Double vertical carbon fiber reinforced polymer plates strengthened to reinforced concrete beams for six months saltwater exposure

Amiruddin Mishad1*, Mohd Hisbany Mohd Hashim2, Azmi Ibrahim1 and Aidan Newman1

1Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia
2Faculty of Civil Engineering, Universiti Teknologi MARA, Pulau Pinang, Malaysia

*Corresponding author: amiruddinmishad@salam.uitm.edu.my

Abstract. Reinforced concrete structures might require rehabilitation after years exposed to extreme environment conditions. The use of Fiber Reinforced Polymer (FRP) material in construction industry has become popular due to its properties such as high tensile strength, durable and lightweight which can be used to improve mechanical behavior of structures. This research emphasis on the use of Carbon Fiber Reinforced Polymer (CFRP) to improve the flexural performance of reinforced concrete beam which is exposed to saltwater for 6 months. The purposes of this research are to determine the maximum flexural strength of normal reinforced concrete beam and reinforced beam strengthened with CFRP plate and to determine the effects of salt water on the flexural strength of concrete beam reinforced with CFRP plate. Two beam samples with dimension of 125mm x 300mm x 1800mm were prepared labelled as control beam and specimen beam respectively. The control beam was cure in fresh water while the specimen beam was cured in salt water for 28 days. All of the beams were tested using four point bending test. The control beam was tested until failure whereas the specimen was subjected to 30% of maximum load from control beam as pre-cracking load. The specimen beam was repaired by installing CFRP plate using near surface mounted (NSM) and is immerse in saltwater for another 6 months. After 6 months, the specimen beam was tested until failure. As a result, the flexural strength for normal beam and specimen beam is slightly the same. The specimen beam has form modes of failure known as concrete cover separation. It is also found that saltwater exposure did affect the performance of beam that has been repaired.

1. Introduction
The main significance of this research is to promote the use of Carbon Fiber-Reinforced Polymer (CFRP) in the construction industry. CFRP is one of the most suitable alternatives to replace the use of steel reinforcement bar in strengthening and repairing of new and old structure. CFRP not only can enhance the performance of the structure, but it can also extend the life of the structure providing long lasting age.

Research show that carbon fiber reinforced polymer (CFRP) has been used to strengthen reinforced concrete beam and enhance its flexural performance. Flexural failure occurs due to excessive load apply on the beam. It also happens due to the condition of the steel reinforced bar inside the beam. When the steel reinforcement bar is corroded causing the strength to decrease, it will result in the
inability for the beam to sustain load. Alternative to that problem, CFRP plate is used so that it can improve the strength and load carrying capacity of the concrete beam. Other than that, CFRP is more durable compare to steel reinforcement bar since it can stand the adverse effects of environment. It has high corrosion resistance against salt water.

Meanwhile, this research can also help the construction industry to reduce the cost in strengthening, rehabilitation and maintaining of new and old structures. Since the cost of repairing and rehabilitation mainly depends on the degree of damage occurs, the introduction to CFRP can reduce the cost in terms of material since CFRP is cheaper than steel and maintenance since it requires less maintenance due to its durability. CFRP also have other good properties such as high strength and long lasting compare to steel.

Fiber reinforced polymer (FRP) or fiber reinforced plastic, is a non-metal reinforcement which is made of glass, carbon or aramid. FRP is a suitable materials used in construction, especially for structure exposed to extreme environment condition such as saltwater from the sea due to its durability and high resistance to corrosion. Recently, Fiber Reinforced Polymer (FRP) composites have developed as a potential answer for issues regarding infrastructure [1]. Plus, FRP can be used to repair and strengthen beams, slabs and columns even after the structure has been damaged due to excessive loading. Civil engineers have been attracted to FRP materials due to its electrochemical corrosion resistance, high weight-to-strength ratio and fabrication versatility [1].

FRP has also offer benefits to construction industry due to its ability to reduce crack and enhance the structures performance. Various researches have been conduct on the use of FRP materials in strengthening of structures. Therefore, FRP has turned out to be progressively noticeable in strengthening and rehabilitation of reinforced concrete structure [2].

Carbon Fiber Reinforced Polymer (CFRP) is the latest high performance composite material which serves numerous benefits such as extended breaking length, corrosion less and superb fatigue resistance [3]. Besides that, the ultimate load carrying capacity of beam can also be increased by up to 53% [1]. Furthermore, CFRP is a wide known material due to its superior properties such as durability, corrosion resistance, flexible application, easy handling and installation and high strength to weight ratio [4]. According to [2], by using CFRP in strengthening structure can be improved the performance of RC beams by increasing the load capacity as nearly as double of unstrengthen beams. Therefore, CFRP is the potential solution to overcome this problem. In addition, based on [4], both CFRP bars and strips are effective methods to improve the shear capacity of RC beams. Reinforced concrete structures commonly lack in shear strength because of insufficient shear reinforcement of steel area due to excessive loads, corrosion and construction defects.

Near surface mounted (NSM) is one of the strengthening techniques that has been commonly used in strengthen reinforced concrete structures [5]. This technique requires the CFRP plate to be inserted into grooves on the beam surface and then bonded using epoxy adhesive. Application of near surface mounted CFRP strips is practical and effective for strengthening and repair damage concrete structures [1]. Shear failure in concrete structure normally occurs due to corrosion, overloading and lack of reinforcement in concrete structure itself. However, this issue can be overcome by using NSM techniques. NSM CFRP method gives more advantages compared to EBR method, which includes reduced of debonding risk, efficient FRP material utilization and a better external damage protection [6]. Bond behavior is the most essential issues in NSM techniques that require further studies. Bond behavior is important during the loading process of reinforced concrete element since it allows the transfer of stress between the concrete and the reinforcement [7]. The bond behavior can affect the load carrying capacity and serviceability of the concrete structure.

2. Flexural strength test
Generally, the objective of using bending test machine is to determine the maximum flexural strength and the deflection of RC beam when subjected to loading. Rectangular RC beam (control beam) and RC beam strengthened with carbon fiber reinforced polymer (CFRP) plate are the specimens used in
this test. The design of reinforcement concrete beam is refer to [8]. The setup of this test is shown in Figure 1.

![Image](image.png)

Figure 1. Setting up of four point bending test.

In this study, two RC beam specimens were prepared. Both of the RC beam specimens were in the same dimension, which is 150mm x 300mm and 1800mm length Figure 2. The beam specimens are also prepared using concrete grade of 30N/mm² and reinforced with steel bar of 12mm diameter and shear link of 6mm diameter.

One of the RC beam specimens is used as control specimen while the other is strengthened with two carbon fiber reinforced polymer (CFRP) plate in vertical position after pre-cracking. The (CFRP) plate used in this study has a dimension of 1.2mm thickness, 50mm width and 1800mm length. This CFRP plate is used to strengthen the RC beam using near surface mounted (NSM) method. The dimension and position of CFRP plate is shown in Figure 3.

The control beam in this study was undergone bending test until failure to determine the maximum applied load. The other beam specimen is exposed in saltwater with ratio of 1 liter of water equal to 40 gram of salt for 28 days. After 28 days, the beam will be subjected with 30 percent of maximum applied load of control beam specimen load until pre-cracked. As soon as the beam cracks, it will be repair and strengthen with carbon fiber reinforced polymer (CFRP) plate attached smooth groove line by using near surface mounted (NSM) method. The purpose of using salt water solution is to represent the condition of beam exposed to sea water. By doing this, the ability of CFRP plate and effectiveness of NSM method can be determined and further studied for future improvement. The four point bending test set up is shown in Figure 4.

In this research, the control specimen was installed with 3 concrete strain gauges (labelled strain gauge 6, 7 and 8) and 2 steel reinforcement strain gauges (labelled strain gauge 4 and 5). Whereas, specimen beam was installed with 3 concrete strain gauges and 2 steel strain gauges which was the same labelling as control beam, but with additional 3 CFRP strain gauges (labelled strain gauge 1, 2 and 3). Other than that, the beams were also installed with Linear Variable Displacement Transformer (LVDT) during the testing to measure the value of deflection. The location of the strain gauges and LVDT are shown in Figure 5.
Figure 2. Dimension of beam.

Figure 3. Dimension and position of CFRP plate.

Figure 4. Four point bending test set up.
3. Result and discussion

3.1. Load versus displacement

The result of bending test for control beam and beam strengthened with double vertical CFRP plate is shown in Table 1 and Figure 6. The flexural strength of reinforced concrete beam depends solely on the steel reinforcement performance to cater tensile stress produce during bending test. However, the performance can be affected due to the presence of saltwater. So, in order to improve the flexural strength of reinforced concrete beam that was exposed to saltwater, CFRP plate is used.

Table 1 shows that control beam has higher displacement value compared to the one strengthened with two vertical CFRP plate installed using NSM method. Figure 6 shows the load vs deflection graph of both control beam and the one strengthened with CFRP. The beam strengthened with CFRP tends to cater load which is more or less the same as control beam. This might be due to the fact that the beam has been exposed to saltwater for 6 months. It also gave a slightly lower deflection value at the ultimate load compared to control beam. Based on these observations, the strengthened beam has similar mechanical properties with the control beam, where the deflection value of both beams is almost the same. The ultimate load where both beam starts to fail is also slightly different. This might be due to the exposure of the strengthened beam to salt water for 6 months. This exposure might have caused the concrete to lose its compressive strength or even deterioration of the steel reinforcement inside the concrete. As a result, both beams have more or less the similar mechanical properties.

However, it is verified that CFRP can be used as a strengthening material to improve the flexural performance of reinforced concrete even after it has been repaired due to pre-cracked loading and expose to salt water. It is proven that CFRP is able to resist the tensile force in the beam even though in this case, it does not increase the flexural strength of the beam itself.
3.2. Load versus strain

In this research, there are 3 concrete strain gauges used labelled strain gauge 6, 7 and 8 for the control beam. Based on Figure 7, strain gauge 6 give a strain reading of 0.001409 at ultimate load of 113.14kN where it starts to break. On the other hand, strain gauge 7 shows positive strain reading. However, most of the reading is observed to be between strain gauge 6 and strain gauge 8 reading. Strain gauge 7 give a strain reading of 0.002779 which breaks at ultimate load of 113.03kN. Whereas, strain gauge 8 give a strain reading of 0.004158 which breaks at ultimate load of 113.09kN. For steel reinforcement of control beam, two strain gauge are used which are strain gauge 4 and 5. It is observed that strain gauge 4 has a higher value compare to strain gauge 5, which is 0.001971 whereas strain gauge 5 has a reading of 0.001923. The ultimate load for strain gauge 4 and 5 is 112.98kN and 99.29kN respectively.

Whereas for the specimen beam, two steel strain gauge labelled strain gauge 4 and 5 were installed. In Figure 8, strain gauge 5 has a strain value of 0.00306 with an ultimate load of 85.96kN. Whereas, strain gauge 4 has a slightly lower strain reading compare to strain gauge 5. The strain value is 0.00305 which breaks at ultimate load of 86.07kN. On the other hand, 3 concrete strain gauges are labelled with strain gauge 6, 7 and 8. It is observed that the reading from strain gauge 6 has the highest strain value of 0.000549 compared to strain gauge 7 and 8. The ultimate load where the strain gauge breaks is 85.38kN. Strain gauge 7 gives a strain reading of 0.000085 with an ultimate load of 60.45kN. Whereas strain gauge 8 gives a reading of 0.000066 which breaks at ultimate load of 46.02kN.

Table 1. Load and deflection.

| Type of Beam          | Ultimate Load(KN) | Deflection (mm) |
|-----------------------|-------------------|-----------------|
| Control Beam          | 113.14            | 11.67           |
| Double Vertical Plate | 113.02            | 11.16           |

Figure 6. Load versus deflection.
3.3. Stress versus strain

The result for control beam is shown in Figure 9. It is observed that the reading for strain gauge installed on steel reinforcement bar has a value of 0.001971 and 0.001923 for strain gauge 4 and 5 respectively. Strain gauge 4 breaks at ultimate stress of 394.2MPa whereas strain gauge 5 breaks at ultimate of 384.6MPa. It is observed that the maximum stress value is not over the maximum tensile strength of steel which is 460MPa. Strain reading for concrete shows that strain gauge 6 breaks at ultimate stress of 43.67MPa with a strain value of 0.001409. Strain gauge 7 breaks at ultimate stress of 86.15MPa with a slightly higher strain value of 0.002779. Whereas, strain gauge 8 breaks at ultimate load of 128.90MPa with the highest strain value among the three strain gauges, which is 0.004158. The maximum strain value of concrete between the three readings does exceed the maximum compressive strength of concrete that is 30MPa.
Figure 10 shows the result for specimen beam. For concrete strain gauge, strain gauge 6 has the highest strain value which is 0.000549 among the three. The ultimate stress when the strain gauge breaks is 17.02MPa. Whereas, strain gauge 8 has the smallest strain value which 0.000066 that breaks at ultimate stress of 2.06MPa. For strain gauge 7, it gives a strain reading of 0.00008508 with an ultimate stress of 2.63MPa. The maximum strain value of concrete between the three readings also exceeds the maximum compressive strength of concrete that is 30MPa. For CFRP strain gauges, researchers can observe that the strain gauge 3 breaks at ultimate stress of 144.67MPa with a strain value of 0.0008767. Compare to strain gauge 2, strain gauge 3 has a higher strain value. Whereas strain gauge 2, it gives a reading of 0.000393 of strain when it started to break at ultimate stress of 64.78MPa. Same as the control beam, the maximum stress value is not over the maximum tensile strength for the CFRP which is 3000N/mm². For steel reinforcement strain gauges, both strain gauges gave quite same value of the strain and stress. At ultimate stress of 611MPa, the steel bar starts to change from elastic state to plastic state with value of 0.00305 and 0.00306 for strain gauge 4 and 5. It is observed that the strain gauge 5 has slightly higher strain value compare to strain gauge 5.

Figure 9. Stress vs strain for control beam.

Figure 10. Stress vs strain for beam with double vertical plate.
4. Mode of failure

Modes of failure can be analyzed by observing the cracks on the beam. Crack started to occur when the loading on the beam increases. Since tensile stress is higher on the bottom of the beam, the cracks formed started from the bottom and continue to the top part of the beam which has less tensile stress.

As seen in Figure 12, the strengthened beam tends to have more cracks compare to the control beam seen in Figure 11. The exposure to saltwater may have reduced the concrete compressive strength which has caused the strengthened beam to have more cracks. Other than that, another reason the strengthened beam has more cracks compare to control beam is because it have been applied to pre-crack loading before.

As researchers can observe from both control beam and strengthened beam, researchers can identify that they have different modes of failure. Modes of failure for control beam are known as shear failure. This is because a large crack is formed on one side of the beam which is near to the support. Whereas for strengthened beam, it is found that it have undergone modes of failure known as concrete cover separation. It is observed that the CFRP plate is still intact and does not bend. However, it had caused the beam to crack as its concrete cover on the bottom. As conclusion, the CFRP has enhanced the beam but due to concrete ability to sustain tensile stress is low; it had caused these types of failure.

Figure 11. Failure mode of the control beam.

Figure 12. Failure mode of the beam with double vertical plate.
5. Conclusions
Flexural strength test method is used to measure the behavior of concrete beam subjected to bending force. In this research, the test is used to analyze the state of failure of concrete and beam to find out whether they undergone elastic deformation, plastic deformation, yield state or even fracture. Based on this research, findings are shown below:

a. At the same ultimate load, it is observed the deflection of control beam and beam strengthened with CFRP plate is slightly the same.

b. The strain produced by concrete for control beam is higher compare to the strengthened beam. Whereas the strain produced by steel reinforcement for control beam has almost the same value as strengthened beam.

c. The CFRP plate does not bend after testing, which result in the modes of failure known as concrete cover separating. This means that it can cater and improve the mechanical properties of the beam but is influence by the concrete compressive strength.

As conclusion, the strengthened beam could have higher flexural strength. However, due to pre-cracking load, the beam has slightly the same performance as control beam. Therefore, the use of CFRP can still produce high performance beam since it can still cater load even after subjected to pre cracking and repaired.

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