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Efficiency of Injection Method in Repairing of Normal Strength and Reactive Powder Reinforced Concrete Beams

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Abstract

The study aims to ensure the possibility of returning the strength of reinforced concrete beams to their original strength as a result of repairing work using epoxy injection method. Four different samples were poured and tested, the main variables in this study are the compressive strength in addition to the longitudinal steel reinforcement ratio and the other parameters are kept constant such as shear reinforcement (ø10@100 mm) and the dimension (180 ×250×1200). The test results showed that the ultimate strength of repaired beams approached greatly to the original beams strength. There is also an improvement in the ductility and stiffness of tested beams. Also, there is a decreasing in toughness of repaired beams in comparison with the original beams.

General

In structural engineering, the maintenance, repair and upgrading of structures are just as important and technical as the design and construction of new structures. In the case of upgrading this usually involves strengthening of an existing structure to satisfy a higher ultimate load and /or more stringent serviceability requirements. The need for such work may be due to changes in design criteria, such as the imposed loading, or due to deficiencies in the existing structure, such as displaced reinforcement bars [(1)].

A number of techniques have been used in the past to achieve the desired importance, and in the case of concrete structures, some of the most common methods are [(2)]:

- Replacing non–structural toppings with structural toppings or with light material, which reduces dead load; thereby, additional capacity for live load is gained.
- Introducing extra supports to reduce span length.
- Adding extra reinforcement by stapling and gunning.
- Prestressing either externally or internally.
- Selection of polymer impregnation to renovate a severely disintegrated concrete structure.

In the case of repairing of an existing structure due to many defects to keep its ultimate flexural or shear capacity and eccentric axial compression load equal their design value, a structural repair must be adopted. Perking [(3)] clarified that there are two types of repairs:

- **Non–structural repair**; the one which when completed, will not increase the load carrying capacity of the member nor the structure.
- **Structural repair**; which is used when the cracked member has suffered strength loss, or when the surface chasing out of cracks is considered undesirable.

Repaired Reinforced Concrete Members

Concrete structures often exhibit cracks due to impact, dynamic loading, static overload, shrinkage, creep or thermal gradients. Major cracks are aesthetically unpleasant and affect the durability of the structure. In addition, there are instances where concrete element exhibit distress by excessive cracking, spalling and even local crushing of the concrete. Cracks need to be repaired if they reduce the strength, stiffness or durability of the structure to an unacceptable level, or if the function of the structure is seriously impaired [(2)]. In such cases immediate remedial measures should be undertaken to prevent further degradation of the concrete and to restore their structural integrity[(4)].

The main techniques for repairing reinforced concrete members can be classified as:

- Conventional methods.
- Epoxy resins technique.
- Plate bonding technique.
- Steel plate bonding.
- Carbon fiber bonding.

Depending on the nature of the damages, one or more repair methods may be selected. For example, tensile strength may be restored across a crack by injecting it with epoxy or other high strength–bonding agents. However, it may be necessary to provide additional strength by adding reinforcement or using post–tensioning. Epoxy injection alone can be used to restore flexural stiffness if further cracking is not anticipated [(3)].

Experimental Program

Beams Geometry

All beams were geometrically similar, having dimensions (1200x250x180) mm^3 as a dimensions of (length x depth x width) respectively and loaded through two points load, the distance between the two points load is (350 mm). The beams are simply supported and the distance from c/c of supports was (1050 mm).

Beams Reinforcement

Two different longitudinal bottom reinforcement ratios were used (2ϕ16 and 3ϕ16), the longitudinal top bars and shear reinforcement are kept constant (2ϕ12) and (ϕ10@100mm) respectively. The tensile strength of deformed bars are (422MPa) and (385 MPa) for longitudinal and shear reinforcement respectively tested according to ASTM A615[5].

Compressive Strength

Cubical (150x150x150)mm^3 specimens were used to test the compressive strength of concrete. The compressive test was done according to ASTM C39[6]and B.S 1881[7]by using a computerized compression machine. The Table (1) below show the compressive strength values of each specimen.

Table (1) Characteristics of the Tested Beams

Beam No.	Type of Concrete	Flexural Reinforcement	Shear Reinforcement	Compressive Strength (MPa)
B1	Normal concrete	2Ø12 top 2 Ø16 bottom	Ø10@100mm	29
B2	Normal concrete	2Ø12 top 3 Ø16 bottom	Ø10@100mm	29.7
B3	Reactive powder concrete	2Ø12 top 2 Ø16 bottom	Ø10@100mm	93
B4	Reactive powder concrete	2Ø12 top 3 Ø16 bottom	Ø10@100mm	90

Mix Proportions

Table (2) show the mix proportions are used in tested beams.

Table (2) Mix Proportions

Concrete Strength (MPa)	Cement (Kg/m^3)	Sand Kg/m^3 Passing Through 600Microne Sieve	Gravel Kg/m^3 Passing Through 4.75mm Sieve Size	w/c Ratio	SP Ltr/m^3	Silica Fume
30	415	535	1250	0.44	-	-
92	800	900	1000	0.30	7%	5%

Technical properties of Epoxy

Table (3) below contains the technical properties of epoxy resin (quick mast 105) , it is the product of Ayla company.

Table (3) Technical Properties of Epoxy Resin

Property	Result
Compressive strength	>72 N/mm^2 w7days w25$\overset{o}{c}$
Flexural strength	>60 N/mm^2 w25$\overset{o}{c}$
Tensile strength	>25 N/mm^2
Pot Life	60 minutes w25$\overset{o}{c}$
Specific Gravity	1.1
Viscosity	10 poise w25 $\overset{o}{c}$
Min. application Temperature	5 $\overset{o}{c}$

Strength and Efficiency

The strength of the tested beams is expressed as the experimented ultimate load the beam can withstand. The efficiency of repairing is defined as a ratio of the repaired beam strength to its original strength (as a percentage).

The beam (B1, B2, B3 and B4) record a decrease in strength above its original strength of (6%, 2.2%, 2.3% and 4.1%) respectively, this mean that the beam exhibit repair efficiency about (94%, 97.8%, 97.7% and 95.9%) respectively. The original beams (B1, B2, B3 and B4) exhibit cracking load (when the applied moment equal to or greater than cracking load) at about (95 kN, 87kN, 175kN and 190 kN) respectively, the repaired beams record an decreasing in appearance of first cracking load about (74 kN, 93kN, 161 kN and 184 kN) and they failed by same manner (shear), see Table (4). and brittleness of failure can be seen in reference specimens (B1, B2, B3 and B4) more than the repaired beam (B1', B2', B3' and B4') this is may be because of high bonding characteristics between epoxy resin and concrete in repaired beams. This is not found in reference beams.

Table (4) Load Characteristics and Failure Mode of Tested Beams

Specimen	Cracking Load (Pcr) (kN)	Ultimate Load (Pu) (kN)	Repair Efficiency Pu/ Pcr	Mode of Failure
B1	95	207.5	94	Shear
B1'	74	195		Shear
B2	87	252	97.8	Shear
B2'	93	247		Shear
B3	175	390	97.7	Shear
B3'	161	381		Shear
B4	190	422.5	95.9	Shear
B4'	184	405		Shear

Deflection and Ductility

Deflection results at cracking load, yielding load and ultimate load of original beams are compared with those of the repaired beams, as shown in Table (5). Deflection of all beams is measured at mid-span of the beams and plotted versus the load, as shown in Figures (1, 2, 3 and 4). Load deflection curves of the beams through loading stages up to failure consist of several main stages. The first stage from starting load application up to formation of the first crack, is of approximately linear. In the second stage the beams becomes less rigid because of reduction in its stiffness due to development of cracks, is of also approximately linear between load and deflection but has smaller slope and extending from cracking load point to yield load point.

The final part which extend from yield load point up to the failure. There is no linear relationship between load deflection and the beam at this stage had little stiffness, see Figures (1, 2, 3 and 4). From these figures, all the deflection values of repaired beams (B1', B2', B3' and B4') are less than the corresponding original beam (B1, B2, B3 and B4) this mean that the improvement in repaired beam stiffness at all loading states is due to the good adhesive between concrete and epoxy resin at the flexural and shear zone of the beam. Also, ductility (which defined as the ability of structure or its components to offer resistance in the inelastic domain of a response which can be calculated by dividing the deflection at the ultimate load to the deflection at yielding, has an improvement in repaired beam in comparison with the original beam by about (0.7%, 11.4%, 34.5% and 13.8%) in beams (B1', B2', B3' and B4') in comparison with reference beams (B1, B2, B3 and B4) .

Table (5) Deflection and Ductility of Tested Beams

Specimens	Deflection at Yield	Ultimate Deflection	Ductility	Improvement in Ductility(%)
B1	187	271	1.45	0.7
B1'	199	289	1.46	
B2	250	331	1.32	11.4
B2'	198	291	1.47	
B3	354	412	1.16	34.5
B3'	260	405	1.56	
B4	300	522	1.74	13.8
B4'	282	560	1.98	

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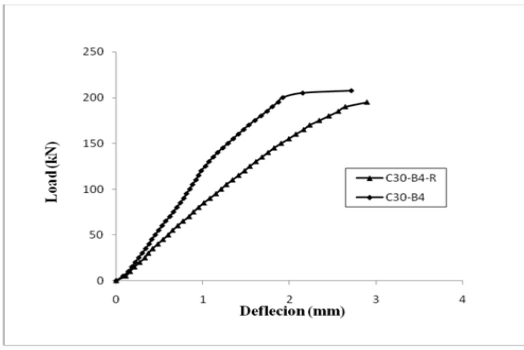

Figure (1) Load-deflection Curves of Original and Repaired Beam (C30-B4)

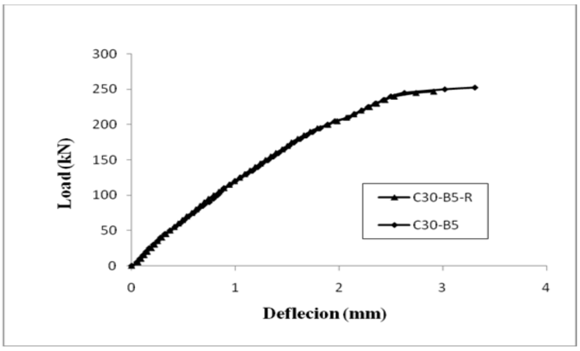

Figure (2) Load-deflection Curves of Original and Repaired Beam (C30-B5)

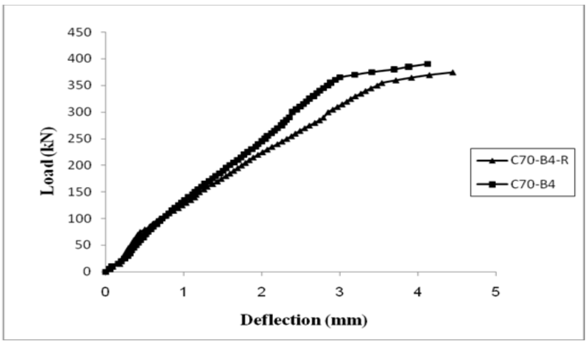

Figure (3) Load-deflection Curves of Original and Repaired Beam (C70-B4)

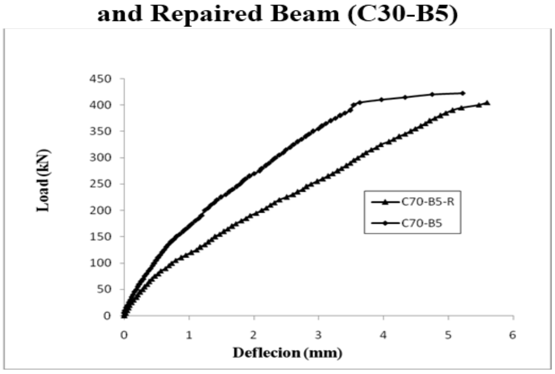

Figure (4) Load-deflection Curves of Original and Repaired Beam (C70-B5)

<u>Crack Pattern and Failure Mode</u>

The initial cracking of all the tested beams was first observed in the tension face of flexural zone under the point load. In original and repaired beams, the first crack opened parallel to the direction of load application and at the advanced stages of load application a relatively wide shear cracks can be start near the support toward point load position, see Figure (5).

In general, width of cracks in repaired beams wider than the crack in reference beams, and the maximum crack width at failure of beams more than this in reference beams because the epoxy resin works as a bridge connect the sides of beams besides the crack.

Figure (5) Typical Failure Mode of Tested Beams

Stiffness

The resistance of structural members to deformation is called a stiffness, it is the slope of the line that connects the starting and the end points of load-deflection curve.

The Table (6) describes the stiffness values of the original and repaired beams. From this table, it was observed that there is a slightly decreasing the stiffness of repaired beams in comparison with original beams, this decreasing is may be due to that there are some cracks have not injected with epoxy resin because of small size, or it is deep cracks far from the beam surface.

Table (6) Stiffness of Tested Specimens

Sample No.	Stiffness (kN/m)	Reduction of Stiffness (%)
B1	765.7	11.9
B1'	674.74	
B2	782.9	4
B2'	751.58	
B3	946.6	4.5
B3'	903.6	
B4	809.4	10.6
B4'	723.2	

Toughness (Energy Absorption)

The ability of material to absorb mechanical energy up to the point of rupture (the resistance of fracturing or breaking), it is the area under load-deflection curve.

In general , there is a decreasing of the toughness of repaired beams in comparison with original beams, see Table (7).

Table (7) Stiffness of Tested Specimens

Sample No.	Stiffness (kN/m)	Reduction of toughness (%)
B1	36.9	13.3
B1'	32.7	
B2	54.13	22.4
B2'	42	
B3	98.78	15.36
B3'	83.6	
B4	154.5	14.6
B4'	132	

Conclusions

The following conclusions can be obtained from this study:-

1. The repaired beams reached to some extent the original beams.
2. The good bonding characteristics between concrete and epoxy resin made the ductility and stiffness of repaired beams greater than the original beams.
3. The failure mode does not change after repairing works.
4. The comparison showed that there is a decrease in toughness of repaired beams.
5. The cracks width of repaired beams is wider than those original beams.

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