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EXPERIMENTS ON FLEXURAL STRENGTHENING OF REINFORCED CONCRETE BEAMS USING VALID STRENGTHENING TECHNIQUES

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Abstract

This study aims to evaluate the efficiency of strengthening reinforced concrete beams using some valid strengthening materials and techniques. Using concrete layer, reinforced concrete layer and steel plates are investigated in this research. Experiments on strengthening beam samples of dimensions 100x150x1100mm are performed. Samples are divided in to three groups. Group "A" is strengthened using 2cm thickness concrete layer only (two types). Group "B" is strengthened using 2cm thickness concrete layer reinforced with meshes (steel and plastic). Group "C" is strengthened using steel plates. The initial cracking load, ultimate load and crack pattern of tested beams are illustrated. The experimental results show that for group A and B, the ultimate strength, stiffness, ductility, and failure mode of RC beams, with the same thickness strengthening layer applied, will be affected by the mesh type, type of concrete layer. While for group C, these parameters affected by the fixation technique and adhesion type.

Keywords: strengthening; Reinforcing mesh; Steel plate; Reinforced; Concrete; Beam.

1. Introduction

The repairing and strengthening processes are aims to improve the performance of the concrete members, restore and increase the strength and stiffness of the concrete, improve the appearance of the concrete surface, increase water tightness, prevent access of corrosive materials to the reinforcing, and improve the overall durability of the concrete members.

The proper repair of deteriorating concrete structures based on the careful evaluation of the causes, consequences of the deterioration, and the repair or strength techniques, procedures, and materials used. The cost and ease of application as well as the efficiency of the repair process are major considerations in choosing the materials and techniques [1, 2]. A strengthened or damaged structure can retrofitted to a satisfactory level of performance at a reasonable cost by different methods. Repairing or strengthening concrete beams by applying repairing technique on the tension face of the beam (such as using reinforced concrete layer [3, 4], Ferrocement layer [5, 6], steel plates [2] and FRP wrap laminates [7-10]) considered as one of the common used repairing or strengthening techniques for beams. The main objective of using beneath layer is to increase the load capacity of concrete beam. Depending on the type of wrap layer used, an increase in stiffness and strength obtained. As any other strengthening or repairing technique, the design of the beneath layer should include the probable extra loads affecting on the beam and the bond between repairing material and

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concrete face. The compressive strength of the new concrete should be not less than that of the existing structure [11].

That technique can apply by several methods. Generally, the concrete beam lower face wrapped with a repairing layer bonded to the tension face of beam [12].

Ferrocement is an ideal material for rehabilitation and strengthening of structures because it improves crack resistance combined with high toughness, the ability to be cast into any shape, rapid construction with no heavy machinery, small additional weight it imposes and low cost of construction [4, 5, 6].

Repair and strengthening using steel plates consider as one of effective rehabilitation methods. Plate end anchorages have a greater effect in beams that are shorter, with a high ratio of shear force to bending moment, than in longer beams. Anchorage is usually provided by anchor bolts or bonded cover plates (Hussain et al. 1995) [2]. The method of strengthening reinforced concrete beams by mechanically attaching an FRP strip not only has the advantage of being rapid, but also provides the necessary anchoring mechanism as part of the procedure. The use of multiple small fasteners as opposed to large diameter bolts distributes the load more evenly over the strip.

Using crack injection method, as individual technique or together with other repairing methods, enhance the load capacity of concrete member. It mainly used to achieve the performance of beams to improve the flexural and shear performance.

A comparison between four methods of repair (epoxy injection, ferrocement, steel-plate bonding, and combined method of epoxy injection and ferrocement) indicated that the beams repaired by ferrocement layer, plate bonding and a combined method exhibited higher flexural strength than did the original beam. Beams repaired by epoxy injection showed the same flexural strength and cracking behavior as the original beams. The beams repaired by ferrocement layer or epoxy injection in combination with a ferrocement layer exhibited superior cracking behavior in the form of a higher number of cracks, and cracks finer than in the original beams. The ductility of beams repaired by plate bonding was reduced significantly, which can lead to sudden failure, which can be circumvented, to a degree by adjusting the design of the steel plate to insure failure that is more ductile [4].

The repair of reinforced concrete beams using ferrocement laminates as a variable alternative to steel plates, which are directly glued to the cracked tension face of the beam by epoxy resin. The test specimens were firstly loaded up to 85% of the ultimate load of the control specimen. After unloading, the damaged specimens were repaired using three different repair schemes and then retested. The experimental results of the repaired beams showed that irrespective of the pre-loading level or the repair method, better cracking behavior of test specimens could be achieved. Under short-term loading conditions, all repaired specimens exhibited more than their original ultimate strengths. The ductility ratio and the energy absorption properties were improved also by this method of repair. It was found that, the ultimate strength of the repaired specimens is affected by the level of damage sustained prior to repairing also, all repaired beams achieved higher strength than the original ultimate strengths [5, 6].

2. Research Significance

This research aims to evaluate the efficiency of using three valid strengthening techniques used for flexural strengthening of beams. The first is based on using concrete layer while the second is based on using mesh reinforced concrete layer and the third is based on using steel plates. The main variables in this investigation are; strengthening technique (concrete layer, reinforced concrete layer and steel plates), concrete layer type (C1S and C2S), mesh type (plastic and steel), mesh dimensions (MS1, MS2, MP1 and MP2) and steel to concrete cohesion material (Sikadur-31CF and Kemapoxy 165).

The initial cracking load, ultimate load and crack pattern of tested beams are illustrated. The flexure strength and deflection values are evaluated and the results are used to judgment the feasibility of using each strengthening type. The influence of the strengthening type and cost is investigated.

The importance of this research is to providing sufficient data for the researchers and engineers that concerns in the field of behavior and cost of available strengthening techniques.

3. Experimental Program

All performed tests in this study were carried out in the Laboratory of Construction Materials in Civil Engineering Department, Faculty of Engineering Science, Sinai University. The materials used, preparing, cast of tested specimens as well as testing procedures are described in this part. Strengthening materials and technique are also discussed.

3.1. Materials Properties

The fine aggregate used in the experimental program was the natural siliceous sand. Its characteristics satisfy the Egyptian Standard Specification (E.S.S. 1109/2008). It was clean and nearly free from impurities with a specific gravity 2.6 t/m^3 and a fineness modulus of 2.7.
The coarse aggregate used was crushed dolomite, which satisfies the ASTM C33 Specification with a specific gravity 2.70 t/m^3 and a fineness modulus of 6.64. The shape of these particles was irregular and angular with a very low percentage of flat particles. The delivered crushed dolomite was size 2, which was available with a maximum nominal size of 12.5 mm.
The cement used was the ordinary Portland cement, from the Suez cement factory. Its chemical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 4756-1/2009).
The water used is a clean drinking fresh water. It used for mixing and curing. It was free from impurities. It meets the requirements of the Egyptian Concrete Code of Practice (E.C.P. 203/2007). A water to cement ratio of 0.5 is used.
High tensile deformed steel bars were produced from the Ezz Al Dekhila Steel, Alexandria. Its chemical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/2011). High tensile deformed steel bars (nominal diameters 10 mm) were used in reinforcing all the concrete beams, there yield stress was 360 MPa and there tensile strength was 520 MPa.
Mild steel bars of 8 mm diameter were used as stirrups and secondary reinforcement with yield strength of 240 MPa and had tensile strength of 350 MPa. It satisfies E.S.S. 262/2011.
The concrete mix used for all the beams is designed with a compressive strength at 28 days tests ($f_{cu, 28}$) equal to 26.5 MPa. The proportion of the beam concrete mix is shown in Table (1). Compressive strength values were obtained at 7 and 28 days by using standard cubes of dimensions 100x100x100 mm. The cubes were cured at water in room temperature (25^{o}C) up to testing dates.

3.2. Tested Beam Samples

The experimental program consists of thirty-nine 100x150x1100 mm reinforced concrete beams are cast. Three control beams are tested. The other 36 beams are divided into three groups according to strengthening materials and method. The first group "A" is strengthened by using two types of 2cm thickness concrete layers C1S and C2S. The second group "B" strengthened using 2cm thickness concrete layer reinforced by using meshes (as ferrocement layer) with two types of concretes "C1S" and "C2S" and four types of meshes (MS1, MS2, MP1 and MP2). The third group "C" is strengthened using externally steel plates bonded using two types of adhesions as shown in Table (1). The details and cross-section of the specimens are illustrated in Fig. (1).

Table 1. Properties of the concrete used.

Cement *(kg/m^3)*	W/C	Sand *(kg/m^3)*	Dolomite *(kg/m^3)*	Slump *(mm)*	$F_{cu,7}$ *(MPa)*	$F_{cu,28}$ *(MPa)*
300	0.5	517	1035	25	20	26.5

W/C = water to cement ratio.
$\mathbf{F_{cu\ 7}}$ = compressive strength at 7 days (M Pa).
$\mathbf{F_{cu\ 28}}$ = compressive strength at 28 days (M Pa).

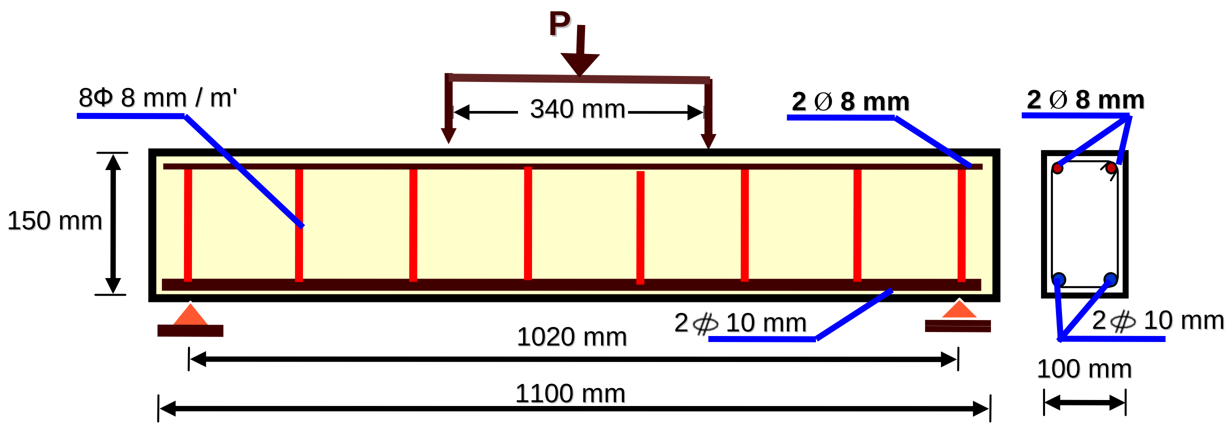


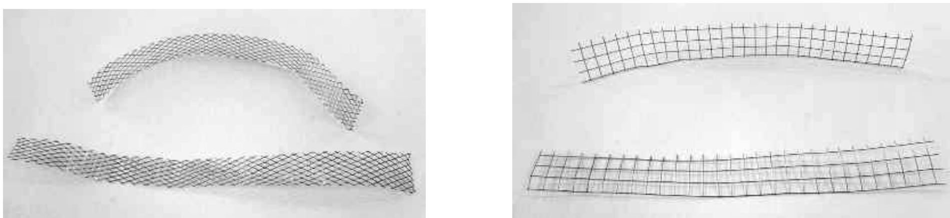
Fig. 1. Detailing of tested beams.

Table 2. Details of the tested beam samples used.

Beam samples		Reinforcement Upper rft	Reinforcement Lower rft	Layer thickness	Strengthening material
Control	C	2 Ø 8	2 Ø 10	--	Control
Group A	C1S			2 cm	Concrete layer (Cement : sand → 1:1)
	C2S				Concrete layer (Cement : sand → 1:2)
Group B	CIS-MS1				Steel mesh type 1 in concrete layer (Cement : sand → 1:1)
	CIS-MS2				Steel mesh type 2 in concrete layer (Cement : sand → 1:1)
	CIS-MP1				Fiber mesh type 1 in concrete layer (Cement : sand → 1:1)
	CIS-MP2				Fiber mesh type 2 in concrete layer (Cement : sand → 1:1)
	C2S-MS1				Steel mesh type 1 in concrete layer (Cement : sand → 1:2)
	C2S-MS2				Steel mesh type 2 in concrete layer (Cement : sand → 1:2)
	C2S-MP1				Fiber mesh type 1 in concrete layer (Cement : sand → 1:2)
	C2S-MP2				Fiber mesh type 2 in concrete layer (Cement : sand → 1:2)
Group C	ST1			--	Steel plate bonded using Sikadur-31 CF
	ST2			--	Steel plate bonded using KIMAPOXY 165

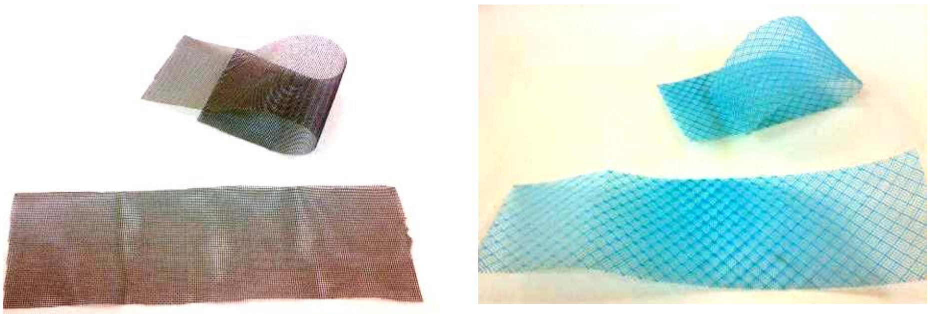
Thirty-six beams are designed according to Egyptian code of practice "Design and Construction of Reinforced Concrete Structures" (ECC 203-2007), these beams are cast with normal strength concrete of 26.5 MPa compressive strength value. Its dimensions are 100x150x1100mm. They reinforced with main steel reinforcement of 2∅10 and stirrup hanger of 2Ø8 and stirrups of 8Ø8 /m\. The longitudinal reinforcement and stirrups are previously prepared before placing it in wooden molds that are specially made for the beam specimens. The prepared steel cage is carefully placed in the wooden mold after oiling its surface so that it is spaced from the sides of the molds by 10 mm using concrete spacers at edges, which is considered to be the concrete cover. The molds with the steel cages are placed on the vibration table at a low speed while the concrete is poured. After casting, the specimens are covered with wet burlap in the laboratory at 24^{o}C and 74% relative humidity. The specimens are demoded after 1 day and wrapped with wet damp cloth for 28 days.

The control and strengthening beam specimens are prepared for testing after 28 days from casting. Three beams are tested up to maximum load under bending test machine as control beams. Other beams are divided in to three groups as shown in Table (2).



a. MS1 **b.** MS2

Fig. 2. Steel meshes used.



a. MP1 **b.** MP2

Fig. 3. Plastic meshes used.

3.3. Properties of Strengthening Materials

The strengthening materials used for all the beams are chosen as available materials in Egyptian markets as follow:

3.3.1. Steel Plates

Steel plates (St. 24) of dimensions of 100x1000mm and 1.5 mm thickness are used. Each plate is fixed on the tension surface of simply supported beam using a bonding material. Two bonding materials are used namely; Sikadur-31CF (beam ST1) and Kemapoxy-165GT (beam

ST2) as shown in Fig. (2). Main mechanical properties of two cohesive are shown in Tables (3) and (4).

Table 3. Main properties of Sikadur-31CF. *(as provided by manufacturer)*

Color	Solid content	Density *(kg/ L)*	Mixing ratio A:B (by weight)	Pot life *(min)*	Setting time			Min application temperature	Theoretical rate of use *(kg./m²)*
					Initial setting time *(hrs)*	Final setting time *(hrs)*	Full hardness *(Days)*		
concrete grey	100%	1.9 ± 0.1	2 : 1	55	12	24	7	+10°C	3.6 when 500 µ thick

Table 4. Main properties of Kemapoxy-165GT. *(as provided by manufacturer)*

Color	Solid content	Density *(kg/ L)*	Mixing ratio A:B (by weight)	Pot life *(min)*	Setting time			Min application temperature	Theoretical rate of use *(kg./m²)*
					Initial setting time *(hrs)*	Final setting time *(hrs)*	Full hardness *(Days)*		
Brawn	100%	1.35 ± 0.02	4 : 1	120	10	24	7	+5°C	0.7 when 500 µ thick

3.3.2. Meshes

Steel meshes: Two different types of steel meshes, MS1 and MS2, as shown in Fig. (2), are used to strengthening the tension surface of beam samples. Their main properties are shown in Table (5). They bonded to the tension layer of concrete beams using cement mortar. Two types of cement mortar are used namely; C1S and C2S. Each type is used to produce a concrete layer of 2 cm thickness. Their mechanical property satisfies the Egyptian specifications for steel meshes E.S.S.261/2006 and E.S.S.262-3/2009.

Plastic meshes: two types are used of plastic meshes, MP1 and MP2, as shown in Fig. (3). Their main properties are shown in Table (5). The fixing method is the same technique mentioned before for steel meshes using C1S and C2S.

Table 5. Properties of meshes used. *(Based on tests)*

Mesh Code	Mesh Type	Opening description		Cross section description		Yield Strength (MPa)	Ultimate Strength (MPa)
		Shape	Dimensions (mm)	Shape	Dimension (mm)		
MS1	Steel	Quadrilateral	3.9x6.4	Rect.	0.45x0.85	240	282
MS2		Rect	3.5x3.7	Rounded	Ø 0.4	240	283
MP1	Plastic	Rect.	1.3x1.3 ±0.1	Rounded	Ø 0.3	--	220.86
MP2		Quadrilateral	1.6x2.2 ±0.1	Rounded	Ø 1.15	--	30.14

3.3.3. Bonding Materials

Sikadur-31CF: is a solvent-free, moisture tolerant, thixotropic, structural two part adhesive and repair mortar, based on a combination of epoxy resins and special fillers, designed for use at temperatures between +10°C and +30°C. It used to fix the steel plates on the tension layer of sample beams as shown in Fig. (4.a). Its main properties are shown in Table (3).

a. Sikadur-31CF

b. Kemapoxy-165GT

Fig. 4. Bonding materials used.

Kemapoxy-165GT: is a solvent free two components adhesive based on polyurethane and epoxy resins as shown in Fig. (4.b). It used to adhering the steel bars or plates to concrete surfaces. It complies with BS EN 12004, ES 4118. It used as alternative to Sikadur-31CF to fix the steel plates. Its main properties are shown in Table (4).

Cement mortar: two types of cement mortars are used. The first is consists of cement: sand 1:1 and 0.5 water to cement ratio and named "C1S". The second is consists of cement: sand 1:2 and water to cement ratio of 0.5 and named "C2S".

Fig. 5. Preparation of beam samples to applying the strengthening layer.

Fig. 6. Cement mortar C1S or C2S used to fix the strengthening layer.

3.4. Strengthening Methodology

Beams are divided into three groups as discussed previously and shown in Table (2). Thirty beams are strengthened using steel and plastic meshes with a concrete layer. Other six beams are strengthened using steel plates.

In the first two groups "A" and "B", the concrete layer is prepared using two mortar types. One is C1S and the other is C2S as shown in Table (2). Beam specimens are sand-blasted to roughen their surfaces for a better bond between the old concrete surface and strengthening layer Fig. (5). A wooden side form of 20 mm height are used as a formwork as shown in Fig. (6). A 5 mm mortar layer, C1S or C2S, is applied then putting the reinforcing mesh then the mortar is adding to the required thickness (20 mm). After 24 hours the formworks are removed then the new layer is cured for 7 days after that, beams are tested.

Fig. 7. Fixing the steel plate strengthening layer.

Fig. 8. Testing frame and loaded beam.

In the third group "C", steel plates are used as strengthening techniques. Two adhesive materials are used namely; Sikadur-31CF and Kemapoxy-165GT. Tension surface is roughened then cleaned. The adhesive material is applied on the tension lower surface of beam then, the steel plates are fixed as shown in Fig. (7). Beams are left for 7 days to insure the full hardened of the cohesion materials then, they are tested.

3.5. Test Procedures

The beam specimen is placed on a steel frame with a hydraulic jack of a capacity of 50tons *(500kN)* and the load is applied as four point load system as shown in Fig. (8). The distance between the two applied loads is 340 mm. Beams are tested and the deflection values are determined. Initial crack load and failure loads are recorded and crack patterns are sketched.

4. Results and Discussion

4.1. Capacity of Strengthened Reinforced Concrete Beams

It is well known that the load carrying capacity of RC beams increases as the beam is strengthened. Fig. (9) shows the initial cracking loads and the ultimate loads of RC beams with different states of strengthening techniques. For control specimen, the initial crack was initiated around 4100kg *(41kN)* (as 76% of ultimate load) and crack patterns were typical flexural crack. At the failure, concrete crushing was shown after tensile reinforcement was failed.

Table 6. Results of the tested beam samples.

Beam samples		% of load increasing compared to control beam		Ductility ratio P_{cr} / P_u	Failure mode
		Initial cracking load P_{cr}	Ultimate load P_u		
Control	C	0.0	0.0	75.93	*Flexure*
Group A	C1S	+ 7.3 %	+ 14.8 %	70.97	*Flexure*
	C2S	+ 2.4 %	+ 7.4 %	72.31	*Flexure*
Group B	CIS-MS1	+ 14.6 %	+ 20.4 %	70.59	*Flexure*
	CIS-MS2	+ 17.1 %	+ 25.9 %	71.88	*Flexure*
	CIS-MP1	+ 12.2 %	+ 18.5 %	71.43	*Flexure*
	CIS-MP2	+ 9.8 %	+ 16.7 %	72.41	*Flexure*
	C2S-MS1	+ 7.3 %	+ 11.1 %	73.33	*Flexure*
	C2S-MS2	+ 26.8 %	+ 22.2 %	78.79	*Flexure*
	C2S-MP1	+ 9.8 %	+ 13.0 %	73.77	*Flexure*
	C2S-MP2	+ 4.9 %	+ 10.2 %	72.27	*Flexure*
Group C	ST1	+ 82.9 %	+ 55.6 %	89.29	*Shear*
	ST2	+ 61.0 %	+ 42.6 %	85.71	*Flexure*

For strengthened beams, both the initial cracking loads and the ultimate loads are increased as the stiffness of strengthening layer is increased as shown in Table (6). For the control beam, the initial crack load was 4100kg *(41kN)* and it failed at the ultimate load of 5400kg *(54kN)*. The increase of the initial crack and ultimate load vales are illustrated in Table (6). The results satisfy previous researchers [2, 5, 6].

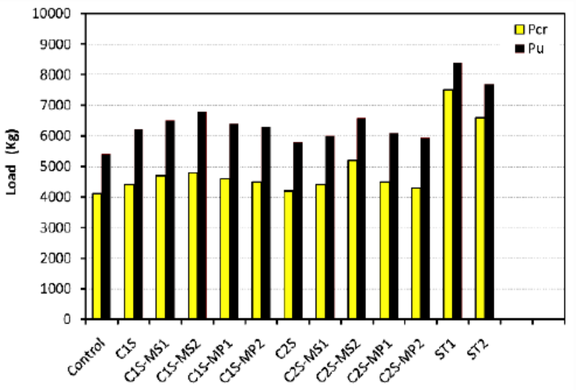


Fig. 9. Initial cracking load and ultimate loads of tested beams.

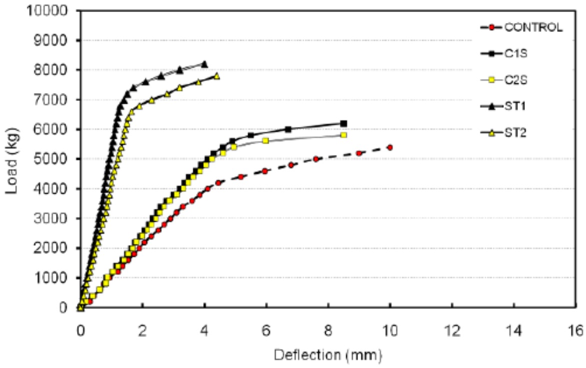


Fig. 10. Effect of using steel plates compared to 2cm thickness C1S and C2S.

4.2. Evaluation of the Structural Behavior

It is well known that the deflection values of RC beams decreases as the beam is strengthened. Figures (10) to (16) show the load-deflection curves of strengthened RC beams.

The maximum deflection at failure was 10mm. The strengthening specimen showed better strengthening effect than the control specimen especially, when using steel plates as strengthening technique. Figure (17) showed a comparison between deflection values for different strengthened beams. Figure (18) illustrates the deflection lines along the span of the tested beams.

Table (6) indicated the summary of the test result in this study. All of strengthening specimen showed better strengthening effect of 7.4~55.6% than the control specimen. For the strengthening, group "A" strengthening specimen showed just 7.4~14.8% larger strengthening effect. Group "B" strengthening specimen showed just 10.2~25.9% larger strengthening effect. Strengthening specimen of group "C" showed almost double times of the strengthened technique used for group "A". Type "B" specimen had the better maximum deflection at failure than, type "A" specimens. With this analyzed point of view, Type "B" specimen can be better strengthening type with the strengthened concrete reinforced layer (which may consider as ferrocement layer). The stiffness of strengthened groups "A" and "B" is greater than control specimens and "C" group. The ductility of beams repaired by plate bonding was reduced significantly, which can lead to sudden failure.

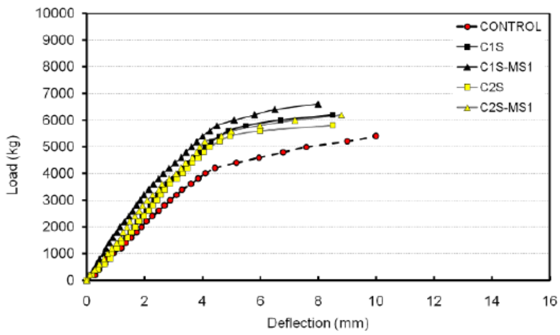


Fig. 11. Effect of using steel mesh MS1 compared to control beam and strengthening using only concrete layer without meshes.

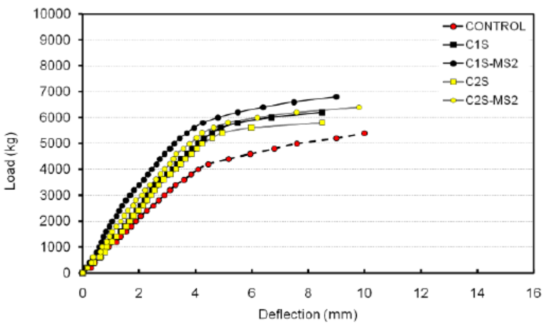


Fig. 12. Effect of using steel mesh MS2 compared to control beam and strengthening using only concrete layer without meshes.

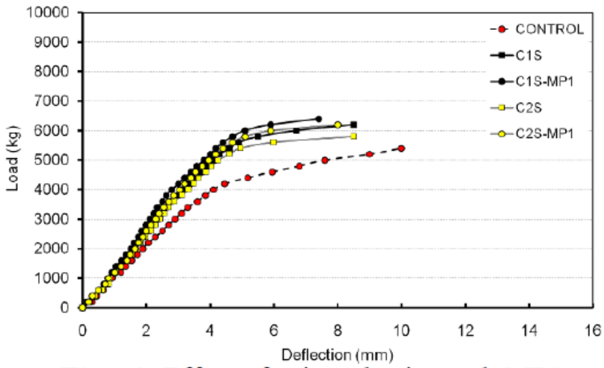


Fig. 13. Effect of using plastic mesh MP1 compared to control beam and strengthening using only concrete layer without meshes.

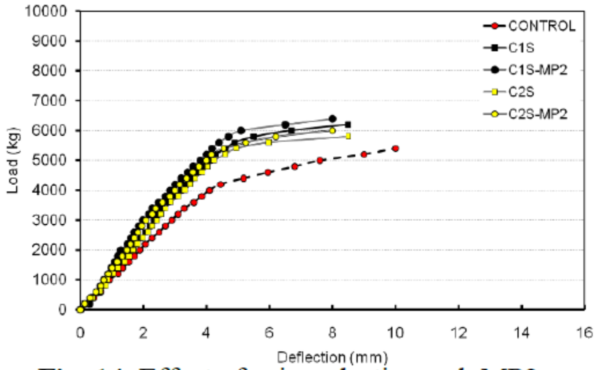


Fig. 14. Effect of using plastic mesh MP2 compared to control beam and strengthening using only concrete layer without meshes.

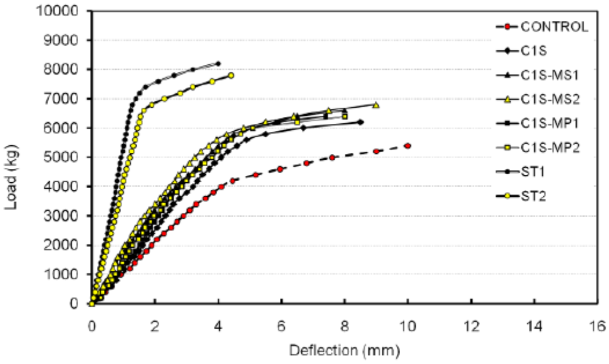


Fig. 15. Effect of using different meshes with a 2cm of C1S concrete layer.

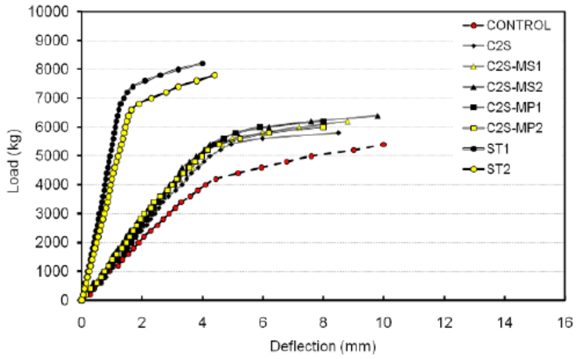


Fig. 16. Effect of using different meshes with a 2cm of C2S concrete layer.

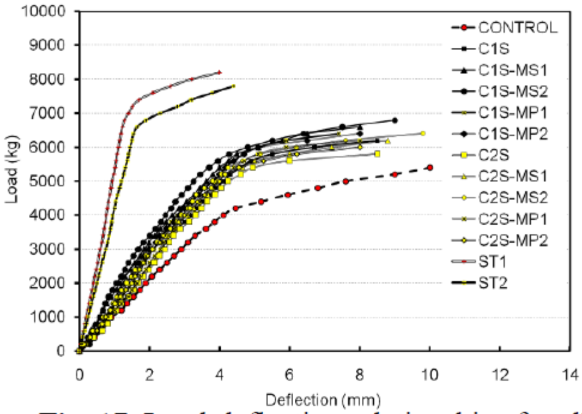


Fig. 17. Load-deflection relationships for all tested beams.

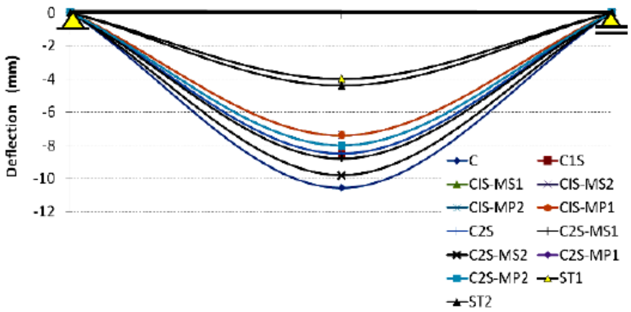


Fig. 18. Deflection lines for different tested beams.

4.3. Crack Pattern and Failure Modes of Tested Beams

Figure (19) shows the crack pattern and the mode of failure of "C" specimen. Before cracking, all the strengthened specimens exhibited bending behavior similar to the un-strengthened specimen.

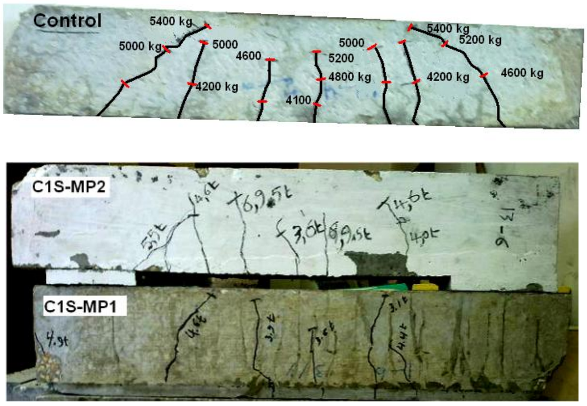


Fig. 19. Crack pattern of samples (*from up to down;* Control, **C1S-MP2** and **C1S-MP1)**.

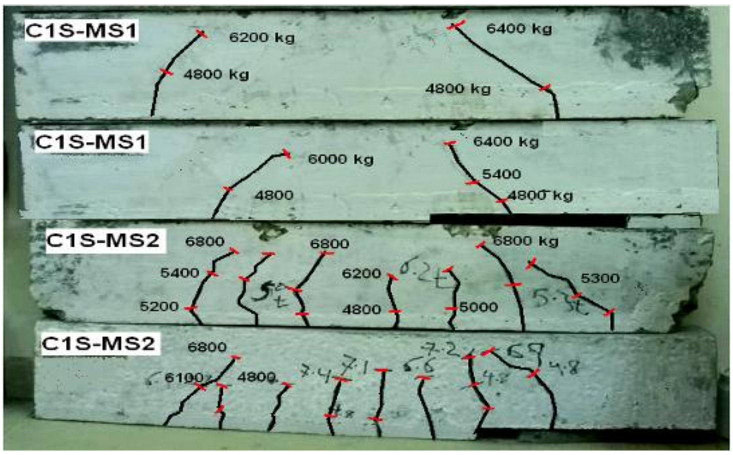


Fig. 20. Crack pattern of samples (*from up to down;* **C1S-MS1, C1S-MS1, C1S-MS2** and **C1S-MS2)**.

For strengthened beams, the interfacial crack initiated along the strengthening surface as approaching the ultimate load. At last, debonding failure between strengthening section and the concrete surface was occurred. This shows that the mesh and steel plates strengthening is able to contribute to the increase of the stiffness and strength in the elastic domain. However, after cracking, the bending stiffness and strength of the strengthened specimens were seen to increase significantly until failure compared to the un-strengthened specimens.

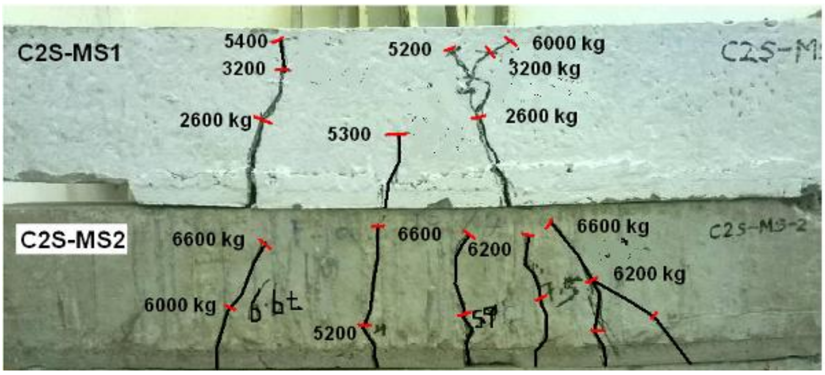


Fig. 21. Crack pattern of samples (*from up to down;* **C2S-MS1** and **C2S-MS2)**.

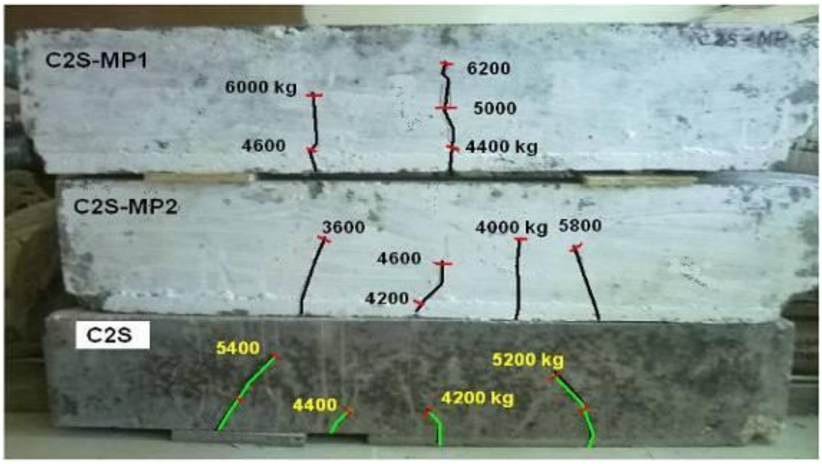


Fig. 22. Crack pattern of samples (*from up to down;* **C2S-MP1**, **C2S-MP2 and C2S)**.

Examining the ultimate failure, the un-strengthened control specimen presented typical bending failure mode which proceeds by the yielding of steel reinforcement followed by compression failure of concrete. The failure of C1S and C2S specimens began with the separation of strengthening concrete layer at mid-span and at the supports to exhibit finally brittle debonding failure as shown at Figures (19) to (22). The failure of ST1 and ST2 specimens began with the separation of steel plates and epoxy from concrete beside the supports to exhibit finally brittle debonding failure Fig. (23). In the case of C1S, C1S-MS1, C1S-MS2, C1S-MP2 and C2S specimen, the interfacial crack along the strengthening surface occurred when the load was nearly about 97% of ultimate load.

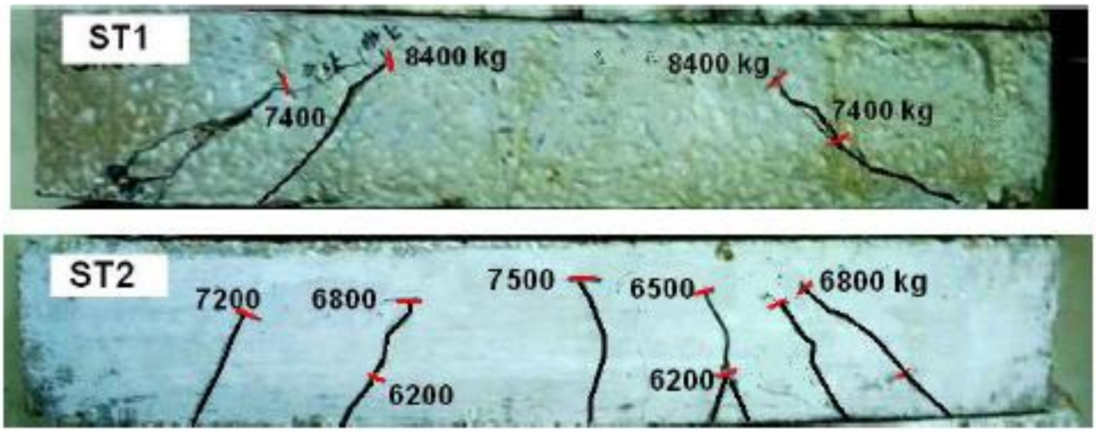


Fig. 23. Crack pattern of samples (*from up to down;* **ST1, and ST2)**.

For crack pattern, the better effective distribution of crack showed for C1S-MS2 and C2S-MS2 specimens. The cracks are finer than in control beams. All of A and B type specimens are failed due to tension failure as shown in Figures (19) to (22). ST1 specimen showed shear failure that it is may refer to increasing the flexural capacity without enhancing the shear capacity of strengthened sample.

The testing identified the following major failure modes:

- Failure mode 1: The tensile steel yields and longitudinal concrete layer breaking occurs (such as C1S-MS1, C1S-MS2, C2S-MS2).
- Failure mode 2: Longitudinal strengthening layer debond (such as C1S, C1S-MP2, C2S).
- Failure mode 3: shear failure near the supports (sample ST1).

A summary of the experimental results and the corresponding code number of failure modes are presented in Table (6). Figures (19) to (23) show the failure modes and the cracking patterns of some of the RC specimens tested.

In all cases of the tested samples, the mode of failure is tensile failure except for ST1 specimen. Its mode of failure is differently showed with other specimens as it is shear failure.

In Figures (10) to (17), the stiffness of ST1 and ST2 specimens before yielding of steel reinforcement was larger than the stiffness developed by other specimens. The ultimate load and yield load are seen to increase with strengthening using steel plates. This proves that the steel plate system is utilizing mesh reinforcement efficiently satisfying previous researchers [2, 6].

4.4. Economic Study

For economic point of view, using steel meshes is considered less cost compared to steel plates by about 60 % due to steel plate and its cohesive material cost. In case of using steel plates, using of Kemapoxy-165GT is cheaper than using Sikadur-31CF but with about 10% lower strength compared to Sikadur-31CF as shown in Table (6).

5. Conclusions

Performance tests have been carried out on RC beams strengthened using reinforcing mesh (which may considered as ferrocement layer) as well as steel plates to evaluate the feasibility of using each type. The following conclusions were derived from the experimental results.

It has been seen that C1S specimens more efficiently than the C2S strengthening specimens by about twice. According to the static loading test results, the strengthening performances were improved in all strengthening techniques used but using steel plates is more efficient than using reinforced concrete layer (in the range of this study) by about 300%.

The using of steel mesh increased the ultimate load by about 11-25%. It also enhanced the stiffness and the crack pattern compared to plastic meshes used (in rang of this study).

However, the specimens C1S, C2S C1S-MS1, C1S-MS2 and C1S-MP2 failed by the separation of the strengthening reinforced concrete layer from the concrete. Consequently, it is necessary to take some countermeasures to prevent debonding failure for such strengthening layer.

Economically, steel meshes costs less compared to steel plates by about 60 %. In case of using steel plates, using of Kemapoxy-165GT is cheaper than using Sikadur-31CF but with a lower strength by about 10% compared to Sikadur-31CF.

Finally, using of steel plates better than reinforcing meshes. In case of using meshes, the specified type of used steel mesh MS2 is recommended. Test results indicates that for groups "A" and "B", the ultimate strength, stiffness, ductility, and failure mode of RC beams, with the same thickness strengthening layer applied, are affected by the type of reinforcing mesh and type of concrete layer. While for group "C" (steel plates), these parameters affected by the fixation technique and adhesion type.

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