# Strengthening Of Corrosion Damaged RC Beams Using Mechanically Fastened CFRP Composites

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***Abstract:*** **Reinforced Concrete structures are suffering from various deteriorations like corrosion, cracks, spalling and large deflection. These deteriorations are caused by various factors such as aging, corrosion of steel reinforcement, environmental effects and accidental impacts on the structure. There are several options available for retrofitting the structural members of the existing reinforced concrete structures. Bonding of thin steel plates is the common method of retrofitting. Nowadays, bonding using fiber reinforced polymer sheets on to the damaged members helps to increase load carrying capacity, ductility and stiffness of the damaged structure. Such technique is an effective way to improve the flexural and shear performance of the reinforced concrete damaged structure. This project mainly focused on retrofitting the corrosion damaged reinforced concrete beams using mechanically fastened carbon fiber reinforced laminates. This type of retrofitting increases the load carrying capacity of the corrosion damaged reinforced concrete beams. It also increases the flexural and fatigue strength of the damaged reinforced concrete beam. Here, the general review of literature on the reinforced concrete structures, in which FRP used for strengthening purpose, is briefly presented and they were listed in the references at the end of the report.**

***Keywords*****: Rectification of damaged RC beams, Flexural strength, Load carrying capacity, Mechanical fastening of CFRP laminates. CB – Control beam, FWB – Fibre wrapped beam, FWB-MF – Fibre wrapped mechanically fastened beam.**

## I. INTRODUCTION

Due to several reasons the infrastructure concerned with Reinforced Concrete (RC) structures are found to be structurally inadequate and the ageing of such structures also often reported. The decrease in the performance of RC structures may due to insufficient design, low-quality construction, or environmental conditions (harsh weather and/or seismic loading). In addition corrosion of reinforcing steel is a major problem facing the concrete infrastructure. The corrosion products occupy a larger volume than the original steel which exert substantial tensile forces on the surrounding concrete and causes it to crack and spall off. Therefore the engineers are constrained to implement new materials and strengthening techniques to efficiently combat this problem. In the past section enlargement method has been proved as a suitable method for the rehabilitation of reinforced concrete structures. However, it resulted in a significant increase in the column cross-section and comparatively construction time is long. Compared to the above method, plate bonding technique provides a practical and cost effective solution. The earliest investigators utilized steel plates for external strengthening. Though the technique was successful in practice, it posed some harms such as adding self weight, required heavy lifting equipment to place the plates in position, difficulty in shaping and fitting in complex profiles and complication in bonding/welding and furthermore added plates are susceptible to corrosion which leads to an increase in future maintenance costs. In contrast, rehabilitation using fiber reinforced polymer (FRP) composites do not exhibit any of these drawbacks. Due to their in-service and superior mechanical properties, fiber reinforced polymer composites make them excellent candidate after upgrading of structures and many researchers have attempted to the use of externally bonded FRP composites for the strengthening of RC structures.

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**Table.1: Mixing Ratio**

| Water content, W | Cement content, C | Fine Aggregate, F.A | Coarse Aggregate, C.A |
|---|---|---|---|
| 177 kg/m3 | 402.3 kg/m3 | 616.5 kg/m3 | 1152 kg/m3 |
| 0.44 | 1 | 1.6 | 2.9 |

**Fig.1: CFRP Laminate**

## II. RESULT

***LOAD-DEFLECTION BEHAVIOUR:***

Load-deflection behavior of CFRP strengthened beams with respect to control specimen is shown in Fig 5.7 to 5.9. Until reach the failure load of control beam, all the strengthened beams with both the wrapping schemes exhibited linear elastic behavior, followed by inelastic behavior when increasing the load. As expected external bonding of CFRP significantly reduce the deflection and also enhance the stiffness of the beam compared to the control beam. The beam strengthened by full wrapping with one and two layers CFRP significantly control the mid-span deflection compared to that of control beam as shown in Fig 5.9.

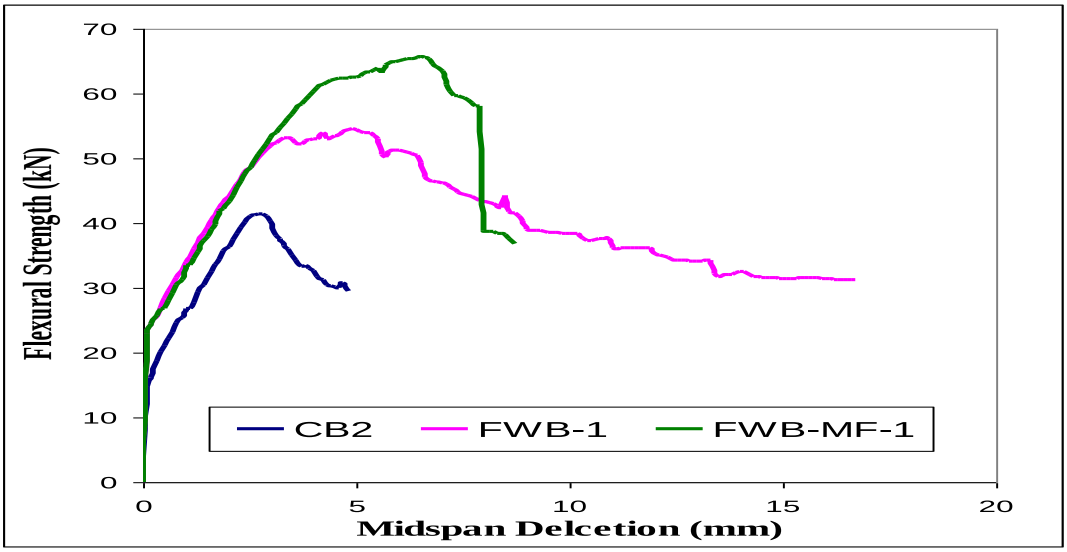


**Fig. 2: Load-Deflection behaviour of CB2, FWB-1and FWB-MF-1-Comparision**

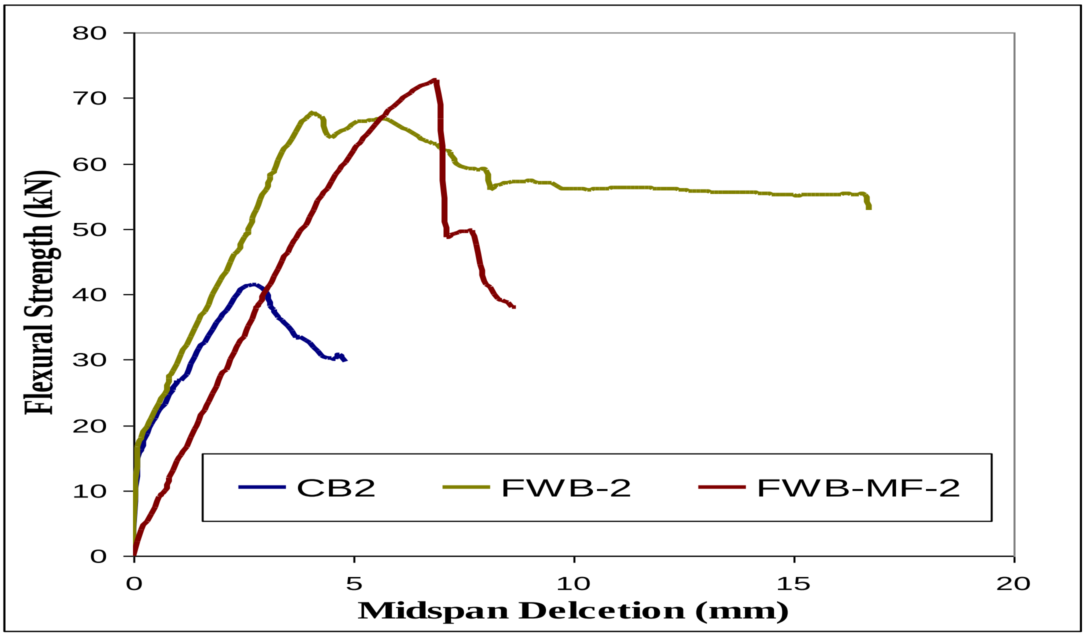


**Fig. 3: Load-Deflection behaviour of CB2, FWB-2and FWB-MF-2-Comparision**

Comparing the behavior of beam FWB-1 and FWB-2 to that of control beam (CB2), all two beams showed significantly enhancement in stiffness and deflection control especially the behavior of FWB-2 was outperformed. At the respective failure load of control beam, the mid span deflection of beams FWB-1 and FWB-2 were 16.9mm and 21mm and this deflection was 3.5 times lesser than that of control beam. Compared to control beam, enhancement in deflection control of beams FWB-1 and FWB-2 were 150% and 256% respectively. The above difference in deflection control attributed to the presence of CFRP layers, while increasing the number of layers, the fiber lie in the outer limits provides required tensile capacity during large bending. In the case of beams FWB-MF-1 and FWB-MF-2, the introduction of fasteners, further reduce the deflection especially in the case beam FWB-MF-2. The beams FWB-MF-1 and FWB-MF-2 enhanced its defection control by 7% and 8% when compared to the CB2.

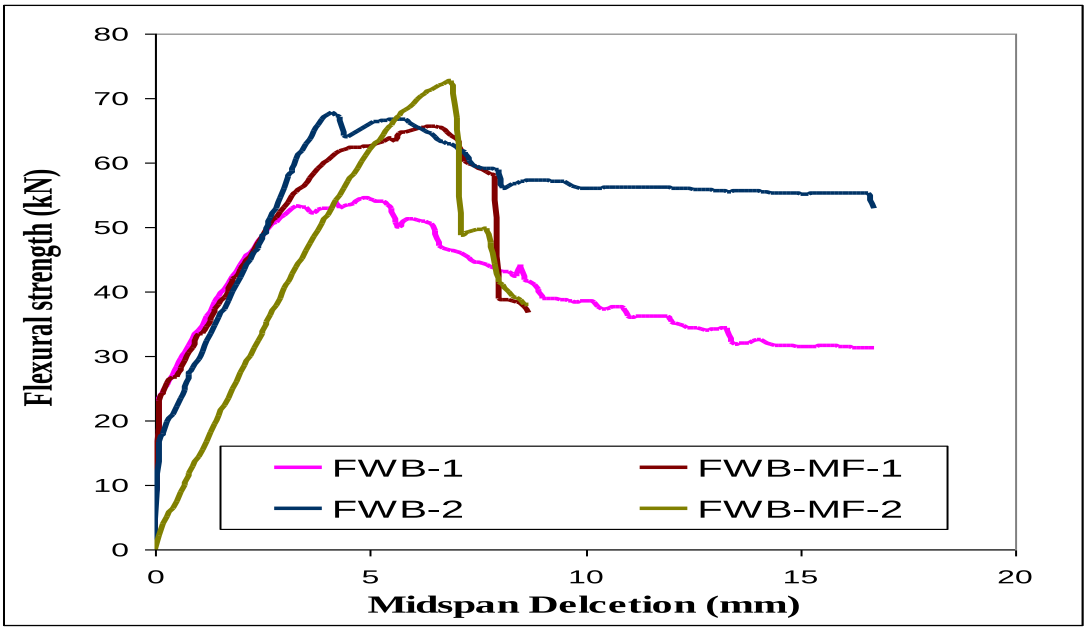


**Fig. 4: Load-Deflection behaviour of all beams -Comparison**

Comparing the behaviour of beams FWB-MF-1 and FWB-MF-2 with respect to beams FWB-1 and FWB-2, the deflection control was 5% and 10% respectively. This is a result of the fact that the fasteners lie in the outer limit increasing the bond between the concrete and CFRP as a result the substantial load transfer was occurred. Another possible reason was introduction of fasteners reduce the effective span of the CFRP as a result during bending tensile strength provide by the CFRP was increased.

***FLEXURAL STRENGTH:***

The main objective of this study is to enhance the flexural capacity of the RC beams using CFRP fabrics. As expected, the external bonding of fibre significantly increases the moment carrying capacity of the RC beams especially for the beam strengthened with mechanical fasteners. Fig 5.10 shows the enhancement in moment carrying capacity of beams strengthened by with and without fasteners by CFRP with respect to control beam.

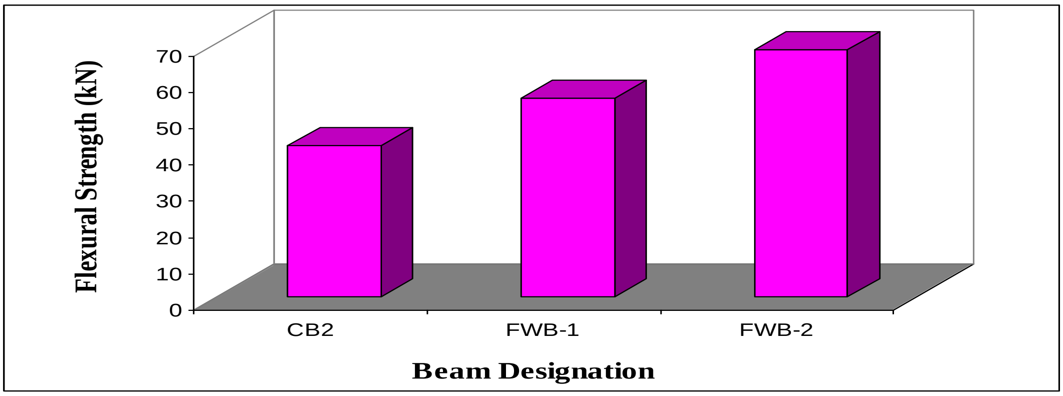


**Fig. 5: Flexural strength of beams strengthened by CFRP without fasteners**

The results obtained from these strengthening technique revealed that, the presence of CFRP in the outer limits considerably increase the flexural strength of the beam especially for the beam strengthened by two layers with fasteners. The enhancement in moment carrying capacity of beams FWB-1 and FWB-2 were found to be 25%, and 47% more than that of control beam (CB2). The increase in strength is attributed to the CFRP lies in the outer limits considerably provide the tensile strength during bending as a result the flexural strength of the beam was increased.

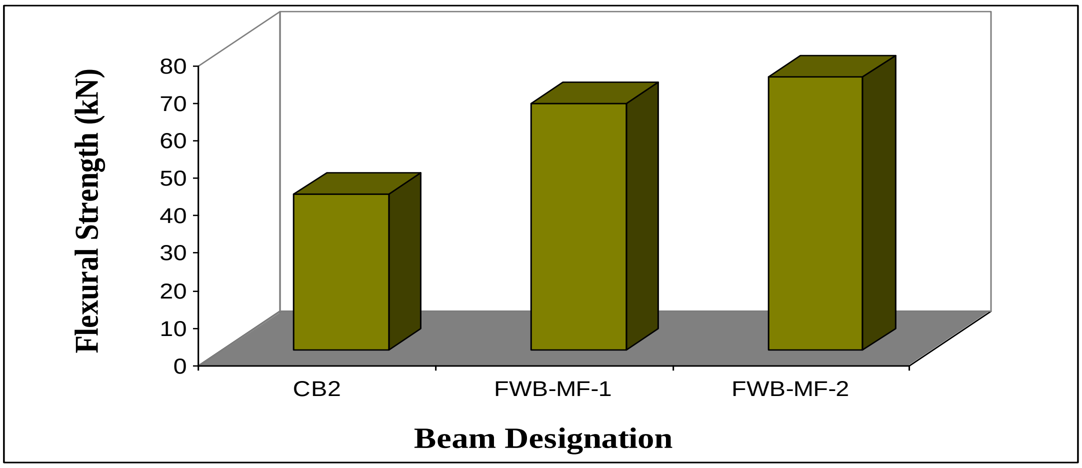


**Fig. 6: Flexural strength of beams strengthened by CFRP with fasteners**

It can be seen from Fig 5.11 that, the beams FWB-MF-1 and FWB-MF-2 increased their flexural strength by 25%, and 47% respectively, when compared to the CB2. Comparing the flexural strength of beam FWB-MF-1 and FWB-MF-2 to that of FWB-1 and FWB-2, beam FWB-MF-1 and FWB-MF-2 enhanced its flexural strength by 4% and 3%. The increase in strength when introducing the fasteners was due to the fasteners lie in the outer limit increasing the bond between the concrete and CFRP as a result the substantial load transfer was occurred. Another possible reason was introduction of fasteners reduce the effective span of the CFRP as a result during bending tensile strength provide by the CFRP was increased.

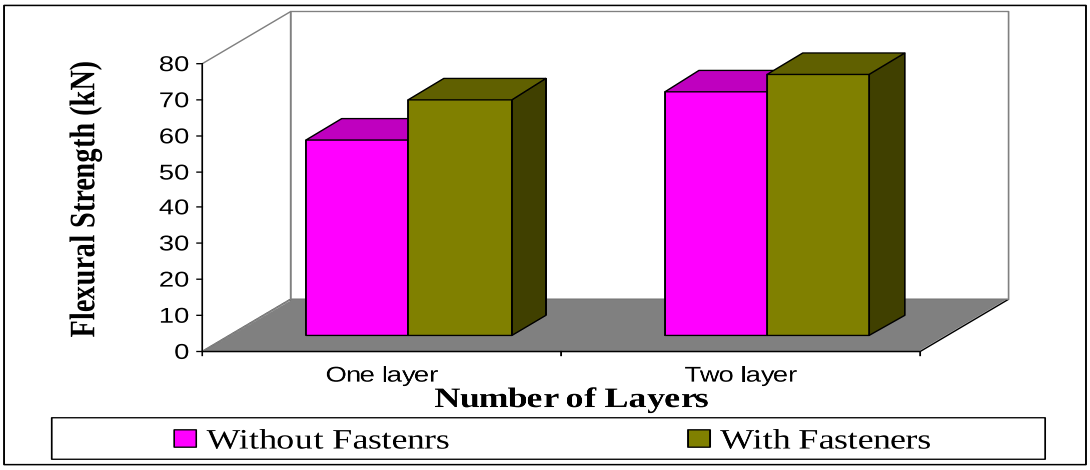


**Fig.7: Flexural strength of all beams strengthened by CFRP -Comparison**

## III. CONCLUSION

Beams FWB -1 and FWB-2 were strengthened by one and two layers of CFRP without fasteners were failed by bending cum shear failure, In addition no rupture of fiber was observed. Beams FWB-MF-1 and FWB-MF-2, the introduction of fasteners change the failure mode and the beams were failed by rupture of fiber. From the observation it can be confirmed that the presence of fasteners significantly increase the bond between the CFRP and the RC beams.

Compared to control beam, enhancement in deflection control of beams FWB-1 and FWB-2 were 150% and 256% respectively. The above difference in deflection control attributed to the presence of CFRP layers, while increasing the number of layers, the fiber lie in the outer limits provides required tensile capacity during large bending.

Comparing the behaviour of beams FWB-MF-1 and FWB-MF-2 with respect to beams FWB-1 and FWB-2, the deflection control was 5% and 10% respectively. This is a result of the fact that the fasteners lie in the outer limit increasing the bond between the concrete and CFRP as a result the substantial load transfer was occurred. Another possible reason was introduction of fasteners reduce the effective span of the CFRP as a result during bending tensile strength provide by the CFRP was increased.

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