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Response Of Reinforced Concrete Beams Retrofitted By Ferrocement

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Abstract: In this paper, experimental works is presented to investigate the behavior of reinforced concrete beams retrofitted by ferrocement to increase the strength of beams in both shear and flexure, ten reinforced concrete beams are casted in order to study different parameters such as shear reinforcement (stirrups), different diameters of wire mesh used in rehabilitation, two types of rehabilitation are used first (strengthening) and second (repairing) the beams are initially stressed to a different prefixed percentage of the ultimate load and finally mechanical method is used to fixed the wire mesh of ferrocement (using bolts) to eliminate the debonding of ferrocementand trying to reach the full maximum tensile strength of ferrocement. The experimental results indicated that the rehabilitation technique (strengthening and repairing) of R.C. beams by using ferrocement system is applicable and can increase the ultimate load from (69.8-175% in case of strengthening) and from (50.94-125% in case of repairing), also the test results for strengthening beams showed that the effect of diameter of ferrocement wire mesh (changing from 1.2 to 2.2mm) on the ultimate strength of R.C. beams will have an increase relation from {(95-175% without steel stirrups) and (69.8-126.4% with steel stirrups)}. Also for repairing beams the results state that the effect of diameter of ferrocement wire mesh (changing from 1.2 to 2.2mm) on the ultimate strength of R.C. beams will have an increase relation from {(67.5-125% without steel stirrups) and (50.94-84.9% with steel stirrups)}.

Index Terms: Ferrocement, Rehabilitation, Strengthening, Repairing, R.C.Beams

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1 INTRODUCTION

Reinforced concrete structural components are found to exhibit distress, even before their service period is over due to several causes. Such unserviceable structures require immediate attention, enquiry into the cause of distress and suitable remedial measures, so as to bring the structures back to their functional use again. This strengthening and enhancement of the performance of such deficient structural elements in a structure or a structure as a whole is referred to as retrofitting [1]. Ferrocement as a retrofitting material can be pretty useful because it can be applied quickly to the surface of the damaged element without the requirement of any special bonding material and also it requires less skilled labour, as compared to other retrofitting solutions presently existing. The ferrocement construction has an edge over the conventional reinforced concrete material because of its lighter weight, ease of construction, low self weight, thinner section and high tensile strength which makes it a favorable material for prefabrication also [1].

2 FERROCEMENT

Ferrocement is a composite material consisting of rich cement mortar matrix uniformly reinforced with one or more layers of very thin wire mesh with or without supporting skeletal steel. American Concrete Institute Committee 549, 1988, [2] has defined ferrocement in broader sense as "a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar, reinforced with closely spaced layers of continuous and relatively small diameter mesh". The mesh may be metallic or may be made of other suitable materials. Ferrocement possesses a degree of toughness, ductility, durability, strength and crack resistance which is considerably greater than that found in other forms of concrete construction .These properties are achieved in the structures with a thickness that is generally less than 25 mm, a dimension that is nearly unthinkable in other forms of construction and a clear improvement over conventional reinforced concrete .One can certainly call it a high technology material.

The construction of ferrocement can be divided into four phases:

1. Fabricating the skeletal framing system.
2. Applying rods and meshes.
3. Plastering.
4. Curing phase

Phase (1) and (3) require special skill while phase (2) is very labour intensive. The development of ferrocement evolved from the fundamental concept behind reinforced concrete i.e. concrete can withstand large strains in the neighbour hood of the reinforcement and magnitude of the strains depends on the distribution and subdivision of the reinforcement throughout the mass of concrete. Ferrocement behaves as a composite because the properties of its brittle mortar matrix are improved due to the presence of ductile wire mesh reinforcement. Its closer spacing of wire meshes (distribution) in the rich cement sand mortar and the smaller spacing of wires in the mesh (subdivision) impart ductility and better crack arrest mechanism to the material. Due to its small thickness, the self weight of ferrocement elements per unit area is quit small as compared to reinforced concrete elements. The thickness of ferrocement elements normally ranges from 10mm to 40mm whereas in reinforced concrete elements the minimum thickness used for shell or plate element is around 75mm. Low self weight and high tensile strength make ferrocement a favourable material for fabrication. With the distribution of small diameter wire mesh reinforcement over the entire surface, a very high resistance to cracking is obtained and other properties such as toughness, fatigue resistance, impermeability also get improved. The major differences between a conventional reinforced concrete structural element and a ferrocement member can be enumerated as follows:

1. Ferrocement structural elements are normally consists of thin sections with thickness rarely exceeding 25mm. On the other hand conventional concrete members consist of

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relatively thick sections with thickness often exceeding 100 mm.
2. Matrix in ferrocement mainly consists of Portland cement instead regular concrete consist of coarse aggregate.
3. The reinforcement provided in the ferrocement consists of large amount of smaller diameter wire or wire meshes instead of directly-placed reinforcing bars used in reinforced concrete. Moreover, ferrocement normally contains a greater percentage of reinforcement, distributed throughout the section.
4. In terms of structural behaviour, ferrocement exhibits a very high tensile strength and superior cracking performance.
5. In terms of construction, form work is very rarely needed for fabrication.

Metallic meshes are the most common type of reinforcement , Meshes of alkali resistant glass fibres and woven fabric ,of vegetables fibres such as jute burlaps and bamboo have also been tried as reinforcement [3].

3 EXPERIMENTAL WORK

Shear collapse of reinforced concrete (RC) members is catastrophic and occurs suddenly with no advance warning. On several occasions existing RC members have been found to be deficient in shear. Deficiencies in shear can be due to insufficient shear reinforcement, use of outdated standards or codes, a reduction in the steel area due to corrosion, construction defects and increase in the service load due to change of the occupancy of the building. Conventional shear strengthening methods like external post tensioning, member enlargement along with internal transverse steel, and bonded steel plates are time consuming and complex, also there are a number of laminates like CFRP (Carbon fiber reinforced polymer),GFRP(Glass fiber reinforced polymer), ferrocement etc are being used for retrofitting of structures. Among all the materials ferrocement due to its inherent properties like lighter weight, ease of construction, low self weight, thinner section etc is gaining popularity. Few researchers had used ferrocement laminates for enhancing either the flexural or shear strength of the beam but in actual the beam may need strengthening or repairing in both shear and flexure. Thus in the present study shear deficient beams are cast and grouped into three series named as (C), (S) and (R). Series (C) represents the two control beams, one without shear steel stirrups and another with shear steel stirrups while series (S) focused on strengthening R.C. beams by ferrocement with two types of meshes, first fine mesh (1.2mm diameter of wire mesh) and second large mesh (2.2mm diameter of wire mesh), series (R) fixed on repairing R.C. beams by fine and large meshes of ferrocement after preloaded to 50% and 70% of the ultimate strength of beams. The variables investigated in this work includes shear reinforcement (stirrups), different diameters of wire mesh (1.2 and 2.2mm) used in rehabilitation, two types of rehabilitation are used first (strengthening) and second (repairing) the beams are initially stressed to a different prefixed percentage of the ultimate load (50% and 70%) and finally mechanical method is used to fixed the wire mesh of ferrocement (using bolts) to eliminate the debonding of ferrocement trying to reach the full maximum tensile strength of ferrocement.

4 MATERIALS USED TO FABRICATE THE SPECIMENS

The materials used in this investigation are commercially available materials, which include cement, fine aggregates, coarse aggregates and reinforcing bars are used in designing and casting of R.C. beams, while ferrocement meshes and cement slurry are used for rehabilitation (strengthening or repairing) of these beams. The specifications and properties of these materials are as under:

4.1 CEMENT

Ordinary Portland cement manufactured by (Kufa Cement Plant) product of (Southern Cement State Company) is used throughout the investigation. The cement was kept in closed plastic containers throughout the experimental work to keep the cement in good condition to minimize the effect of humidity. Physical and chemical composition and properties for the used cement are conform to the Iraqi standard No.45/1984 [4] for ordinary Portland cement.

4.2 COARSE AGGREGATE (GRAVEL)

Natural gravel of maximum size 19mm obtained from Al-Nibaey region is used throughout the experimental work. Its grading satisfied the limits of Iraqi standard No.45/1984 [5] for graded gravel.

4.3 FINE AGGREGATE (SAND)

Natural sand from Al-Najaf valleys region was used as fine aggregate. The fine aggregate was sieved at sieve size (4.75mm) to separate the aggregate particle of diameter greater than 4.75mm. The grading test results conform to Iraqi standard No.45/1984 [5].

4.4 STEEL REINFORCING BARS

For all beams, three sizes of steel reinforcing deformed bars are used, 10mm, 8mm and 6mm diameters are used as longitudinal steel. 10mm diameter bars are used as tension reinforcement and 8mm bars are used as compression steel while 6mm diameter bars are used as shear stirrups. The properties of these steel bars are shown in Table (1) that tested in strength of material laboratory (Mechanics Engineering Department in Engineering College, Kufa University).

Table (1) Properties of steel reinforcement

Bar Size	*Yield Stress (MPa)*	*Yield Strain*	*Ultimate Strength (MPa)*	*Ultimate Strain*
Φ10mm	*485*	*0.0025*	*590*	*0.0305*
Φ8mm	*472*	*0.0027*	*560*	*0.0315*
Φ6mm	*465*	*0.0029*	*528*	*0.0326*

4.5 STEEL MESH

Two different sizes of steel wire mesh diameters with square grids are used in ferrocement jacket (2.2 mm and 1.2 mm) to make the strengthening and repairing process of the tested R.C. beam specimens. The properties of these types: large mesh (diameter of 2.2mm) and fine mesh (diameter of 1.2mm) are shown in Table (2). The grid size of mesh was (25X25 mm).

Table (2) Properties of steel mesh wires

Mesh Wire Size	*Yield Stress (MPa)*	*Yield Strain*	*Ultimate Strength (MPa)*	*Ultimate Strain*
Φ2.2mm	*412*	*0.00281*	*518*	*0.0321*
Φ1.2mm	*405*	*0.00286*	*502*	*0.0329*

4.6 CONCRETE MIX

A typical concrete mix proportion by weight is used throughout the present study, the mix used is 1: 2: 4 (cement: sand: aggregate) with a water/cement ratio of 0.5. This mix yielded average compressive strength after 7 days and 28 days is 20 MPa and 30 MPa respectively.

4.7 MORTAR MIX

The range of mix proportion recommended for common ferrocement application are between 1:1.5 to 1:2.5 (cement:sand) by weight, but not greater than 1:3 and water cement ratio by weight, 0.35 to 0.5. In the present study the proportion of (cement:sand) mortar used for the wire mesh of ferrocement is 1:2 (cement: sand and the water-cement ratio for mortar taken as 0.40).

4.8 CEMPATCH SBR400

The (Cempatch SBR400) liquid polymer bonding agent additive for cement containing mixes is used to bonding of new to old concrete when used as slurry coat. SBR400 is single component styrene butadiene rubber latex which is designed to improve the mechanical and physical properties of cement mixes and slurries by effectively increasing the bonding adhesion of cement mixes, tensile, flexural and adhesive strength. Also it is reduces the shrinkage and cracking effect in rehabilitation process of R.C. structural members. In the present study the proportion of (SBR:Cement) used is 10% as weighting ratio.

4.9 BOLTS PROPERTIES

This section describes the mechanical properties of the bolts which are used in this work, the results are shown Table (3).

Table (3) Properties of steel bolts

Bolt Diameter (mm)	*Yield Stress (MPa)*	*Yield Strain*	*Ultimate Strength (MPa)*	*Ultimate Strain*
Φ10mm	*600*	*0.00278*	*740*	*0.0317*

5 SPECIMENS DESCRIPTION

In the present study a total of (10) R.C. beams are cast and cured under laboratory conditions, the specimens are designed considering it to be an under reinforced section. The beam is designed having 2 steel bars of 8mm diameter at compression face and 2 bars of 10mm diameter at tension face. The stirrups used are of 6mm diameter at the spacing of 300 mm which is more than the minimum required spacing, so that the beam should behave as a shear deficient beam. All of the test beams are of the same dimensions (140 mm X 240 mm X 2000 mm) shown in Figures (1) and (2) with reinforcement details, support locations, and location of loads.

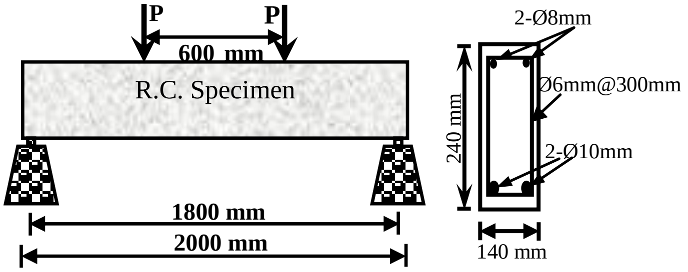

Fig.1 Geometry and cross-section laboratory specimens

6 SPECIMEN IDENTIFICATION AND REHABILITATION SCHEMES

In order to identify the test specimens with different rehabilitation (strengthening and repairing) schemes, the following designation system is used: the variables includes shear reinforcement (stirrups), different diameters of wire mesh (1.2 and 2.2mm) used in rehabilitation, two types of rehabilitation are used first (strengthening) and second (repairing) the beams are initially stressed to a different prefixed percentage of the ultimate load (50% and 70%) and finally mechanical method is used to fixed the wire mesh of ferrocement (using bolts) to eliminate the debonding of ferrocement trying to reach the full maximum tensile strength of ferrocement. Table (4) illustrates the specimen identification system used based on the specimen identification described above, Strengthening and repairing schemes are chosen carefully based on the practical needs and the field conditions.

7 FABRICATION OF THE TEST SPECIMENS

The casting of beams is done in a single stage, the beams are casted in a mould of size 140 x 240 x 2000 mm. First of all the entire beam mould is oiled, so that the beam can be easily removed from the mould after the desired period. Spacers of size 25 mm are used to provide uniform cover to the reinforcement. When the bars have been placed in position as per the design, concrete mix is poured in the mould and vibrations are given with the help of needle vibrator. The vibration is done until the mould is completely filled and there is no gap left. After casting, the molds are left in the laboratory for about 24 hours, then the specimens are removed from their molds. The burlap sacks are placed over the slabs and wetted down. The burlap sacks are monitored and kept wet until the fully twenty-eight days had past.

Table (4) Classifications of beams

Symbol	*shear reinf. (stirrups)*	*Type of wire mesh used*	*Type of rehabilitation*	*Percent of repairing load*
CB1	*without*	*Nil*	*Nil*	*Nil*
CB2	*with*	*Nil*	*Nil*	*Nil*
BS1	*without*	*Fine mesh*	*Strengthening*	*Nil*
BS2	*with*	*Fine mesh*	*Strengthening*	*Nil*
BS3	*with*	*Large mesh*	*Strengthening*	*Nil*
BS4	*without*	*Large mesh*	*Strengthening*	*Nil*
BR1	*with*	*Fine mesh*	*Repairing*	*50%*

BR2	*with*	*Large mesh*	*Repairing*	*70%*
BR3	*without*	*Large mesh*	*Repairing*	*70%*
BR4	*without*	*Fine mesh*	*Repairing*	*50%*

8 INSTRUMENTATION AND TEST SETUP

All specimens are tested in a universal testing machine with a capacity of 2000 kN at the laboratory of structures in Engineering college of Kufa University. The test beams are simply supported over a span of 1800mm rested on stiff steel frame loaded with two-point loads with shear span to depth ratio (a/d) approximately equal to 3. The load is applied vertically and monotonically increasing up to failure and crash at the top face of reinforced concrete beams. Readings of applied load and central deflection are recorded at regular intervals during the tests, (see Figure (2)).

Fig.2 Test setup and instrumentation of beams

9 REHABILITATION OF REINFORCED CONCRETE BEAMS

By using two types of ferrocement meshes (large equal to 2.2mm in diameter and fine equal to 1.2mm in diameter), four beams are strengthened and four beams are repaired after stressed up to a specified limit from the ultimate load (50% or 70%) and then retrofitted by applying the U wrap of steel wire mesh of ferrocement with dimension of (150 x 240 x 1800mm) fixing by mechanical method (using bolts) to eliminate the debonding of ferrocement and trying to reach the full maximum tensile strength of ferrocement. The fixing procedure includes at first cleaning of three sides of beam then drilling the beam along it's width to make many of holes, every one equal to 10mm which is equal to bolt diameter {(8 holes at bottom of beam side spacing at every 25cm and 5 holes at top of beam side spacing at every 45cm)} as shown in Figure (3), the next step is enters the connector bolt of diameter 10mm in each hole with using of two nuts and two washers and tightening together to get perfect fixed of ferrocement mesh on the sides of beam. After this step the plaster layer of cement mortar up to the thickness of 20mm in the form of 1:2 cement mortar (w/c= 0.4) is applied on three faces of beams for all eight beams. Therefore final cross section of beam with ferrocement laminate will become (180 x 260 x 2000 mm). After this the beams are cured for 7 days, then with the same procedure as of control beams, testing of beams is done under two points loading in order to calculate ultimate load and corresponding deflections.

10 RESULTS AND DISCUSSION

Firstly control beams are tested to failure and the data corresponding to it is recorded through data acquisition system. Subgroup control beams (CB) consisted of two control beam specimens, (CB2) had steel stirrups throughout its shear span while beam (CB1) did not. The a/d ratio of these two specimens was taken as approximately 3. The specimen (CB2) failed in shear. Initially there are some flexural small cracks along the beam bottom, the closest crack to the support (in the shear span at the left hand side of the beam) propagated directly towards the nearest loading point, (which is called diagonal shear crack). At the same time a diagonal shear crack formed in the middle of the shear span at the right hand side of the beam .With increasing load additional shear cracks formed throughout the shear span, which are widening and propagating until failure occurred because the right diagonal crack became very wide (the main shear crack) and reached the loading point. Figure (4) shows the crack pattern of specimen (CB2) at ultimate load. In the control beam specimen (CB1) (without shear reinforcement), just few cracks are observed close to the middle of the shear span, it is observed that with little increase of the applied load the single diagonal crack rapidly propagated and became wider. Then collapse happened by splitting the beam into two pieces along the main diagonal crack, Figure (4) shows the failure pattern of the beam specimen (CB1).

Fig.3 Rehabilitation system of reinforced concrete beams

Fig.4 Failure pattern of Beams (CB1) and (CB2)

The differences between the failure of the beams with and without shear reinforcement are as follows, the failure load is only slightly greater than the diagonal cracking load in the case of the beam without shear reinforcement (CB1). Also, there are few diagonal cracks which caused the separation of the beam or by splitting the concrete around the main reinforcement near the support if the development length of the main reinforcement (hooks) is not adequate. While beams (CB2) with steel stirrups failed by diagonal shear crack because the shear reinforcement is not enough but sudden failure do not happen (explosively) and the beam continued carrying the applied load even after many diagonal shear cracks are observed. At higher applied load one of the diagonal cracks propagated to reach the nearest loading point and sudden failure happened. The stirrups provided a better distribution of diagonal cracks throughout the shear span, see Figure (5).

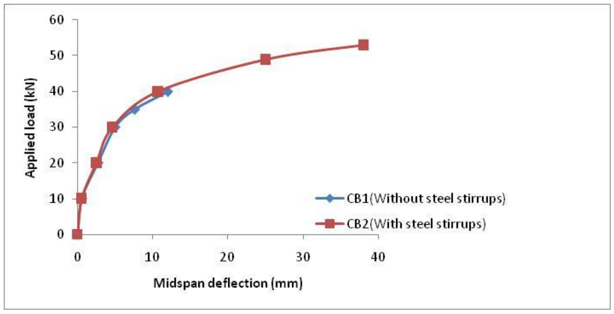

Fig.5 Load- deflection relationship of Beams (CB1) and (CB2)

10 COMPARISON OF STRENGTHENED AND CONTROL BEAMS

The effect of using fine mesh (1.2mm) and large mesh (2.2mm) of ferrocement diameter mesh in strengthening of two types of R.C. specimens (first with and second without steel stirrups) is shown in Figures (6) and (7). It is observed from the experimental data and the corresponding graph that strengthening leads to increase in the ultimate load carrying capacity from (40kN) for (CB1) to (78kN) for (BS1) (strengthening with fine mesh) and to (110kN) for (BS4) (strengthening with large mesh) respectively. While for the case of R. C beam with steel shear stirrups the strengthening process leads to increase the ultimate load from (53kN) for (CB2) to (90kN) for (BS2) (strengthening with fine mesh) and to (120kN) for (BS3) (strengthening with large mesh) respectively. The deflection corresponding to ultimate load of (BS1) of (78kN) is (14mm) as compared to (12mm) for the (CB1) at (40kN). Also for the (BS4) specimen exactly similar trend is observed and the deflection is (17mm) at ultimate load of (110kN) compared to (12mm) for the (CB1) at (40kN). By similar the deflection corresponding to ultimate load of (BS2) of (90kN) is (42mm) as compared to (38mm) for the (CB2) at (53kN). Also for the (BS3) specimen exactly similar trend is observed and the deflection is (45mm) at ultimate load of (120kN) compared to (38mm) for the (CB2) at (53kN). Thus there is an increase in ultimate load of (95%) for (BS1) and (175%) for (BS4) comparing with (CB1) respectively. Also by similar there is an increase in ultimate load of (69.8%) for (BS2) and (126.4%) for (BS3) comparing with (CB2) respectively. The failure pattern of specimens (BS1), (BS2), (BS3), and (BS4) are shown in Figure (12).

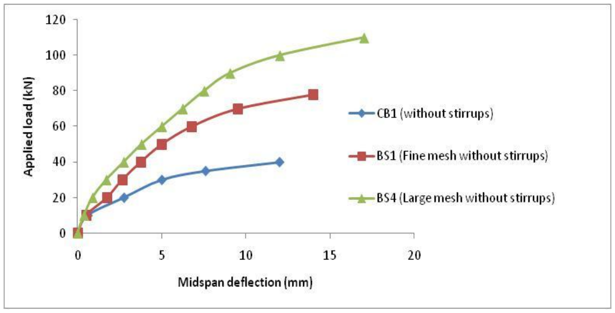

Fig.6 Load- deflection relationship of Beams (CB1), (BS1) and (BS4)

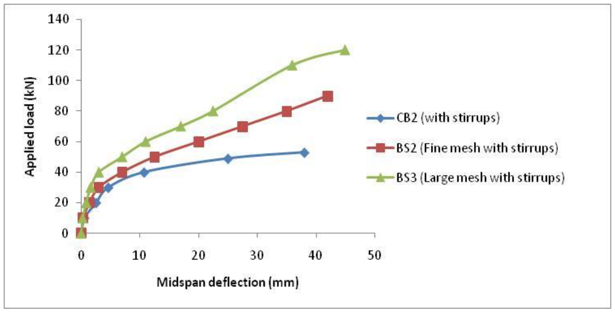

Fig.7 Load- deflection relationship of Beams (CB2), (BS2) and (BS3)

11 COMPARISON OF REPAIRED AND CONTROL BEAMS

The effect of using fine mesh (1.2mm) and large mesh (2.2mm) of ferrocement diameter mesh in repairing of two types of R.C. specimens (first with and second without steel stirrups) is shown in Figures (8) to (11). It is observed from the experimental data and the corresponding graph that repairing leads to increase in the ultimate load carrying capacity from (40kN) for (CB1) to (78kN) for (BS1) (strengthening with fine mesh) and to (67kN) for (BR4) (repairing with fine mesh and preload to 50% of ultimate load) respectively. Also it can observed that repairing process leads to increase the ultimate load from (40kN) for (CB1) to (110kN) for (BS4) (strengthening with large mesh) and to (90kN) for (BR3) (repairing with large mesh and preload to 70% of ultimate load) respectively. While for the case of R. C beam with steel shear stirrups the repairing process leads to increase the ultimate load from (53kN) for (CB2) to (90kN) for (BS2) (strengthening with fine mesh) and to (80kN) for (BR1) (repairing with fine mesh and preload to 50% of ultimate load) respectively. Also it can observed that repairing process leads to increase the ultimate load from (53kN) for (CB2) to (120kN) for (BS3) (strengthening with large mesh) and to (98kN) for (BR2) (repairing with large mesh and preload to 70% of ultimate load) respectively. The deflection corresponding to ultimate load of (BR4) of (67kN) is (12.85mm) as compared to (12mm) for the (CB1) at (40kN). Also for the (BR3) specimen exactly similar trend is observed and the deflection is (15.44mm) at ultimate load of (90kN) compared to (12mm) for the (CB1) at (40kN). By similar the deflection corresponding to ultimate load of (BR1) of (80kN) is (39mm) as compared to (38mm) for the (CB2) at (53kN). Also for the (BR2) specimen exactly similar trend is observed and the deflection is (40mm) at ultimate load of (98kN) compared to (38mm) for the (CB2) at (53kN). Thus there is an increase in ultimate load of (67.5%) for (BR4) and (125%) for (BR3) comparing with (CB1) respectively. Also by similar there is an increase in ultimate load of (50.94%) for (BR1) and (84.9%) for (BR2) comparing with (CB2) respectively. The failure pattern of specimens (BR1), (BR2), (BR3), and (BR4) are shown in Figure (12).

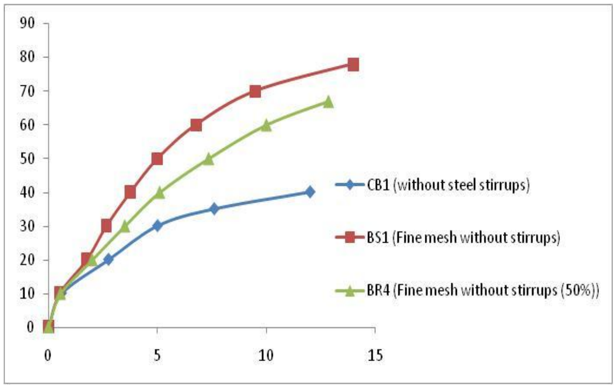

Fig.8 Load- deflection relationship of Beams (CB1), (BS1) and (BR4)

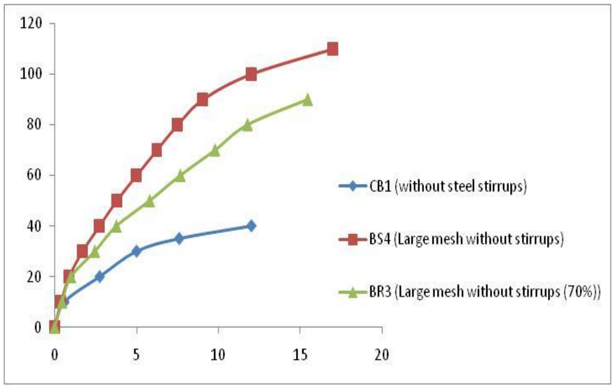

Fig.9 Load- deflection relationship of Beams (CB1), (BS4) and (BR3)

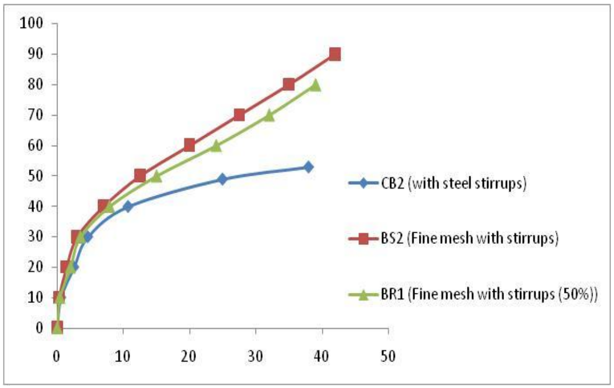

Fig.10 Load- deflection relationship of Beams (CB2), (BS2) and (BR1)

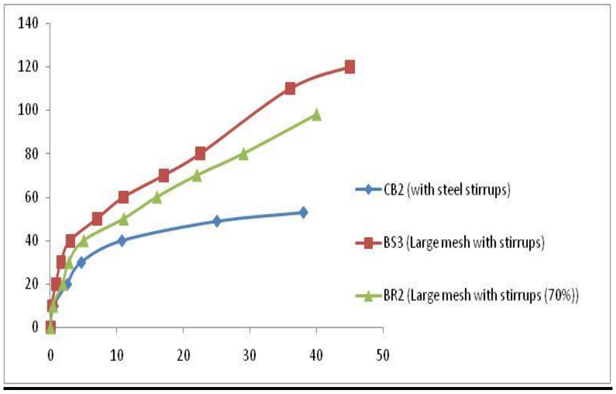

Fig.11 Load- deflection relationship of Beams (CB2), (BS3) and (BR2)

Fig.12 Failure pattern of strengthened and repaired beams

12 Conclusions

The most important conclusions that can be drawn from the present paper are:

1- The rehabilitation technique (strengthening and repairing) of R.C. beams by using ferrocement system is applicable and can increase the ultimate load from (69.8-175% in case of strengthening) and from (50.94-125% in case of repairing) compared with the unritrofitted (control) beams.

2- The test results for strengthening beams showed that the effect of diameter of ferrocement wire mesh (changing from 1.2 to 2.2mm) on the ultimate strength of R.C. beams will have an increase relation from {(95-175% without steel stirrups) and (69.8-126.4% with steel stirrups)}.

3- For repairing beams the results state that the effect of diameter of ferrocement wire mesh (changing from 1.2 to 2.2mm) on the ultimate strength of R.C. beams will have an increase relation from {(67.5-125% without steel stirrups) and (50.94-84.9% with steel stirrups)}.

4- The use of ferrocement meshes as external strengthening or repairing have a significant effect on crack pattern of the reinforced concrete beams by delaying the crack appearance and reducing the crack width, also causing in large deflection at the ultimate load.

5- Same behavior is noticed for the reinforced concrete beams strengthened or repaired with using ferrocement system, furthermore the ultimate load increases in both the strengthened or repaired beams, but the percentage of increase by strengthened is more than that in the repaired specimens with same conditions.

6- The failure of composite is characterized by development of shear and flexural cracks over the tension zone, the spacing of cracks is reduced for beams retrofitted with large wiremesh of ferrocement indicating better distribution of stress compared with the specimens retrofitted with small wiremesh of ferrocement.

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