Shear Behavior of Corrosion Induced Reinforced Concrete Beams Retrofitted with Ferrocement Jackets

JeenaSulaikha, S. R. Akhil Raj

Abstract—Corrosion of reinforcement steel in reinforced concrete structures affects the long term performance RC structures are originally designed for. Only limited studies have been conducted to investigate the shear behavior of corrosion induced reinforced concrete beams. This study investigates the shear behavior of retrofitted corrosion induced reinforced concrete beams. For this, twenty four shear deficient beams of size 100x150x1000mm using M20 concrete are prepared. The specimens have been subjected to various percentages of corrosion, 5%, 10% and 15% of mass loss of steel reinforcement. The beams to be retrofitted, after corrosion, are subjected to preloading up to 67% of the respective ultimate load bearing capacity. They were then retrofitted at the shear spans by means of U-wrap ferrocement, containing two layers of woven wire mesh. All the beams are tested in UTM and subjected to two- point loading. The ferrocement U- wrap containing two layers of welded wire mesh increased the load bearing capacities and hence has proved efficient in restoring the strength of the beams.

Index Terms—Corrosion, Coefficient of Resistivity, Shear Behaviour, Crack Pattern, U- Wrap Ferrocement, Retrofitting, Ferrocement

1 Introduction

CCorrosion is a natural process which occurs when conditions become favorable. It is thermo dynamical in nature and is the major cause of degradation of metals. This process depends upon many parameters including environmental conditions and metal properties. Corrosion in steel is strongly related to both concrete and environmental factors. There are many factors involved in this process. Hence, great caution should be taken while considering factors that can affect corrosion of steel in concrete. However the need for understanding corrosion of reinforcement in existing projects and under construction concrete structures has accelerated the studies in the field of corrosion of reinforced concrete. Various techniques for inducing accelerated corrosion of steel in concrete are used by the researchers. The corrosion of reinforcing steel is generally accelerated by means of the impressed current technique. This is done to induce a significant degree of corrosion of reinforcing bars embedded in concrete in limited available time[1].

Corrosion of steel reinforcement in concrete structures deteriorates the load carrying capacities of these structures tremendously. Hence, structural repair and rehabilitation of these structures is necessary to enhance the load bearing capacities and to increase the life span of these structures. Ferrocement is the most commonly used retrofitting technique. It exhibits high tensile strength, high crack arresting capacity and higher ductility. Because it possesses the above mentioned qualities and also because of its economy and requirement of unskilled labor, it is considered as one of the most extensively used ret

rofitting and rehabilitation technique[2].

Impressed current technique of corrosion acceleration has many advantages, mainly time saving and ability to control rate of corrosion[1],[3].Corrosion of steel reinforcement is one of the major causes affecting the long term performance of RC structures[4],[5],[6],. Ferrocement is most commonly used retrofitting technique, mainly due to its efficiency in retrofitting of structures and its economy in cost and labor [2].

This work aims to determine the coefficient of resistivity of the surrounding concrete and also to study the shear behavior of corrosion induced retrofitted RC beams subjected to various degrees of corrosion (5%, 10%, and 15% mass loss of steel reinforcement).

2 Materials Used

Portland Pozzolana Cement (PPC), Manufactured sand (M Sand), coarse aggregate, water, reinforcement steel and woven wire mesh were used for the study. Reinforcement steel used was of grade 500. 10mm and 8mm diameter bars were used as longitudinal reinforcement and 6mm diameter bars were used as stirrups. Water used in this work was potable water which is available in the college water supply system. Wire mesh used here is square woven wire mesh of grade 6-22.

M20 grade conventional concrete was used for preparation of specimens for this work. Mix was designed as per IS 10262: 2009[7]. The ratio adopted as the optimum mix was 1: 2.05: 3.93 by weight to obtain the M20 grade concrete. The cement content taken was 340kg/m3 and the water cement ratio adopted was 0.45. The cube compressive strength obtained after 28 days water curing was found to be 26.67N/mm2.

Following table lists the specimens used in this study and their designations.

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Table 1 Beam Designations

Specimen Designation	Specimen	Number
CB	Control Beam	3
CB5	5% Corroded Beam	3
CB10	10% Corroded Beam	3
CB15	15% Corroded Beam	3
RB	Retrofitted Control Beam	3
CRB5	5% Corroded Retrofitted Beam	3
CRB10	10% Corroded Retrofitted Beam	3
CRB15	15% Corroded Retrofitted Beam	3

3 Preliminary Study

Impressed Current Technique consists of applying constant current applied by a D.C. source to the embedded steel reinforcement inside the concrete specimen to induce significant corrosion. The time required to achieve a pre- decided percentage of corrosion is determined from Faraday's Law[3],

(1)

Where,   – mass loss

M – Atomic weight of metal (56gm)

I – Current supplied (amperes)

t – Time (seconds)

z – Ionic charge (2)

F – Faraday's constant (96500 amp/sec)

Initial weight of the steel reinforcement is required to obtain the value of   The direction of current flow is set in such a way that the reinforcement steel acts as the anode and stainless steel plate acts as the cathode, which are kept in 4% NaCl solution.

The specimens used for this test are prisms of size 100x100x500mm, containing two each of 10mm and 8mm diameter longitudinal bars with two stirrups of 6mm diameter bar.

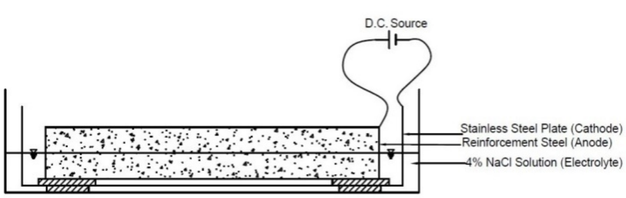

Figure 1 Schematic Diagram of Impressed Current Technique set up

Before preparation of the prisms, the weight of the reinforcement steel was noted. The prisms were prepared and left for curing. These prisms were then subjected to various degrees of corrosion, i.e., 5%, 10%, 15% of mass loss of steel reinforcement. After the required corrosion was achieved, the prisms were demolished to extract the corroded reinforcement. They were then cleaned as per ASTM G1[8]. The coefficient of resistivity, , was obtained from the ratio between the predicted theoretical mass loss to the actual mass loss of the reinforcement steel[9]. The average value of λ is obtained as 1.45.

Figure 2 Corroded Prism Specimen

Figure 3 Figure showing Corroded Reinforcement

Table 2 Results of tests on Corroded RC Prisms

Percentage (%) of corrosion	Initial Weight (kg)	Predicted Mass Loss (kg)	Actual Mass Loss (kg)	λ
5	1.005	0.050	0.035	1.435
10	0.993	0.099	0.068	1.449
15	1.016	0.1524	0.104	1.465

4 Experimental Investigation on Shear Defcient Beams

4.1 Specimen Size and Detailing

Twenty four shear deficient beams of size 100x150x1000mm were prepared using M20 grade concrete designed according to IS 456-2000[10]. The reinforcement detailing is shown in the figure below. Longitudinal reinforcement used includes two 10mm diameter bar as tension steel and two 8mm diameter bars as compression steel and 2 legged 6mm diameter stirrups were used at both ends. The corrosion terminal was made at one end of a 10mm diameter bar.

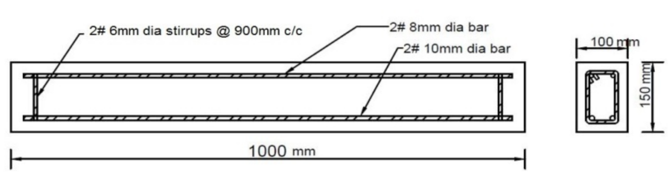

Figure 4 Specimen detailing for RC beam

4.2Reinforced Concreete Beam Preparation

All twenty four beams prepared using M20 grade conventional concrete were made shear deficient in order to study the shear behavior.

4.3Corrosion of RC Beams

After a curing period of 28 days, they were subjected to various degrees of corrosion (5%, 10% and 15% of mass loss of reinforcement). The beams were immersed in 4% NaCl solution along with a stainless steel casing which acts as the cathode and the reinforcement steel inside the beams act as the anode. The beams were connected to a DC source with constant current. The time required for corrosion was obtained from the modified Faraday's Law, wherein the coefficient of resistivity was multiplied to (1).

Figure 5 Corrosion of RC Beams

After the beams were corroded, they were tested in UTM under two point loading to determine the respective ultimate loads.

4.4Pre- Loading of Corrosion Induced RC Beams

The corroded beams that are to be retrofitted are preloaded up to 67% the respective ultimate load bearing capacities. This is done to distress the beams further in order to retrofit the beams using U- wrap ferrocement jackets. Three beams from each group, 5%, 10% and 15% corrosion were distressed up to 67% of the respective ultimate loads, after which they were retrofitted using ferrocement.

4.5Retrofitting of Pre- Loaded Corrosion Induced RC Beams

After preloading the corroded beams, cracks were observed at higher percentages of corrosion. Ferrocement jacket containing two layer wire mesh was done as U- wrap at the shear spans. For this study, three beams were retrofitted from each group, 5%, 10% and 15% corrosion. Another three beams that were neither distressed by corrosion nor preloaded, were retrofitted at the shear spans to be the control retrofitted specimens. The cement mortar was mixed in the ratio 1:3 and water cement ratio as 0.5.

Figure 6 Ferrocement Jacketing done at Shear Spans

4.6Testing of Corrosion Induced Retrofitted RC Beams for Shear Strength

The beams were prepared shear deficient, and hence the shear behaviour of these beams was studied. The beams that were retrofitted at the shear spans with ferrocement jackets were then left for curing for 14 days. After the completion of curing period, the beams were then tested in a 1000kN universal testing machine. The shear behaviour of the corroded reinforced beams and retrofitted corroded reinforced beams were compared to that of the respective control beams.

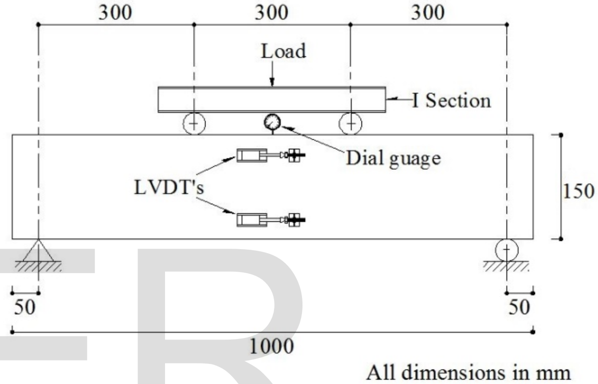

Figure 7 Schematic Diagram for Beam test set

5 Results and Discussion

5.1Crack Patterns

As the beams were shear deficient, these beams failed in shear and exhibited shear cracks at the support. The crack pattern for non- retrofitted beams can be seen in figure 8.
The beams were retrofitted at shear spans by means of ferrocement U- wraps. From figure 9, it can be seen that the beams were safe in shear after retrofitting the shear spans.

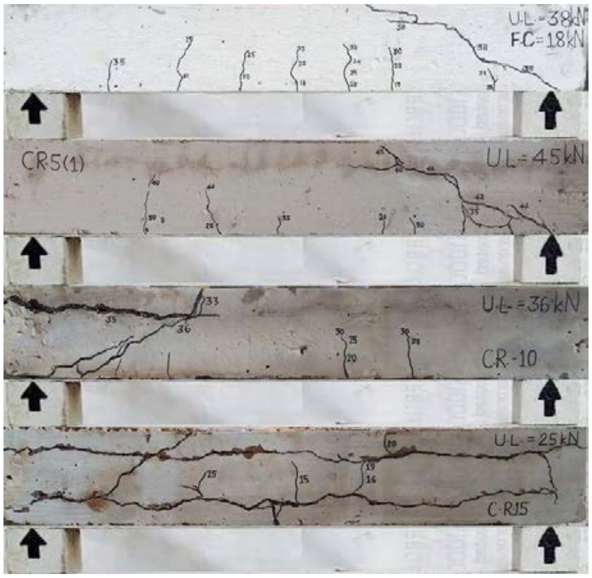

Figure 8 Crack Pattern for Corrosion Induced RC Beams

Figure 9 Crack Pattern of Corrosion Induced Retrofitted RC beams

5.2 Load Deflection Curve

The loads applied and the corresponding dial gauge readings were plotted to obtain the load deflection graph as shown in figures 10 and 11.

The load deflection curve remains linear up until the first crack load for all specimens. Further increment in loading makes the curve deviate from linearity. This is due to multiple crack formation[11].

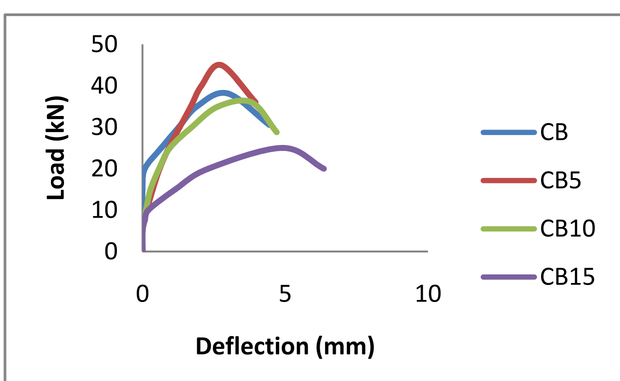

Figure 10 Load Deflection Curve of Corrosion Induced RC beams

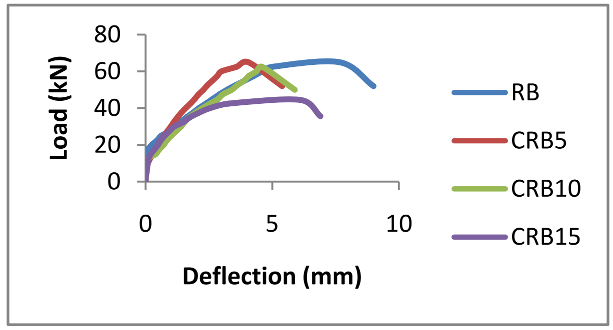

Figure 11 Load Deflection Curve of Corrosion Induced Retrofitted RC beams

5.3 Displacement Ductility

Displacement ductility: It is calculated as the ratio between the displacement at ultimate load to the displacement at yield load which is taken as 80% of the ultimate load[11].

It can be seen from the results that when compared with control beam, there is a reduction of ductility in 5% corroded beam and an increase in ductility in 10% and 15% corroded beams. As the percentage of corrosion increased, the value of ductility increased, and this is due to the effect of longitudinal cracks, loss of bond between steel and concrete, and spalling of concrete cover induced due to corrosion.

Table 3 Displacement Ductility of Corrosion Induced RC beams

Non- Retrofitted Specimen	Displacement Ductility	Retrofitted Specimen	Displacement Ductility
CB	2.12	RB	2.09
CB5	1.53	CRB5	1.65
CB10	2.31	CRB10	2.38
CB15	2.13	CRB15	3.38

5.4 Energy Absorption

Energy absorption is taken as the area under the load deflection curve shown in figure 10 and 11. Due to instrumental limitations, the curve could be plotted only up to 80% of the ultimate load in the descending portion of the graph. Hence the energy absorption determined here is the area under the load deflection curve up until the 80% of ultimate load at the descending portion of the curve[11]. From the table 4, it can be seen that the energy absorption capacity decreased with increase in percentage of corrosion.

Table 4 Energy Absorption of Corrosion Induced RC beams

Non- Retrofitted Specimen	Energy Absorption (kNmm)	Retrofitted Specimen	Energy Absorption (kNmm)
CB	141.65	RB	403.25
CB5	130.43	CRB5	255.29
CB10	128.22	CRB10	250.51
CB15	125.07	CRB15	248.67

When comparing the retrofitted specimens with that of non-retrofitted specimens, it can be seen that the energy absorption has increased. Hence, it can be understood that the retrofitting technique has successful at restoring the strength of the control beam.

5.5 Ultimate Load

It can be seen from table 6 that the ultimate of 5% corroded beam is slightly higher than that of the control beam which is in accordance to the results of other similar studies. This is because with slight reinforcement corrosion, increased confinement is observed in absence of corrosion cracks[4].

Table 5 Ultimate Load of Corrosion Induced RC beams

Non- Retrofitted Specimen	Ultimate Load (kN)	Retrofitted Specimen	Ultimate Load (kN)
CB	30.4	RB	52
CB5	36	CRB5	52
CB10	28.8	CRB10	50
CB15	20	CRB15	35.6

5.6 Initial Crack Load

Table 6 Initial Crack Load for Corrosion Induced RC beams

Non- Retrofitted Specimen	Initial Crack Load (kN)	Retrofitted Specimen	Initial Crack Load (kN)
CB	20	RB	15
CB5	10	CRB5	7.5
CB10	7.5	CRB10	7.5
CB15	7.5	CRB15	5

Table 6 shows the initial crack load for the non- retrofitted and retrofitted corroded specimens.

5.7 Moment Curvature Relationship

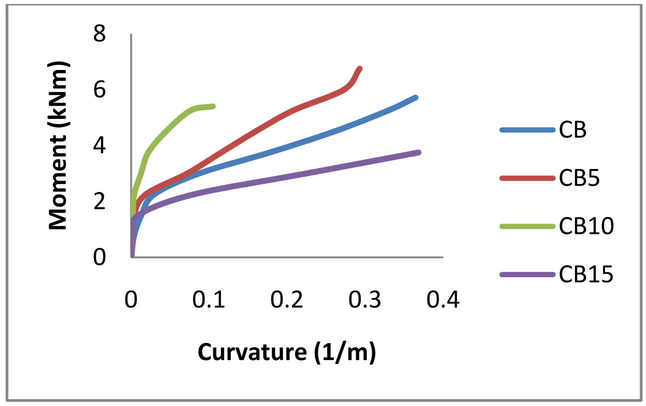

Figure 12 Moment Curvature Graph of Corrosion Induced RC beams

Figures 12 and 13 shows the moment curvature graphs for the corrosion induced RC beams. The curve is linear up to first crack moment. Further when the moment increases, the curve shifts from linearity. When the moment reaches yield moment, the curves become flat. When steel yields, a large increase in curvature occurs with a small change in moment[11].

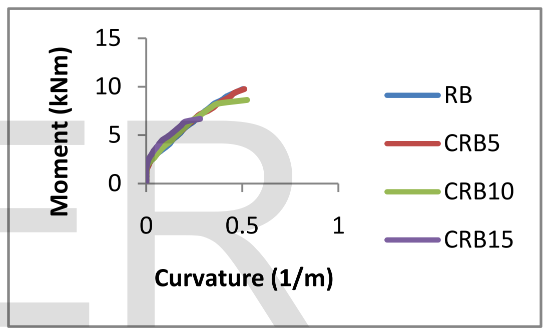

Figure 13 Moment Curvature of Corrosion Induced Retrofitted RC beams

5.8 Curvature Ducitlity

Curvature ductility: It is calculated as the ratio between curvature at ultimate load to the curvature at yield load. Under reinforced beams fail due to failure in tension. This is because failure takes place primarily due to yielding of steel. Hence, large increase in curvature with increase in moment, indicates the ductile failure of the beam[11].

Table 7 Curvature Ductility of Corrosion Induced RC beams

Non- Retrofitted Specimen	Curvature Ductility	Retrofitted Specimen	Curvature Ductility
CB	1.42	CRB	1.57
CB5	1.28	CRB5	1.46
CB10	2.61	CRB10	1.94
CB15	1.64	CRB15	2.0

It can be seen from the table 7 that when compared with control beam, there is a reduction of ductility in 5% corroded retrofitted beam and an increase in ductility in 10% and 15% corroded retrofitted beams. As the percentage of corrosion increased, the value of ductility increased, and this is due to the effect of longitudinal cracks, loss of bond between steel and concrete, and spalling of concrete cover induced due to corrosion[9].

6 Conclusions

Based on the preliminary studies and experimental investigation, the following conclusions are made:

•Previous studies have showed that the actual corrosion achieved varies from the theoretical corrosion calculated due to various reasons. Hence, the coefficient of resistivity of the surrounding concrete was obtained from the preliminary study and was found to be 1.45.

•The ultimate load bearing capacity of 5% corroded beam was found to undergo an increment of 18.42% when compared to that of control beam. This was due to the reason that a small amount of corrosion leads to slight deposition of corrosion residue at the concrete- steel reinforcement interface, thereby leading to increase in volume fraction of steel which further results in increased load bearing capacity.

•With increase in percentage of corrosion, there was significant decrease in load bearing capacity, energy absorption and ductility as there is significant decrease in cross section and tensile strength of steel.

•As the percentage of corrosion increased, the value of ductility increased, and this is due to the effect of longitudinal cracks, loss of bond between steel and concrete, and spalling of concrete cover induced due to corrosion.

•As these beams failed in shear, they were retrofitted at the shear spans by means of ferrocement U- wraps. This resulted in significant increase in the load bearing capacities of the corroded retrofitted beams.

•The crack pattern in corroded retrofitted beams shows that the beams have been made safe in shear when retrofitted using ferrocement at shear spans.

•When compared with unretrofitted control beam, the load carrying capacity of:

- •5% corroded retrofitted beam increased by 41.5%
- •10% corroded retrofitted beam increased by 39.2%
- •15% corroded retrofitted beam increased by 14.6%

•The ductility index for 5% corroded retrofitted beams reduced when compared to that of control retrofitted beam, but for 10% and 15% corroded retrofitted beams, the ductility index increased when compared to control retrofitted beams.

•The retrofitting technique adopted here has proved efficient in arresting shear cracks and making the beams safe in shear. Hence, the retrofitting technique adopted here has proved efficient in arresting shear cracks and making the beams safe in shear.

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