



BEHAVIOUR OF CORROSION DAMAGED RC BEAMS WITH UDCGFRP LAMINATE

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Keywords

A B S T R A C T

Corrosion	This paper presents the results of an experimental study conducted to evaluate the performance of corrosion damaged reinforced concrete beams with glass fibre reinforced polymer (GFRP) laminates. A total of seven beam specimens 150 x 250x 3000 mm were cast and tested for the present investigation. One beam specimen was neither corroded nor strengthened to serve as virgin. Two beams were corroded to serve as corroded control. The reinforcement mass loss for the corroded beams was 10% and 25%, respectively. The remaining four beams were corroded and strengthened with Uni-Directional Cloth GFRP laminates. The ultimate strength and ductility of the corroded - strengthened specimens were improved by an average of 83% and 60% when compared to the control specimen.
Ductility	
GFRP	
Strength	
UDC	

1 INTRODUCTION

Soudki et al (2005) carried out an investigation on control of corrosion induced damage in reinforced concrete beams using carbon fibre reinforced polymer laminates. A total of eight large scale beams, each measuring 152x254x3200mm were tested. Two different corrosion configurations namely, Uniform corrosion and shear span corrosion, were used to represent corrosion in main reinforcement at locations of negative or positive flexural moment. The different degrees of corrosion were induced using an accelerated corrosion technique with an impressed current. Based on the results, the authors concluded that, GFRP laminate confinement reduces corrosion expansion by 70% and 65% for shear span and uniform corrosion beams respectively. Hassan et al (2009) performed a study on the Corrosion resistance of self-consolidating concrete in full-scale reinforced beams. The corrosion of steel reinforcement embedded in full scale self-consolidating concrete beams was (SCC) compared to normal concrete (NC). 400 × 363 × 2340 mm size beams containing epoxy- and non-epoxy-coated stirrups were monitored under an accelerated corrosion

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test.

The corrosion performance of NC/SCC beams was evaluated based on the results of current measurement, half-cell potential tests, chloride ion content, and mass loss and bar diameter degradation. The investigation also included the effect of admixture type and size of specimen on the corrosion performance. In general, SCC beams showed superior performance compared to their NC counterparts in terms of corrosion cracking, corrosion development rate, and half-cell potential values, rebar mass loss and rebar diameter reduction. Based on the results, it was concluded that the difference between SCC and NC mixes in terms of corrosion was more pronounced in large-scale beams and that the types of admixture used in SCC had no influence on the corrosion performance.

Pritpal et al (1997) conducted a study on Flexural Strength of Concrete Beams with Corroding Reinforcement. A total of 111 under-reinforced beams were subjected to accelerated corrosion damage by two external power supply sources and then tested under flexure. The beams were precured for different periods of up to 1 year before accelerated corrosion was induced in the reinforcement. Different degrees of reinforcing bar corrosion were induced in increments ranging from 1.25 to 10% at corrosion rates of 1, 2, 3 and 4 mA/cm². The beams were reinforced with two longitudinal bars, shear reinforcement was provided by external means using steel collars. Based on the results, the authors concluded that the period of precuring beams (up to 1 year) before corrosion is induced in their reinforcement has no influence on their flexural strength. The reduction in reinforcing bar cross section due to corrosion has a significant effect on the residual flexural strength of beams. The reduction in residual strength was primarily due to the loss (or) break down of the steel/concrete interfacial bond.

Bonacci et al (2000) reported a study on externally bonded fibre reinforced polymer for rehabilitation of corrosion damaged concrete beams. The authors considered the effects of corrosion-induced damage, load-induced damage and sustained load on the load-carrying capacity and deflection capacity of the CFRP strengthened beams. The results indicated that the efficiency of CFRP external reinforcement was reduced as a result of corrosion damage and that the layout of external reinforcement was more important than the amount used. A promising application of composite materials is in the strengthening and repair of reinforced concrete (RC) structures. Many researchers like almusalam (1996), Lee (1997) and Soudhi (1998) have shown that concrete repair using FRP laminates is very successful in restoring or increasing the strength of concrete members. A further promising aspect of FRP repair is the prevention of deterioration due to rebar corrosion by confinement of the concrete member. By strengthening concrete members with FRP laminates, concrete spalling and cracking caused by the expansive forces of the corrosion products may be delayed or even prevented. Based on different researcher's conclusion, the corrosion cracking around the steel rebar is an essential component contributing to the loss of structural strength. That is if corrosion cracking can be prevented, or at least reduced, a certain degree of structural strength may be maintained in a corroding R C beam. This study focuses such a relationship based on experimental data.

2 MATERIAL PROPERTIES

- Mix Proportion 1: 1.39: 3.08 with water cement ratio of 0.48
- Compressive Strength of concrete 29.7 MPa and Yield strength of HYSD bars 450.67MPa for tension reinforcement and 300.82MPa shear reinforcement.
- Uni-directional cloth glass fiber reinforced polymer (GFRP) sheets with 3mm and 5 mm thickness

were used for this study.

The mechanical properties of GFRP laminates are shown in Table 1.

Table 1 Mechanical Properties of GFRP Laminates

Type of Fibre	Thickness (mm)	Tensile Strength (MPa)	Ultimate Elongation (%)	Elasticity Modulus (MPa)
Glass fiber	3	446.9	3.02	13965.63
(uni- directional cloth)	5	451.5	2.6	17365.38

3 DETAILS OF TEST SPECIMEN

The reinforcement detail of the beam specimen consisted of two 10mm diameter bars at top and two 12mm diameter at bottom with the Shear reinforcement of 8mm diameter stirrups at 150mm spacing. For making external electrical connections, the 12mm diameter bars (bottom reinforcing steel) extended 50mm beyond the end concrete face. Details of the test program are presented in Table 2.

Table 2 Details of the Test Programme

Specimen	Level of Corrosion	Type of GFRP	GFRP Thickness(mm)
Virgin	0	-	-
A10%	10	-	-
A10 UDC3	10	UDC	3
A10 UDC5	10	UDC	5
A25	25	-	-
A25 UDC3	25	UDC	3
A25 UDC5	25	UDC	5

Note: A 10%, A25%, UDC3 and UDC5 refers to degrees of corrosion damage at 10 and 25% and UDC 3mm and 5mm thick respectively

3.1 Corrosion Process

The specimens were placed in a tank with 3.5% NaCl solution used as an electrolyte. The solution level in the tank was maintained to somewhat exceed the concrete cover plus reinforcing bar diameter to make adequate submersion of the longitudinal reinforcement. The specimens were provided with a direct current power supply with an output of 11Amps; thereby achieving theoretical steel mass loss of 10% and 25%.

According to Faraday's law,

$$\Delta w = \frac{A_m \cdot I \cdot t}{z \cdot F}$$

Where Δw is denoted for mass loss due to corrosion, A_m is for atomic mass of iron (55.85 g), I is corrosion current in amps, t = time since corrosion initiation (sec), Z = valency (assuming that most of rust product is due to $Fe(OH)_2$, Z is taken as 2), F = Faraday's constant 96487 coulombs (g/equivalent)]. Thus, by knowing the original mass of the rebar and the total current of the mass loss, the duration of corrosion activity can be determined.

3.2 Strengthening & Testing

All loose materials on the soffit of the beam were removed by using wire brush and roughening with a surface grinding machine. Two-component room temperature curing epoxy adhesive was applied for bonding the GFRP laminates. The laminated specimens were cured for a period of 7 days. The beam specimens were tested in a loading frame capacity of 750KN. By using mechanical dial gauges the deflections were measured at mid span and load points. The crack widths and curvature measurement was also done. The load was applied in consistent increments. The deflections, curvature and crack widths were measured at every load stage. The loading was continued until failure. The instrumentation and test set-up detail are shown in Fig.1.

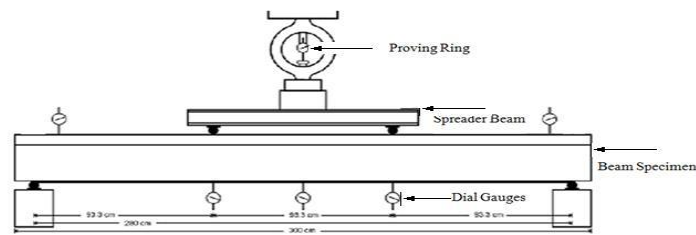


Fig. 1 Details of Instrumentation

4 RESULTS AND DISCUSSION

The test results on the strength properties and ductility performance of the beam specimens were presented in Table 3 and 4.

Table 3 Test Results on Strength

Designation	First Crack Load (kN)	Yield Load (kN)	Service Load (kN)	Ultimate Load (kN)	Maximum Crack Width (mm)
Virgin	26.98	51.5	47.41	71.123	1.2
A10%	19.62	34.34	34.34	51.5	1.24
A10UDC3	34.35	117.7	85.03	127.5	0.88
A10UDC5	36.78	120.17	88.29	132.43	0.88
A25%	12.26	29.43	31.09	46.59	1.3
A25UDC3	31.88	105.45	78.48	117.7	1.04
A25UDC5	34.335	110.36	85.03	127.53	1

Table 4 Test Results on Deformation

Designation	First Crack Load Deflection (mm)	Yield Load Deflection (mm)	Service Load Deflection (mm)	Ultimate Load Deflection (mm)
Virgin	2.36	8.43	6.5	40
A10%	0.83	7.75	7.75	36
A10UDC3	2.39	9.5	6.66	68
A10UDC5	1.85	10	5.63	75
A25%	2.2	7.25	10.56	32
A25UDC3	1.86	9.75	6.19	62
A25UDC5	1.07	10	4.88	70

The first crack loads were obtained by visual examination. The service loads were obtained from the ultimate loads with the usual partial safety factors. The yield loads were obtained (by inspection) corresponding to the stage of loading beyond which the load-deflection response was not linear. The

ultimate loads were obtained corresponding to the stage of loading beyond which the beam would not sustain additional deformation at the same load intensity.

The service load for beams with 3mm thick GFRP laminates exhibit an increase up to 86.22% at 10% and 79.35% at 25% mass loss respectively, compared to the virgin beam. Beams with 5mm thick GFRP laminates an increase up to 79.35% at 10% and 69% at 25% mass loss respectively, compared to the virgin beam. However the strength decreased by an average of 27.56 and 34.42% for 10 and 25% degrees corrosion damage respectively, for corroded un-strengthened specimens.

The yield load for beams with 5mm thick GFRP laminates exhibit an increase up to 133.33% at 10% and 114.29% at 25% mass loss respectively, compared to the virgin specimen. Beams with 3mm thick GFRP laminates exhibited an increase up to 133%, compared to the virgin beam. However, the strength decreased by an average of 37% for corroded un-strengthened specimens.

The ultimate load for beams with 5mm thick GFRP laminates exhibit an increase up to 86.22% at 10% and 79.30% at 25% mass loss respectively, compared the virgin beam. Beams with 3mm thick GFRP laminates an increase up to 86.2% at 10% and 79% at 25% mass loss respectively, compared to the virgin beam. However the strength decreased by an average of 27.58% and 34.49% for 10% and 25% degrees corrosion damage respectively, for corroded un-strengthened specimens. Based on the test results, it was found that GFRP laminates beneficial effects even at the corrosion-damaged stage.

The deflections got reduced at all load levels in GFRP strengthened beams, The deflection at yield load stage, UDCGFRP laminated beams exhibit a decrease of 17.28% at 10% mass loss and 83.78% at 25% mass loss, when compared to the corroded control beam. The deflection at the ultimate stage, UDCGFRP laminated beams exhibit a decrease of 24.35% at 10% mass loss and 20.08 at 25% mass loss, when compared to the corroded control beam. From the Table 3, It is clear that the corroded- GFRP strengthened specimens showed lesser crack width when compared to the control specimen, the maximum reduction being 33.33%.The deflection ductility performance of the corroded strengthened specimens was improved by an average of 60% when compared to the control specimen. But in the case of corroded unwrapped beams, the ductility values got reduced marginally.

5 CONCLUSIONS

The following conclusions are drawn based on the experimental results.

1. GFRP laminates properly bonded to the tension face RC beams increase the ultimate strength substantially. The UDCGFRP strengthened beams show signs of an increase up to 86% in ultimate strength for 10% steel mass loss and up to 79% at 25% steel mass loss when compared to the virgin specimen.
2. The deflections got reduced at all load levels in GFRP strengthened beams. At the ultimate stage, UDCGFRP laminated beams exhibit a decrease of 19% at 10% mass loss and 21.5% at 25% mass loss when compared to the corroded control beam (A10% and A25%).
3. UDCGFRP laminated beams show enhanced ductility. The increase in deflection ductility was found to be 62% at 10% mass loss and 58% at 25% mass loss.

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