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Research paper

Bonding capacity of GFRP sheet for concrete beams strengthening under saline water environment

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Abstract

Structures built in aggressive environments such as in the sea/marine environment need to be carefully designed, due to the possibility of chloride ion penetration into the concrete. One way to reduce the strength degradation in such environment is to use FRP, which is attached to the surface of reinforced concrete using epoxy. A series of the specimen of reinforced concrete beams with dimension 100×120×600 mm were cast. Beams were immersed in the saline water for 3 months (B3), 6 months (B6) and 12 months (B12). Three specimens were prepared to control beam without immersion in the saline water (B0). Write the study presented is focused on determining the effect of the saline water environment to the capacity of GFRP as flexural external reinforcement elements. The result indicated that the bonding capacity of B3, B6, and B12 compared to B0 decrease of 7.91%, 11.99%, and 37.83% respectively. The decreasing was caused by the weakening of the bonding capacity GFRP due to the influence of the saline water environment.

Keywords: *Bonding Capacity; GFRP-S; Saline Water; Flexural.*

1. Introduction

FRP is a material made from the synthetic fiber such as glass, aramid, and carbon, held together by a matrix substance such as epoxy or polyester. Clappers use of FRP is the easy installation, high tensile strength, lightweight and corrosion resistance. There are various types of FRP depending on fiber was used, which is commonly known there are 3 types of GFRP (glass fiber reinforced polymer), AFRP (aramid fiber reinforced polymer), and CFRP (carbon fiber reinforced polymer). [1]- [2].

GFRP is a fiber that is commonly used today because they are relatively lower cost compared to the other FRP materials. The tensile strength of high glass fiber can be used as a make GFRP external reinforcement to receive the tensile force off to the structural elements.

Concrete structures that are not protected or close to the sea may be deteriorating, then if maintenance or preventive repairs is not done on the structure, it may cause the collapse [3]. FRP was evaluated as one the best method to deal with the problem because FRP does not corrode even in marine environments [4]. The repair of damaged reinforced concrete members by the externally bonding of fiber reinforced polymer (FRP) was becoming increasingly popular in the construction industry. Flexural strengthening of concrete beams accomplished by epoxy bonding the FRP material was bonded to the beam in the tension area. Several studies conducted on concrete structures with FRP have been done intensively, Z. G. Guo reported that using FRP composites were successfully used for strengthening of existing reinforced concrete structures because of their superior properties [5], Banthia reported that using GFRP. Composite materials in the area interested in the beams and plates, the increase of the moment capacity [6]. Djamaluddin et al conducted research using GFRP as reinforcement flexural in reinforced concrete beams, The result is average bond stress due to flexural loading was lower than the direct shear bond stress [7].

Several studies have concluded that the effects of seawater reduce the bonding capacity of GFRP with concrete [8-16]

2. Research method

2.1. Specimen

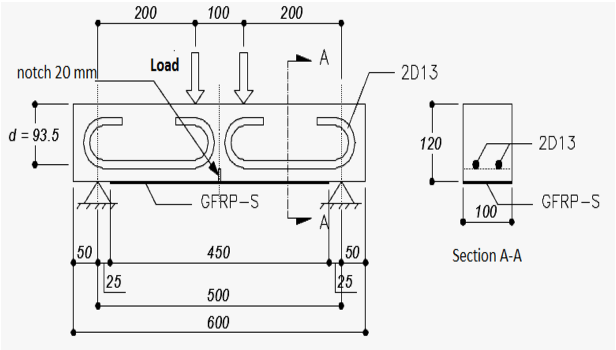


Fig. 1: Detail of Specimens.

A series of concrete beams specimen were prepared in this study with the parameters that influence the time of the saline water environment. The cross-section of beam specimen was 100 x 120 mm with a total length of 600 mm. All specimens were given the notch on the side of the center beam with a dip of 20 mm that serves as a weakness on the beam. Un continuous D13 steel reinforcement was applied on both sides of the beam with the space of 20 mm between them (Figure1). The concrete beams were cured, 28 days before applying GFRP.

Before installing GFRP sheet, the bottom surface of the beam smoothed with a disk sander. The epoxy resin impregnated on the surface of the concrete and GFRP-S with a brush roller. The specimen was cured for 3 days until the resin hardens. Table 1 shows the material properties of GFRP and Table 2 shows properties epoxy used in this study

Table 1: Material properties of GFRP

Items	Properties
Tensile strength (MPa)	575,0
Modulus young (GPa)	26,1
Laminate thickness (mm)	3,3

Table 2: Material Properties of GFRP

Items	Properties
Tensile strength (MPa)	72,4
Modulus young (GPa)	3,18
Laminate thickness (mm)	2,12

2.2. Test set up

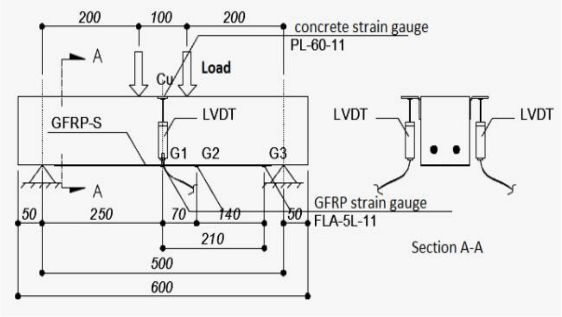


Fig. 2: Test Set Up.

The beam specimens were tested under simply supported beams subjected to two-point load using a universal testing machine, as shown in Figure 2. Each specimen was instrumented with strain gauges on the concrete surface at the extreme compression surface and on the GFRP sheet, respectively. The deflection and loading were measured using LVDT and load cell. All instrumentation was connected to a computer-based data logger for data recording.

3. Result and discussion

3.1. Flexural capacity

Table 3 shows the flexural capacity of each specimen, here indicates that once influenced the marine environment flexural capacity decreases, due to the weakening of bonding between GFRP with concrete. Decreasing flexural capacity of the beam B3, B6 and B12 compared B1 is 3.90%, 13.92% and 38.85% respectively.

Table 3: Summary of Maximum Moment, Deflection, and Stiffness

Beams	Moment (kN. m)	Deflection (mm)	Stiffness ratio (kN/ mm)
B0	0.286	0.278	15.76
B3	0.246	0.237	14.63
B6	0.245	0.236	13.43
B12	0.275	0.167	9.20

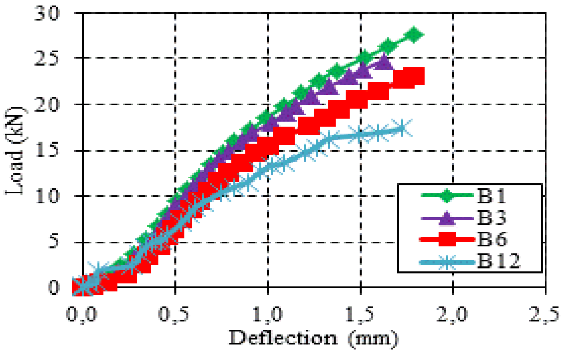


Fig. 3: Load-Deflection for all Specimens.

Figure 3 shows a graph load and deflection in the middle span of each specimen. The graph shows the beam B1, B3, B6 and B12 has a maximum load 27.71 kN, 23.74 kN, 23.73 kN and 16.61 kN respectively, the maximum deflection 1.763 mm, 1.622 mm, 1.766 mm and 1.806 mm, respectively. This indicates that the load capacity and stiffness ratio decreased after the affected saline water environment. A decrease in the load capacity for B3, B6, and B12 for B1 is 14.33%, 14.36% and 14.50% respectively

3.2. Strain distribution of GFRP

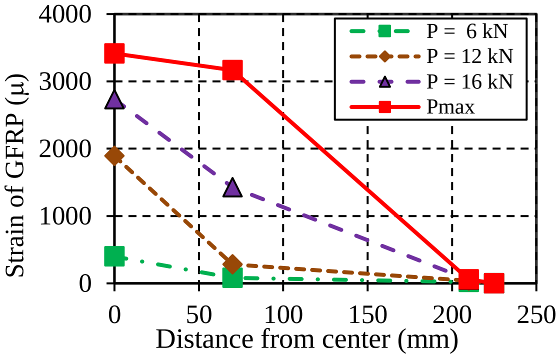


Fig. 4: Distribution of Tensile Strain from the Middle of the Span to the End of the GFRP-S.

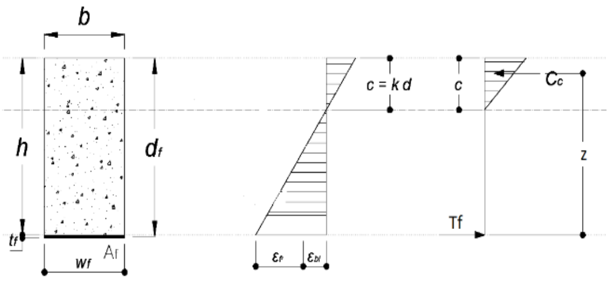
Figure 4 shows the distribution of tensile strain from the middle of the span to the end of the GFRP-S which represents the distribution of the bonding. The collected data from the strain gauges to develop the strain distribution profile. Each curve is plotted for a given load level. Figure-4 at early stages of loading has curve has a nonlinear shape. The strain of GFRP-S decrease with an increase of distance from the center. As the load increases, the graph tends to achieve a linear shape. A certain load level, the strain distribution curve becomes linear, which means the joint begins failure. This corresponds to the attainment of a uniform bond stress along the portion of the laminate which is taking the load.

The interface failure occurs in stages which indicated by the strain. The strain shape becomes horizontal at the beginning of the bent length, this means that reinforcement is not able to transfer the load so that the load is transferred to GFRP-S. The strain gauge far from the mid-span reads strain, which means the load transfer zone shifted.

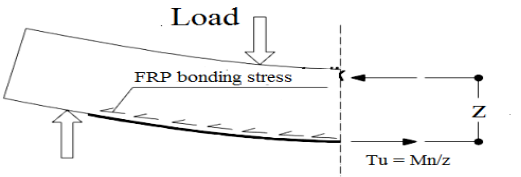
3.3. Bonding capacity

Figure 5 illustrates the flexural strain and stress diagram as well as the illustration of the flexural bonding stress on GFRP-S. Due to the relatively still small value of the concrete strain and stress may be assumed. The moment capacity Mn of the flexural beam was developed by the coupler action between compression force Cc and the tension force on GFRP-S Tf with the arm z.

Table 4 shows the bonding capacity of each specimen, having influenced the marine environment. Bonding capacity of GFRP-S decreased 7.91%, 11.99%, and 37.83%. respectively, compared to the specimen without the influenced of the saline water environment.



(a). Cross section (b). Strain distribution (c). Internal force



(d) Bonding stress due to Flexural Tensile Stress

Fig. 4: GFRP-Sheet Beam Analysis Model.

Table 3: Summary of Bonding Capacity

Beams	Tf (kN)	Abf (mm^2)	Tf (MPa)
B0	23.137	22500	1.028
B3	21.301	22500	0.947
B6	20.359	22500	0.905
B12	14.380	22500	0.639

3.3. Failure patterns of the specimens

Figure 6 shows the beams pattern of failure B0, B3, B6, and B12. It can be seen that failure of beams patterns show tendencies similar pattern is debonding failure. Debonding failure that occurs causes the propagation of cracks from the bottom propagate rapidly to the top up and knocked out of the beam. Failure occurs suddenly after GFRP-S apart, so that the beam failed. GFRP-S apart starting at the crack tip propagates to the end of the GFRP-S

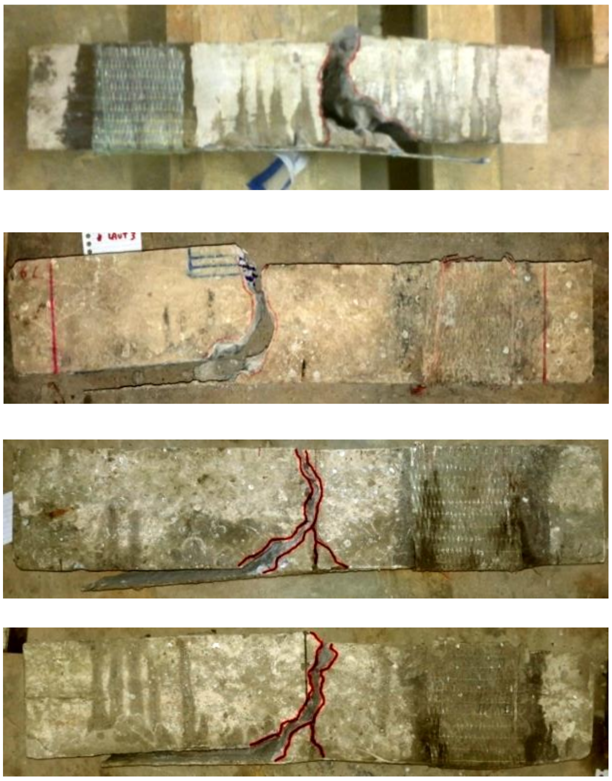


Fig. 5: Pattern of Failure of Specimen.

4. Conclusion

Concrete beams strengthened with GFRP-S at the flexural area will decline bonding capacity if affected the saline water environment. Debonding capacity decrease, respectively by 7.91%, 11.99%, and 37.83% compared to concrete beams strengthened GFRP-S without being influenced saline water environment.

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