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The Effect of Seawater on Reinforced Concrete Beam with CFRP Lamination

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ABSTRACT
Advancement of technologies in the world of construction time is very fast, the use of concrete was applied not only on land but also in the area of extremes environmental such as regional seawater. One of the ways repair structures that were popular when this is by using a material CFRP (Carbon Fiber Reinforced Polymer) which has one advantage that is resistant to corrosion. The experimental study aims to investigate the effect of seawater pitch toward the strengthening of concrete reinforced using CFRP is done by way of immersion in seawater for 3, and 6 months with the different number of laminated CFRP. The specimen consists of 36 reinforced concrete beams with dimensions (150x150x750) mm which have been reinforced with CFRP in the bending area. Flexural testing is carried out with three points of loading using displacement control method. Results of the analysis showed occur decrease the capacity of the load maximum and ductility of concrete as long soaking; both concrete normal and concrete with reinforcement. In the beam of concrete with reinforcement 1 to 2 layers CFRP increase the strength value respectively 2,54%, 9,16% but three CFRP the strength same as the normal beam. The ductility of beam with one to two layers CFRP reinforcement increase value of 42,58%, 11,8% but when using three lamination CFRP decrease 18,47% compare with beam without reinforcement. The ductility with two layers CFRP immersion therapy for 3 and 6 months value decrease of 39,13%, 35,74%, while three layers CFRP immersion for 3 and 6 months the ductility increase again 4,7% and 16,67% compare with beam without immersion. The two layers is CFRP is the best reinforcement. Failure model that occur in all beams without reinforcement fail due to flexural, and the beams with CFRP reinforcement is CDC (Critical Diagonal Crack)

Keywords: *Seawater, CFRP, immersion, flexural*

1. INTRODUCTION

Structural reinforcement needs to be applied to structures that have experienced a decrease in strength. The cause of the decrease in power is a result of the age structure, changes in the function of the structure, the influence of the environment and the care that is less good. One of the decreases in strength due to the influence of the environment is the structure which is located in seawater. The structure of reinforced concrete were directly exposed to water ocean will easily occur a decrease in strength due to seawater containing compound chloride. Compounds chloride would cause reinforcement that exist in the concrete become corroded so happens damage in concrete [4].

Damage beams of concrete reinforced in seawater environmental usually occurs at the dock which is caused from the duration exposed to water the sea and as a result of the collision the vessel which cracks create a gap for water entry into the concrete. Environmental seawater is quite extremely good so that the needs for methods of reinforcement are easy, fast and resistant to corrosion. One of the improvements is with Carbon Fiber Reinforced Polymer (CFRP), because CFRP is a lightweight, strong material, and is resistant to corrosion. Advantages more that installation, which is more convenient because of the form sheet.

Although many studies are superbly carried out to investigate the reinforcement elements of concrete reinforced with CFRP materials, but still many aspects of the user who still need to be investigated for example the use of CFRP in the environment seawater.

Several studies were associated with the use of FRP say that the concrete are coated CFRP able to increase the capacity of the bending capacity of the moment of bending and the capacity of the load on the beam. Not only in bending, the application of CFRP in the area of the shear beam also increases the capacity of the shear such as that say [1] [2].

Research the use of FRP in the water the sea a few in them saying that occur decrease the adhesions in FRP with concrete along the length of immersion [1] [6]. Will but although adhesiveness is reduced, CFRP can increase the capacity of the sliding of the beams in the environment seawater for 3 months full in the range of 14-18% of the beam control [8].

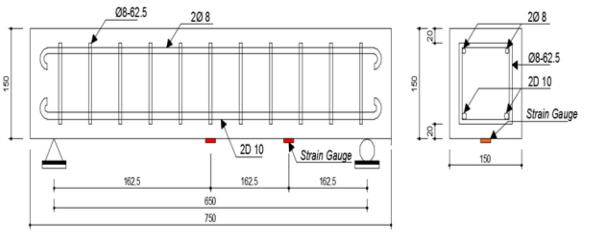


Figure 1 Concrete Beam Design

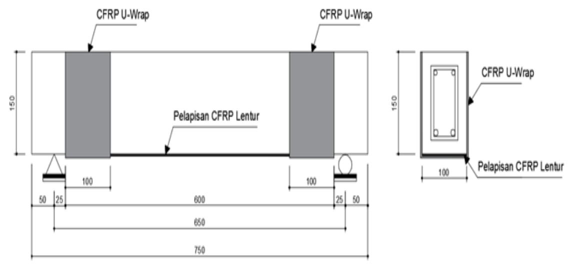


Figure 2 Reinforced Concrete Beam with CFRP

All studies were mentioned previously using two layers of FRP and long immersion ranges 1, 3 and 6 months. Research time it will use the number of layers and the duration of immersion are different to determine the effectiveness of CFRP. Extra anchors made for frequent occurrence of debonding on laminations [7]. Some studies that discuss the failure on the beam that is reinforced with FR P stated that the failure of debonding often occurs at the beam with reinforcement FRP [9], the failure of debonding influenced by the propagation of cracks pliable that only strengthened the hand pull the beam [10]. Debonding failure occurred from the flex crack location which then propagated to the end of the FRP reinforcement [11].

2. RESEARCH METHOD

In this research to get the intended results, this study conducted several tests including:

2.1. Specimen

This study used 36 specimens of reinforced concrete beam with dimensions of 100 mm x 150 mm x 750 mm, in the compressive area two bars 8 mm diameter reinforcement and two bars 10 mm diameter screw reinforcement were installed in the tensile area. The stirrup reinforcement used plain reinforcement with a diameter of 8 with a distance of 62.5 mm. The specimen consists of normal specimens without reinforcement and using CFRP. Details of the test object as **Figure 1** and **Figure 2**.

Table 1 Variation of Test Objects

No	Code	Soaking Time (month)	Jumlah Benda uji
1	0L0B	0	3
2	1L0B	0	3
3	2L0B	0	3
4	3L0B	0	3
5	0L3B	3	3
6	1L3B	3	3
7	2L3B	3	3
8	3L3B	3	3
9	0L6B	6	3
10	1L6B	6	3
11	2L6B	6	3
12	3L6B	6	3

In Table 1 there are 36 specimens with 12 different variations. This variation is simplified by the code, 0L, which explains that 0 CFRP layer means no CFRP reinforcement is used, 0B explains that 0 months of immersion means the long duration of immersion of the test object.

CFRP installation is carried out after the test object is 28 days old using the wet lay-up method. Wet lay-up is a method of installing FRP by wetting the concrete surface with epoxy then coated with CFRP and so for the addition of the next layer of CFRP. CFRP is installed in the tensile area of the beam.

After installing the CFRP, then the test object is allowed to stand until the CFRP is fully adhered and then immersed in sea water. When the immersion starts, it is the beginning of the determination for the time of observation.

Soaking the specimens is done by increasing the NaCl content in seawater up to 30mg / L. This was done to maximize the effect of sea water on the test object [12].

2.2. Testing

Testing of reinforced concrete beams is carried out by providing a centered load which is at a distance of 1/3 from the left of the span and 1/3 from the right of the span which refers to the ASTM C78 standard [13] and in the middle of the span at the bottom is installed LVDT as in **Figure 3** The loading system uses deflection control. The load is increased at a rate of 0.05 mm / s monotonically until the beam collapses. Gradual loading was carried out in order to be more careful in seeing the behavior of concrete and CFRP.

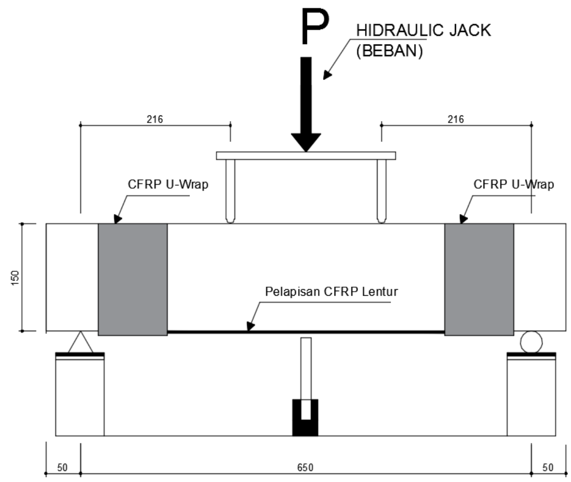


Figure 3 Concrete Flexural Strength Testing Scheme

3. RESULT AND DISCUSSION

3.1. Test Result

The results of beam testing without and using the CFRP sheet are presented in the form of a load-deflection relationship graph (**Figure 4**).

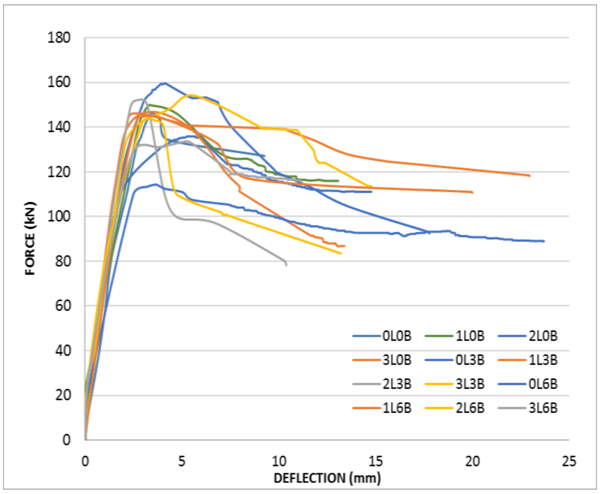


Figure 4 Graph of Relationship between Load and Deflection

3.2 Discussion of Test Result

The discussion of the test results was carried out on the load capacity and deflection at maximum load, stiffness, ductility and failure mode.

3.2.1 Load Capacity and Deflection at Maximum Load of test beam

The strength of test beam is generated from the graph of the load and deflection relationship to get the maximum load and deflection value for each beam. The results of the strength analysis are shown in Table 2.

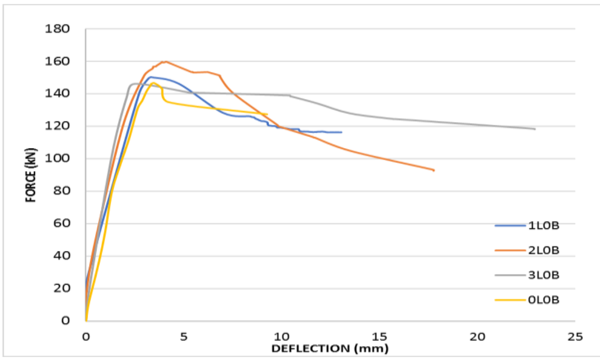
Table 2 Load Capacity and Deflection at Maximum Load

No	Code	Pmax (kN)	Deflection at Pmax (mm)
1	0L0B	146,37	3,49
2	1L0B	150,09	3,34
3	2L0B	159,78	4,11
4	3L0B	146,15	2,49
5	0L3B	135,77	5,37
6	1L3B	146,91	3,41
7	2L3B	151,52	2,52
8	3L3B	153,89	5,65
9	0L6B	114,47	3,65
10	1L6B	144,48	3,84
11	2L6B	143,02	3,64
12	3L6B	133,27	5,02

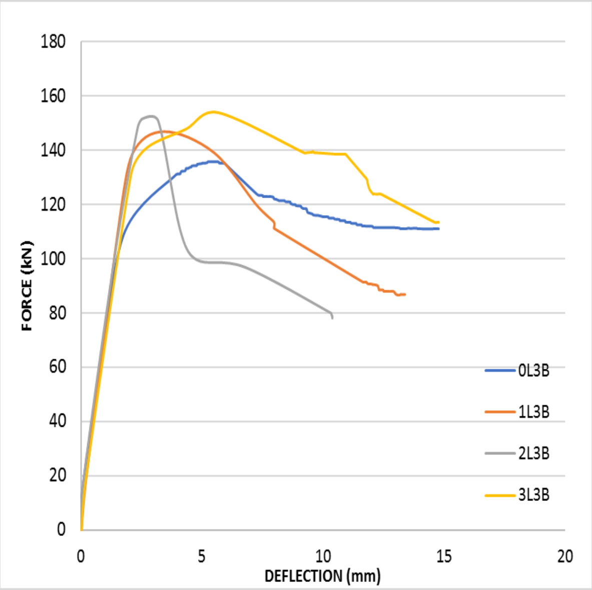
Table 2 shows that use if one CFRP in the flexural area can increase the strength by 2,54% whereas using two CFRP increase the strength of 9,16% but three CFRP the strength same as the normal beam. The duration of immersion increases, the maximum load on the test object will decrease, as in normal specimens without reinforcement 21,8%, as well as normal specimens with reinforcement. In the test specimens with reinforcement given the immersion behavior there was also a decrease in the duration of immersion, as in the test specimens with 1 layer of CFRP reinforcement immersed for 3 months (1L3B) to 6 (1L6B) decrease the strength of 3,73%. Likewise, the maximum load test results on variations of the CFRP layer and other immersion times. The strengthen of the test beam is the beam with two CFRP reinforcement.

3.2.2 Stiffness and Ductility of The Test Beam

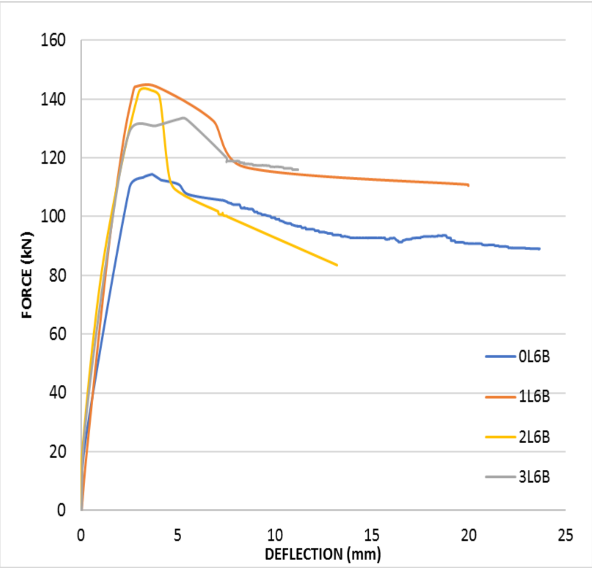
In this study, stiffness and ductility focused on the number of layers that differed from the duration of immersion. In order to make it easier to analyze the stiffness and ductility of the test data, it will be presented in a graph like **Figure 5** and then simplified again in **Table 3 and 4**. The following graph below show the results of the loading test which is divided into different immersion variations.



(a) Load and Deflection relationship graph for Test Objects without Immersion



(b) Load and Deflection relationship graph for Test Objects immersed for 3 months



(c) Graph of the relationship between Load and Deflection for Test Objects immersed for 6 months

Figure 5 Relationships between Load and Deflection

The stiffness of the beam with the reinforcement of 1 to 3 sheets of CFRP was analyzed based on the load value and proportional limit deflection using Equation 1[3].

$$K = \frac{Pprop}{\delta prop}$$

(1)

Information:

K : stiffness (kN/mm)

Pprop : proportional load (kN) = 0.4 Pmax

δprop : proportional deflection (mm) = δ 0.4 Pmax

Ductility is the ratio value of δu / δy where δy and δy are the deflection at the ultimate load and the deflection at the yield limit load, respectively. The deflection value at the ultimate load δu was determined based on the ultimate PU load = 0.8 Pmax and the yield limit deflection value δy = 1.25 * δ0.4Pmax, while the ductility value (μ) was calculated using Equation 2[3].

$$\mu = \frac{\delta u}{\delta y}$$

(2)

Information:

μ : ductility value

δu : ultimate deflection (mm)

δy : deflection at yield load (mm)

The result of the stiffness analysis are shown in Table 3 and the ductility are shown in Table 4 as follows.

Table 3 Stiffness of the test beam

Code	Pmaks (kN)	δmaks (mm)	Pprop (kN)	δprop (mm)	K (kN/mm)
0L0B	146.37	3.49	58.55	1.00	58.55
1L0B	150.10	3.34	60.04	0.70	85.77
2L0B	159.78	4.11	63.91	0.70	91.31
3L0B	146.15	2.49	58.46	0.80	73.08
0L3B	135.77	5.37	54.31	0.80	67.88
1L3B	146.91	3.41	58.76	0.80	73.45
2L3B	151.52	2.52	60.61	0.65	93.24
3L3B	146.91	3.41	58.76	0.80	73.45
0L6B	114.47	3.65	45.79	0.80	57.23
1L6B	144.48	3.84	57.79	0.90	64.21
2L6B	143.02	3.64	57.21	0.60	95.35
3L6B	133.27	5.02	53.31	0.60	88.84

As shown in **Table 3**, using one lamination CFRP can increase the stiffness value of 46,49% while using two lamination CFRP increase 55,95% but when using three lamination CFRP only increase 24,81%. The three lamination of CFRP is increase compare to beams without reinforcement but not strengthen two CFRP lamination, where with three lamination CFRP on flexural region, result damage in to shear region so that stiffness decrease due to occurrence of shear first before the CFRP work optimally. At the immersion condition the stiffness decrease as the duration of immersion increases, like example the stiffness of one lamination CFRP with immersion for 3 months decrease 14,35% and for 6 months decrease 25,13% compare with beam without reinforcement. The value is reduced due to the influence of sea water where the chloride content do that. If on two layers of CFRP with 3 month immersion the stiffness value increase of 2,11% and for 6 months immersion increase 4,43%, while three layers CFRP the stiffness decrease again.

Table 4 Ductility of the test beam

Code	δu (mm)	δ0.4 Pmaks (mm)	δY = 1,25*δ0,4Pmaks (mm)	μ (δU/ δY)
0L0B	2.30	1.00	1.25	2.30
1L0B	2.30	0.70	0.88	3.29
2L0B	1.80	0.70	0.88	2.57
3L0B	1.50	0.80	1.00	1.88
0L3B	1.70	0.80	1.00	2.13
1L3B	1.60	0.80	1.00	2.00
2L3B	1.75	0.65	0.81	2.69
3L3B	1.70	0.60	0.75	1.70
0L6B	1.90	0.80	1.00	1.90
1L6B	1.90	0.90	1.13	2.11
2L6B	1.80	0.60	0.75	3.00
3L6B	1.70	0.60	0.75	2.83

As shown in **Table 4**, using one lamination CFRP can increase the ductility value of 42,58% while using two lamination CFRP increase 11,8% but when using three lamination CFRP decrease 18,47% compare with beam without reinforcement. As the load test result the strength of the beam increase with add thin CFRP, but when use three CFRP, the CFRP is too strong than the beam so makes the beam so stiffness and decrease the ductility. If on one layers of CFRP with 3 month immersion the ductility value decrease of 39,13% and for 6 months immersion decrease 35,74%, while three layers CFRP immersion for 3 months the ductility increase again 4,7% and for 6 months 16,67% compare with beam without immersion. The two layers is the highest ductility than 1 layer and 3 layer cause the CFRP works optimally. According to Muñoz, the concrete specimen that is included in the ductile state is concrete with a ductility value of 1.5 $<\mu<4.0$ [5]. Based on the results of tests carried out (**Table 4**), almost all concrete categorized into the ductile,

2.2. Failure Model

According to stiffness and ductility with immersion therapy the beam experience changed cause of influence seawater. All the beams which were immersed and reinforced underwent the same failure model, namely loose CFRP followed by a concrete blanket attached to the CFRP. When the beam is subjected to flexural, the CFRP is debonding along with removing the concrete blanket. There were crushing and small cracks in concrete at the middle bottom and then suddenly cracks at shear area and debonding with removing concrete blanket. Discharge starts from the side as shown in **Figure 6**. This collapse is called CDC (Critical Diagonal Crack) which is a type of debonding failure that occurs in FRP reinforced beams in the flexural region while the ends of the FRP are located in a zone with high shear forces but with low moments [11]

In normal beams without reinforcement, all beams experience a bending failure model and the cracks starting in the middle of the span as shown in **Figure 7**.

Figure 6 Seawater-immersed Concrete Failure Model

Figure 7 Normal Concrete Failure Model

4. CONCLUSION

Based on the result of testing and analysis, it can be concluded:

1. The effect of seawater immersion has an impact on the decrease in the maximum load capacity of the beam. The decrease in load capacity occurs along with the immersion time.
2. One layer CFRP in the flexural area can increase the strength by 2,54% whereas using two CFRP increase the strength of 9,16% but three CFRP the strength same as the normal beam. In the test specimens with reinforcement given the immersion behavior with 1 layer of CFRP reinforcement immersed for 3 months (1L3B) to 6 (1L6B) decrease the strength of 3,73%. The strengthen of the test beam is the beam with two CFRP reinforcement.
3. Using one lamination CFRP can increase the ductility value of 42,58% while using two lamination CFRP increase 11,8% but when using three lamination CFRP decrease 18,47% compare with beam without reinforcement. If on one layers of CFRP with 3 month immersion the ductility value decrease of 39,13% and for 6 months immersion decrease 35,74%, while three layers CFRP immersion for 3 months the ductility increase again 4,7% and for 6 months 16,67% compare with beam without immersion. The two

layers is the highest ductility than 1 layer and 3 layer.

4. The failure of the beam on the beam using CFRP which is treated with immersion is CDC failure, where there is a release at the end of the FRP followed by a concrete blanket.
5. CFRP can be used in sea water environment, because there is no sign that CFRP has decreased in strength due to corrosiveness.

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