImagee 2.0 program) divided by the area of slab face. The cracks intensity for the slabs is given in Table 9. Fig. 8 show the reinforced concrete slab after testing.

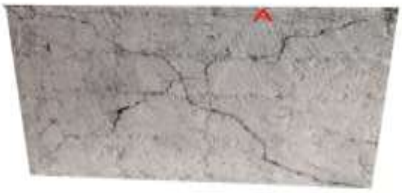

Fig 8: Cracks Pattern of Control Slab (A)

Fig. 9: Slab after testing

Table 9: Cracks intensity for all slabs

Group	The purpose	No. of specimens	Ferrocement thickness (mm)	Total slab thickness (mm)	No. of wire mesh	Conne-ction method	Compressive strength of ferrocement	Cracks intensity (mm^2/mm^2)	% Decrease of cracks intensity
A	control	SA1	-----	800	----	-----		0.0191	--------
B	Strength-ened	SB1	20	800	1	Epoxy	55	0.0179	6.28
		SB2	30	800	1		55	0.0174	8.90
		SB3	40	800	1		55	0.0170	10.99
		SB4	50	800	1		55	0.0162	15.18
		SB5	20	800	1		21	0.0186	2.61
		SB6	20	800	1		32	0.0182	4.71
C	Repaired	SC1	20	800	1	Bolts	55	0.0161	15.7
		SC2	20	800	1	Epoxy	55	0.0153	19.89
D	The effect of varying the number of layers	SD1	20	800	2	Epoxy	55	0.0142	25.6
		SD2	20	800	3		55	0.0125	34.5

It is clear from the results above that the number of wire mesh layers, compressive strength of ferrocement, thickness of ferrocment and any connection method, caused a significant reduces in the cracks intensity. And to show the effect of every parameter (No. of wire mesh, ferrocement thickness, compressive strength of ferrocement and connection method) on the cracks intensity it is necessary to draw the relation between effects of each parameter with the percentage decrease of crack intensity of all slabs as shown in Fig.(10.1) to Fig.(10.3). The conclusion that can be stated from the Fig.(9.1) and (9.2) is that by increasing the number of wire mesh layers and the compressive strength of ferrocement led to decrease cracks intensity, and this due to the increase in specific surface of ferrocement reinforcement (specific surface is the total bonded area of reinforcement (interface area) per unit volume of composite) and the increase of compressive strength of ferrocement led to increase on the stiffness's of ferrocement .On the other hand; increasing of ferrocement thickness from 20mm to 50 mm caused a reduction in the percentage of cracks intensity due to the reduction in specific surface of ferrocement reinforcement caused by increasing ferrocement volume and that can be clearly noticed by comparing between (SB1,SB2,SB3 andSB4) as shown in Fig.(9.3).The connection method was also had a clear effects on cracks intensity and this can clearly be shown when making a comprehension between (SC1 and SC2) . Table 9 shows the reduction in cracks intensity for slabs repaired by ferrocement using epoxy resin as a connection method was higher than that when bolts are used as connection tools.

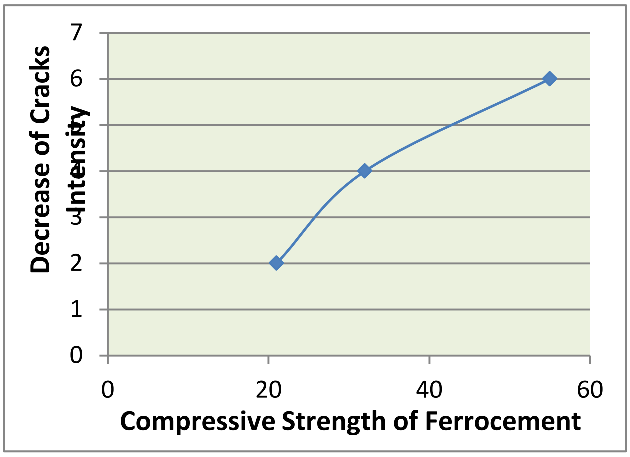

Fig.(10.1) Relation between effects of compressive strength & cracks intensity

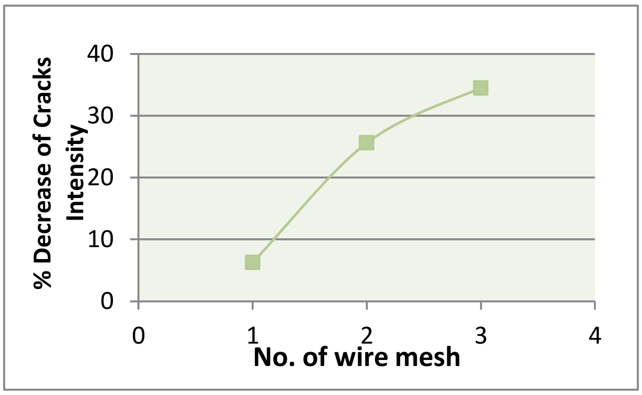

Fig.(10.2) Relation between effects of number of wire mesh & cracks intensity

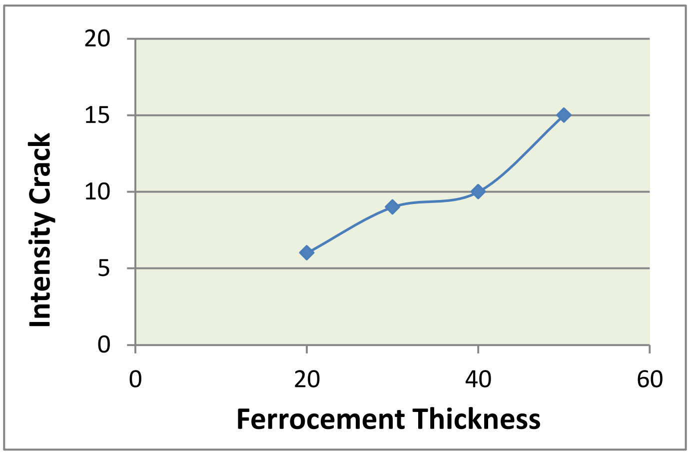

Fig.(10.3) Relation between ferrocement thickness & cracks intensity

6. Conclusion

Based on the test results obtained from the experimental 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 and repaired slabs is the compressive strength of ferrocement,
3- Used a Epox connection method represent batter than Bolt method.
4- The major factor that affects the strength of strengthened and repaired slabs is the number of wire mesh layers of ferrocement and the compressive strength of ferrocement.
5- Increasing the thickness of ferrocement has only marginal effects in enhancing the ultimate load of slabs.
6- Increasing of wire mesh layers considerably decreased the cracks intensity.

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