EXPERIMENTAL STUDY ON THE INFLUENCE OF REINFORCEMENT CORROSION ON FIRE PERFORMANCE OF CONCRETE BEAM WRAPPED WITH GFRP

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Abstract - *One of the main causes of structural repairs worldwide is that the corrosion of ferroconcrete structures, like residential buildings and piers, which are exposed to harsh marine environments. This investigation aims to guage and compare the flexural parameters of the corroded concrete beam wrapped with GFRP specimens and ferroconcrete beam after fire exposure. Evaluation of the corrosion level of the specimens by mass loss measurements and crack scoring were done. For this adequate number of ferroconcrete beams are going to be caste and tested. After proper moist curing, all beams are corroded, in two phases, with accelerated corrosion test, then others were exposed to fireside, following the ASTM E-119-12 time-temperature curve. Finally, fire testing specimens are going to be tested for flexural strength by using the four-point loading method and compare the flexural properties of ferroconcrete beam with ferroconcrete beam wrapped with GFRP*

Key Words: GFRP, accelerated corrosion test, fire test, and corroded reinforced concrete beam

1. INTRODUCTION

The deterioration of civil engineering infrastructures such as buildings, bridge decks, girders, offshore structures, parking structures are mainly due to ageing, poor maintenance, corrosion, exposure to harmful environments. These deteriorated structures cannot take the load for which they are designed. A large number of structures constructed within the past using the older design codes in several parts of the world are structurally unsafe consistent with the new design codes and hence need up gradation. Corrosion leads to the decrease of the sectional area of reinforcement [W.P. Zhang et. al., 2012] and the reduction of the bond strength between the steel bar and concrete [Z.M. Ma, F.Z. Zhu, G.Z. Ba, 2019]. Corrosion can also change the shear transfer mechanisms of RC members. Elevated temperatures associated with fire exposure cause severe damage to reinforced concrete (RC) structures, resulting in loss of strength and stiffness and the development of relatively large permanent deformations during and following exposure [Lingzhu Chen et. al., 2019].

The degradation of both concrete and steel reinforcement alter mechanical properties and thus the redistribution of stresses within the beam after fire exposure .The corrosion products of steel bars used to reinforce concrete produce a high hoop tensile stress, which cause concrete cracking or spalling off [Guangzhong Ba, et.al, 2019]. In a fire, the cracks caused by the reinforcement corrosion provide passageways for warmth transfer into the concrete. It found that heat propagation tends to increase within the cracked regions compared with undamaged regions at elevated temperatures.

The exposure to fireside, either natural or man-induced, can aggravate the structural damage in already corroded structures. Structural fire safety is one among the most concerns in high rise buildings and bridges, where concrete members are often utilized because of innate to inherent good fire resistance of concrete materials. Structural members answer the high temperatures during a fire with a mixture of the subsequent detrimental effects: (1) Deterioration of fabric properties, i.e. the loss in mechanical strength, stiffness and durability; (2) No uniform temperatures and stress distributions across the cross sections; (3) Induced mechanical stresses thanks to thermal expansion and thermal gradient; and (4) Possible spalling of concrete, which changes the temperature distribution within the concrete and reinforcement. [Hadi, M. N. S. 2018].This mix can have devastating consequences on structural stability. As per the increasing the technologies and research, there are so many methods are introducing for retrofitting the structure in many advantages ways. Introduction of Fiber Reinforced Polymer (FRP) Composite is one among them.

Reinforced concrete structures near the coastlines are at very high risk of corrosion due to the high concentration of chloride ions in the environment. [Jialiang Liu et.al.

2019].More researches are contacted to increase the stability of structures in such areas. Due to the presence of high chloride ions structures may corrode and crack will form in the structural components. The corroded structures could be subjected to elevated temperatures due to a catastrophic fire, and the coupled effects of both corrosion and fire further deteriorate the integrity of the structure and cause earlier failure. The main goals of this research were: Based on the mass loss measurements and crack scoring, the level of corrosion is compared. Determine the flexural loading capacities and load-displacement response of the corroded reinforced concrete beam wrapped with GFRP and corroded reinforced concrete beam after fire exposure.

2. MATERIALS AND EXPERIMENTAL DETAILS

2.1 Design and Manufacturing Specimen

Sixteen identical beams were designed and manufactured with a total length of 500 mm and section size of 150 x 150 mm and a concrete cover of 25 mm. Among the sixteen identical RC beams, uncorrored Specimen II-1, Specimen II-2 were used for the loading test to obtain its ultimate beating capacity. The concrete mixture consisted of ordinary Portland cement, natural river sand is passing through 4.75 mm sieve and having a specific gravity of 2.59 and the coarse aggregates of two grades are used one retained on 10 mm size sieve and another grade aggregates retained on 20 mm size sieve. The maximum size of coarse aggregate was 20 mm and is having specific gravity of 2.85.the cement sand and aggregate proportion by weight were 1:1.199:2.33 with a water cement ratio of 0.4. The compressive compressive strength achieved by concrete cube at 28 days was 32.96 MPa. Mix proportion of the concrete are shown in Table 1.

Table -1: Details of M25 concrete

Mix proportion of concrete (kg/m^3)				
cement	Fine aggregate	Coarse aggregate	water	Water cement ratio
502.825	603.26	1175.99	201.13	0.4

All the specimen is identical with same arrangement of 2 numbers of 10 mm φ HYSD bars and three bars of 8 mm φ steel bars as stirrups. The yields strength of the specimens (10 mm φ and 8 mm φ) are averaged 532 (N/mm^2) and 523 (N/mm^2). The modulus of elasticity of steel bars was 2×10^5 MPa. Longitudinal tensile reinforcements were extended 50 mm at both ends, and they were used to accommodate the extra power required during the accelerated corrosion tests.

2.2 Accelerated corrosion tests

In this experiment, the acceleration corrosion tests was done in two phase. The specimen in the first phase, the specimens were used for determining the crack score and material loss of reinforcement bar. Second phase specimen were used for determine the flexural load capacities of beam.

2.2.1 Phase I specimens accelerated corrosion

Beam specimens were corroded within the same marine-simulated environment, that is, a tank crammed with 5% NaCl solution. An initial DC voltage of 30V was applied following the procedure distributed by Andrade (2008). After seen a really high and explosion in current, and an oversized quantity of corrosion products within the tank (saline water turned orange), then the DC voltage supply was reduced to 5V after 30 hours. At 103 hours, the voltage was increased to 12V because significant current increases weren't observed. The test was ended at 127 hours due to the massive quantity of corrosion products within the water and therefore the severe concrete spalling within the beams.

2.2.2 Phase II specimens accelerated corrosion

The experimental setup was similar to that of the phase I. Direct current passing through the specimen remain constant throughout the experiment. Different degrees of corrosion is tabulated within the Table 2. The specimens being subjected to the accelerated corrosion procedure within the same 130 gallon plastic tank.

2.3 Crack Scoring

Based crack scoring criteria, crack score is evaluated. The number of cracks, their average lengths, and maximum widths were measured, the total crack score per specimen, Cs, was calculated as shown in the following equation (1).

Cs = No of cracks x average crack length x average max crack width (1)

Table -2: Time calculation for different degree of corrosion

Percentage of Corrosion	Current (Amps)	Duration of Corrosion (Days)
2.5	10	9
5	10	15
7.5	10	20

2.4 Measurement of Reinforcement Corrosion

The corroded rebar were initial immersed in acid solution for 30 mins before being sent to alkali solution for a further 10 mins. Afterwards, wetting and drying process were done simultaneously. The specimens were weighted at the accurate level of 0.01g. The loss percentage of rebar was studied by Equation (2).

$$\text{Mass loss} = \frac{W - W_c}{W} \times 100 \qquad (2)$$

Where W and Wc are the weight of bars before and after the deterioration, respectively. The averaged diameter of at least six measurements the specimen of corrored rebar gives the value for the area of cross-section of reinforcement. Cross-section area loss of reinforcements can be determined by Equation (3).

$$\text{Section area loss} = \frac{F - F_{min}}{F} \times 100 \qquad (3)$$

Where F and F_{min} are the section areas of bar before and after the corrosion, respectively.

2.5 Fire Testing

Six specimens were exposed to elevated temperature following the temperature curve of ASTM E-119-12 "Standard Test Methods for Fire Tests of Building Construction and for Fire Tests of Building Construction and Materials, and taking into account the reduction in time for small scale specimens, based on the test findings of Young (2006). Small scale specimens, based on the test findings of Young (2006).An Olympic 2827G Torchbearer gas kiln was used for the fire testing of all the specimens Figure 1.

Fig-1:.Gas kiln used for fire test

2.6 Load -Bearing Capacity Test

Load bearing capacity of the corroded beam and the corroded beam wrapped with GFRP was determined using the four-point loading method, according to ASTM C78 - "Standard Test Method for Flexural Strength of Concrete.

3. RESULT AND DISCUSSION

3.1 Cracking and Material Loss Evaluation

In first phase specimens, a large amount of concrete were peeled out due to the weak bonding of reinforcement and the concrete. After the accelerated corrosion process the beams became more weak and instable. The crack scores for the Phase I specimens, are summarized in the histogram, Figure 2.The mass losses of the reinforcing bars of Phase I specimens, were measured as summarized in the histogram, Figure.3.

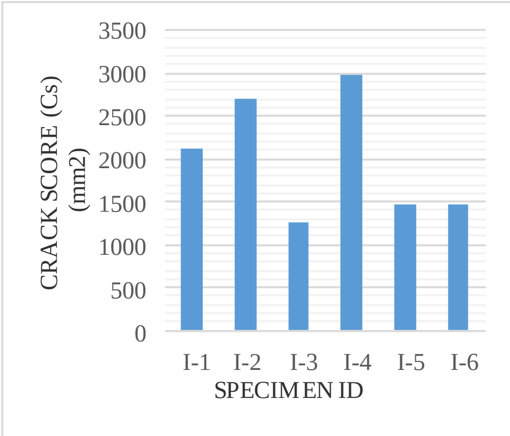

Fig-2: Crack Scores for Phase I, specimens

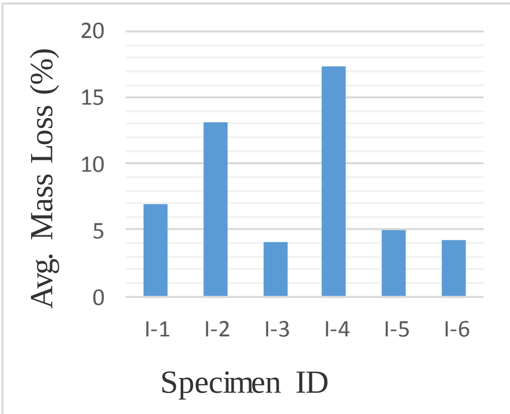

Fig-3: Phase I, Rebar Mass Losses

As the specimen is subjected to same corrosion, some of the beams show high level of corrosion compared with other ones. This is because of the localized corrosion. This leads to the premature spallation of concrete, leading to extreme loss of cross- sectional area of the rebar. Table 3. records the observations of whether corrosion pitting corrosion or uniform corrosion occurred in the specimens. As the level of corrosion increases, there was a rise in the mass loss, this leads to the pitting corrosion.

Most specimens of Phase I, specimens, experienced a corrosion mass loss of less than 7%, with only two specimens presenting corrosion mass loss above 10%, due to localized corrosion of the rebar. The three least corroded specimens (I-3, I-5, and I-6) had the three corresponding lowest crack scores. However, due to some corrosion-induced segmental deboning, occurring at the end of the specimens, higher crack scores were observed for specimens I-1, I-2, and I-4.

As the Table 3, two forms of corrosion were spot out in the reinforcements, specified as uniform corrosion as well as pitting corrosion. The horizontal corrosion in the steel bar was quantitatively evaluated from the perspective of mass loss and cross-sectional loss. For samples corroded only under uniform corrosion, the ratio of mass loss to cross-sectional loss is approximately 1.0, which indicates that both the mass loss and the cross-sectional area loss of the steel bar may reflect the degree of corrosion of the steel bar. When the steel bars are corroded in a uniform manner, both methods can effectively measure the corrosion state. The samples with pits show that the ratio of mass loss to cross-sectional area loss is much less than 1.0. Therefore, the quality loss of the steel bar cannot properly represent the corrosion level, because the occurrence of pitting corrosion significantly affects the mechanical properties of the steel bar due to the modification of the cross-sectional area.

3.2 Flexural Testing

After the corrosion of phase II specimens, were subjected to fire in the kiln. For every 15 min the temperature were measures and plotted. The ASTM E 119-12 temperature curve, as shown in Figure 4. As the specimen were corroded in different degree of corrosion ,the beam show a severe spalling of concrete and show a reduction in the strength of the beam compared with the controlled beam.Table 4 shows Ultimate Load & Deflection for Different Percentages of Beams corrosion. Table 5 show the Ultimate Load & Deflection for Different Percentages of corroded Beams wrapped with GFRP.

3.3 Load Vs Deflection Curves for Specimen

Four-point static loading was done on the beam and at each increment of 5 kN, deflections were taken. All the specimen show a reduction in the load carrying capacity. Using this load and deflection of beam, load vs deflection curves were plotted. At the load of 25 kN initial cracks were started on the beam. As the load increases the cracks started propagating throughout the length. The specimen wrapped with GFRP show a positive nature in attain load carrying capacity. Figure 5 and Figure 6 shows the load vs. deflection curves for corroded concrete beam wrapped with GFRP specimens and reinforced concrete beam after fire exposure.

Table 3: Phase I, Rebar Mass Loss Measurements

Specimen ID	Mass Loss (%)	Note
I-1	6.97	Corrosion-induced segmental debonding/Pitting corrosion
I-2	13.10	Corrosion-induced segmental debonding/Pitting corrosion
I-3	4.08	Uniform corrosion
I-4	17.35	Corrosion-induced segmental debonding/ Pitting corrosion
I-5	4.93	Uniform corrosion
I-6	4.17	Uniform corrosion

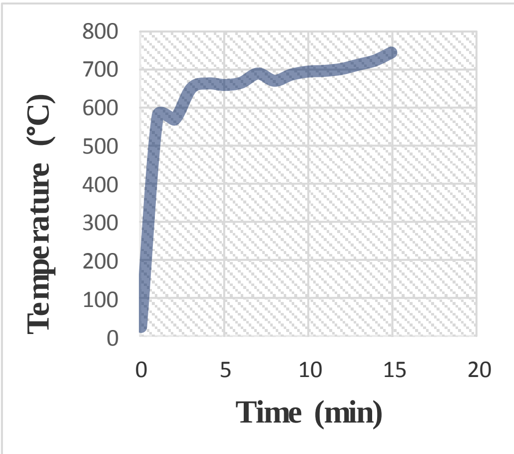

Fig-4: Temperature curve of fire exposure of Phase I beams

The 0% corroded beams increases the load carrying capacity 14% when strengthened with 1.2mm thick of GFRP sheet. After strengthening the 2.5%, 5%, 7.5% corroded beams the flexural loading capacity of the beam increases by 7%, 5% and 2%.

Table: 4 Ultimate Load & Deflection for Different Percentages of Beams corrosion

Specimen ID	Beam Specimen	Initial Crack Load (kN)	Ultimate Load (kN)	Deflectio n (mm)
Specimen II-1	0 %	25	95	10.2
Specimen II-3	2.5%	20	90	12.1
Specimen II-4	5%	15	85	10.6
Specimen II-5	7.5%	10	70	8.9

Table: 5 Ultimate Load & Deflection for Different Percentages of corroded Beams wrapped with GFRP

Specimen ID	Beam Specimen	Initial Crack Load (kN)	Ultimate Load (kN)	Deflection (mm)
Specimen II-1	0 %	25	95	10.2
Specimen II-3	2.5%	20	90	12.1
Specimen II-4	5%	15	85	10.6
Specimen II-5	7.5%	10	70	8.9

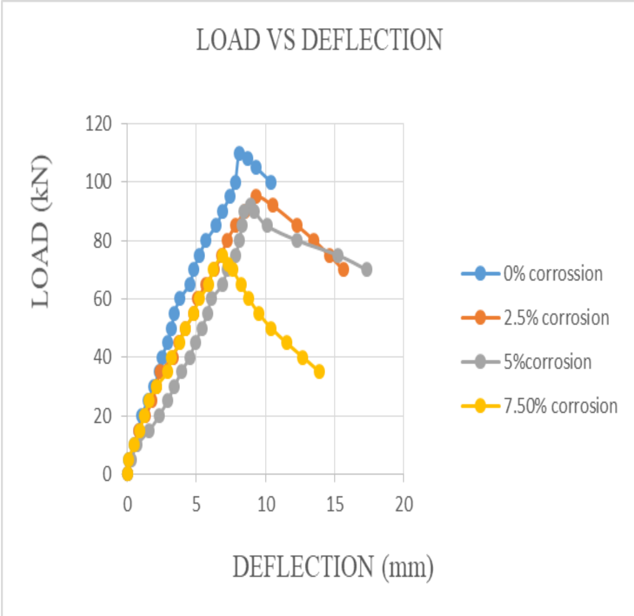

Fig-5: shows the load vs. deflection curves for corroded and reinforced concrete beam after fire exposure.

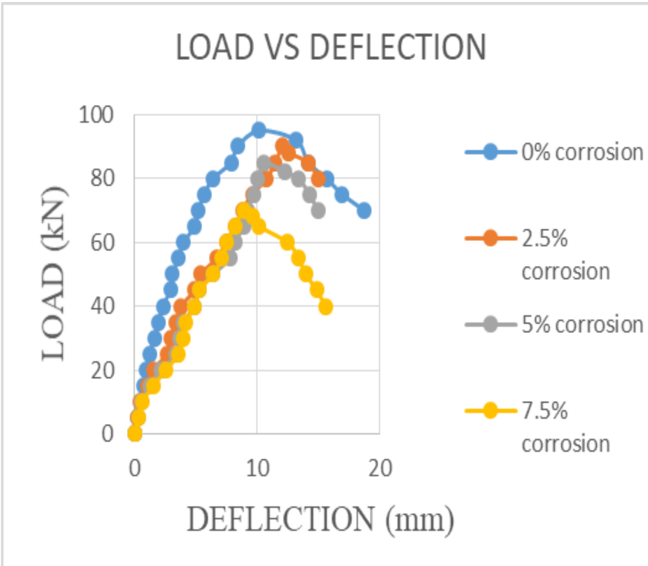

Fig-6: shows the load vs. deflection curves for corroded concrete beam after fire exposure wrapped with GFRP specimens.

4. CONCLUSIONS AND FURTHER RESEARCH

- As the corrosion period increases the rate of corrosion also start increasing. Corrosion level of steel bars should be estimated based on cross-sectional area loss rather than quality loss, especially for steel bars with corroded pits. Through the loss of cross-sectional area to enhance the degree of corrosion of steel, especially for pitting corrosion of steel.

- Flexural loading capacity of the corroded and fired can be improved when the beams was wrapped externally with GFRP sheets.
- The initial cracks in the strengthened beams are formed at a higher load compared to the ones in the control beam.
- The 0% corroded beams increases the load carrying capacity 14% when strengthened with 1.2mm thick of GFRP sheet.
- The 2.5 % corroded beams increases ultimate load carrying capacity by 7 % when strengthened with 1.2mm thick of GFRP sheet.
- The 5 %and 7.5 % corroded beams increases ultimate load carrying capacity by 5% and 2% respectively when strengthened with 1.2mm thick of GFRP sheet.
- Usage of GFRP sheets upgrade the load carrying capacity; the crack propagation and toughness of beam can be detained. Decrees in the deflection indicates the rise in stiffness.
- This paper has conducted a preliminary study on the influence of steel bar corrosion on the fire resistance of concrete beams, but there are still some limitations that need further study. The percentage of the package is different, and the result is compared with the control beam. FRP strengthening of corroded and fired RC beam with different types of fibers such as carbon, aramid & basalt. Strengthening of corroded and fired RC beam weak in shear. The flexural behavior of corroded and fired reinforced concrete beams strengthened with different sizes of GFRP sheets.

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