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Relationship model of the moment capacity of GFRP sheet strengthened RC beams to the duration of sea water exposure

Rudy Djamaluddin[a]* and Rita Irmawaty[a]

[a]*Hasanuddin University, Jl.Perintis Kemerdekaan Km 10, Makassar, 90222, Indonesia, Email: rudy0011@gmail.com*

Abstract

Fiber Reinforced Plastics (FRP) has been widely applied in many purposes in civil engineering fields. Especially, FRP sheet is very suitable for strengthening of the existing structures. FRP sheet may be applied in various environment conditions of the structures. Many structures have to resist aggressive environment condition such as sea water exposure. Study on the effect of sea water exposure to the moment capacity of the concrete beams strengthening using GFRP sheet is important regarding to the effectiveness of strengthening. An experimental program has been conducted to find out the relationship of the moment capacity of the RC beams strengthened using FFRP sheet to the time of sea water exposure. A series of experimental specimens were prepared to be exposed in the sea water for 24 months. The beam specimens had the dimension of 3000 mm length with 150 x 200 mm of cross section. The specimens were reinforced by steel bars based on the under reinforced condition. The strengthening of the RC beams was conducted after 28 days of curing. The strengthened specimens were then submerged into sea water. The investigation on the moment capacity was conducted for 6 month, 12 month, 18 month and 24 months of exposure, respectively. Results indicated that the moment capacity of the beams decreased as the increasing of the exposure duration. Based on the experimental data, a relationship model of the effect of sea water exposure duration to the moment capacity was developed. The developed model may be used to predict the effect of sea water exposure to the moment capacity of GFRP sheet strengthened RC beams in design.

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Keywords: GFRP Sheet; Concrete Beams; Sea Water; Bonding; Flexural Moment.

1. Introduction

The corrosion is still a main problem in the reinforced concrete structures. Many alternatives has been develop as a solution such as epoxy coated steel, galvanized steel. However, those materials are relatively high cost and their

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life time is still questionable. In the last some decades, the noncorrosive FRP reinforcement has been also developed as an alternative to the steel reinforcement and it has been applied to eliminate the potential of corrosion and the associated deterioration, [1,2,3,4]. Due to the advantages, Fiber Reinforced Plastics (FRP) material is becoming a promising solution for corrosion. To fulfill the demand of the concrete construction, various forms of FRP have been developed such as bars, strip, cables as well as sheet. They have been applied on some structures as the reinforcement for concrete on the new structures. Compared to the steel reinforcement, it has some advantages such as higher tensile strength, the lower modulus of elasticity, bond characteristics, light in weight and non-corrosive [5,6,7].

Following the growing application, the FRP materials application is not only for new structures but also has been applied to strengthen the deteriorated structures. FRP in the form of sheet or grid is most commonly used for strengthening of deteriorated structures. Extensive research programs have been conducted to study the application of the FRP material for strengthening of the existing concrete structures and its flexural behavior [8,9,10,11]. The use of FRP materials as externally bonded reinforcement for strengthening is a practically efficient and technically sound method of strengthening and upgrading structurally inadequate or otherwise damaged or deteriorating load-bearing members. Fig.1 shows the application of FRP sheet for strengthening of the bridge girders (Malelleng Bridge, South Sulawesi). The advantages of FRP such as a low specific mass, and easy to handle, particularly when operating in constrained and enclosed situations are the advantages in the application process. These practical consideration and favorable mechanical properties, together with their uncorrosive characteristic have resulted in many practical application of FRP sheet in the strengthening of the existing structures.

In the strengthening purposes, the FRP sheet is bonded to the concrete surface to have its advantages in the flexural action of the beams. FRP sheet can be effectively used to increase the flexural strength by attaching at the extreme tension surface [12,13,14]. The interaction between FRP sheet and the concrete surface is an important factor to achieve a mechanical flexural action. The failure may occur when the bond stress in the FRP exceed the bonding capacity to concrete surface. Bonding capacity is depend on the bonding strength of the FRP to the concrete surface. The bonding stress is influenced by tensile stress of the FRP sheet attached at the extreme tension surface. In order to develop equilibrium of internal forces, then the compression is resisted by concrete and the tension is resisted by existing steel rebars and FRP sheet. In the strengthening by bonding the FRP sheet to the concrete surface, the bonding capacity becomes most important parameters to ensure the mechanical interaction between FRP and the concrete structures. The bond should have enough capacity to develop flexural action during the service life. However, it has been reported that mechanical interaction of bonded FRP sheet to concrete surface may decrease due to environmental impact. The delaminating of the FRP should be prevented since it causes a catastrophic failure [11,12,13]. The bond mechanism by which sustained stress might affect the properties of FRP sheet is a function of the flexural capacity of the beams externally reinforced by FRP sheet. In application, the failure of the FRP strengthened structures may occur by FRP rupture as well as debonding due to peeling off of the FRP plate, resulting in a sudden drop in loads and brittle failure [12,13].

(a) Concrete Girder Bridge (b) Strengthened Girder using GFRP Sheet
Fig.1. Application of GFRP Sheet for Strengthening of a Concrete Bridge

(a) Direct shear bonding stress (b) Flexural bonding stress

Fig.2. Application of GFRP Sheet for Strengthening of a Concrete Bridge

Bonding stress on FRP sheet may occur due to direct tensile force or due to flexural action on a reinforced concrete beam. The bonding capacity of FRP sheet as well as its behavior on the flexural reinforced concrete beam may different with the bonding capacity under direct axial loading. Fig.2 shows the illustration of bonding stress of FRP. In case of flexural strengthened beams, the initiation of delaminating may be induced by the opening of the flexural cracks [5,15]. This results in a reduction of bond strength of FRP in the flexural beam. Hence, the bond performance of the strengthened beams depends not only on the bonding area but also on the combination of the cracks occurred on the beams.

In order to fulfill the gab on the research regarding the application of FRP to the structures on the severe environment such as exposure of sea water, the experimental studies was prepared and analyzes to develop a relationship model. This study used Glass based FRP (GFRP) sheet due to its economical advantages compared to another types. The developed model was proposed as a tool in predicting the flexural capacity of beams strengthened using GFRP sheet after exposing to sea water. The relationship model between the duration of exposure and the flexural capacity was developed based on the experimental investigation for 24 month of exposure duration.

2. Experimental Observation

2.1. Simulation Pool of Sea Water Exposure

For simulation purposes, a simulation pool of sea water was prepared to submerge the beams specimen into the sea water. Simulation pool was considered because of the difficulties in transportation and safety of the beams specimens when they are put in direct sea. The simulation pool as shown in Fig.3 has dimension of 6 m x 8 m with depth of 1.2 m. A series of concrete beams were prepared with parameters of the time of exposure to sea water in simulation pool. The simulation pool was prepared and constructed outside of the laboratory to have a closer environmental condition to the actual sea, such as the effect of temperature change and wind, respectively. To control the sea water of simulation pool, then the chloride content as well as pH of the sea water in simulation pool was monitored periodically during the exposure period. If water tank characteristic indicated a relatively wide deviation to the sea water condition, then the water tank was corrected or replaced by new sea water.

(a)Placement of Specimen (b) Filling of Sea water

Fig.3. Preparation of Concrete Beams into Sea Water Simulation Pool

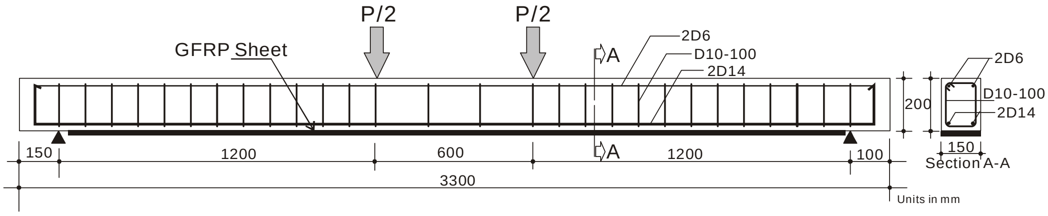

Fig.4. Detail of Beam Specimens

A series of specimen was prepared to be exposed to sea water in the simulation pool for 24 month of exposure duration for this investigation. The specimens were designed according to the standard design of reinforced concrete beams. The cross section of beam specimen was 150 x 200 mm with the total length of 3300 mm. All specimens were reinforced using the same tensile reinforcement ratio. D10 steel shear reinforcement was applied on shear span of the beam with the space of 100 mm to avoid concrete failure or cracks on the shear span. For main tensile reinforcement, 2D14 steel bars were used. Two D6 steel reinforcements were also attached on the compression side for easy installation only. The details of specimens are shown in the Fig.4. Normal concrete was prepared and applied to all specimens. The casted concrete beams were cured for 28 days before the application of the GFRP sheet by covering using a wet blanket. The cylinders as well as beam specimens for compression and rupture test were also prepared to determine the material properties of concrete. Compressive strength of concrete at 28 days was 25.2 MPa with Young of Modulus of 23.82 GPa. Rupture strength of concrete was 3.3 MPa. Before the application of GFRP sheet, the bottom surfaces of the beams were smoothed by a disk sander. The epoxy resin was applied on the GFRP sheet placed on a table using a soft roller to impregnate all the fibers with resin. The epoxy resin was also applied on the treated surface before patching of the impregnated GFRP sheet to the treated surface. The patched GFRP sheet was positioned with the application of slight pressure using a soft roller. The beams were then cured again for 3 days to allow the hardening of resin.

Fig.5 and Fig.6 shows the measurement of chloride content and pH level of the sea water at the simulation pool and compared to the sea water at the direct sea location, respectively. The measurements were done to ensure that the sea water parameters such as chloride content and pH level was similar to the sea water at the direct sea location.

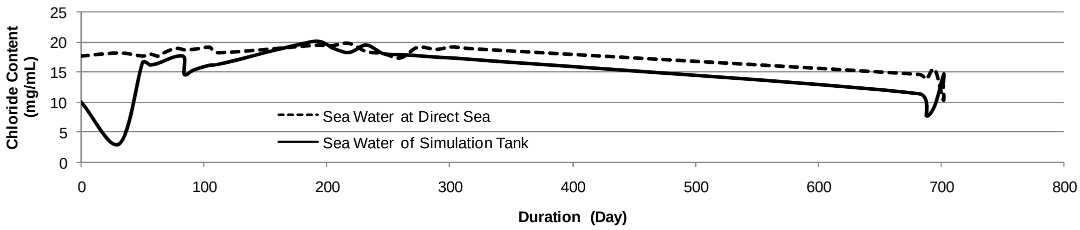

Fig.5 Control of Chloride Content of Sea Water

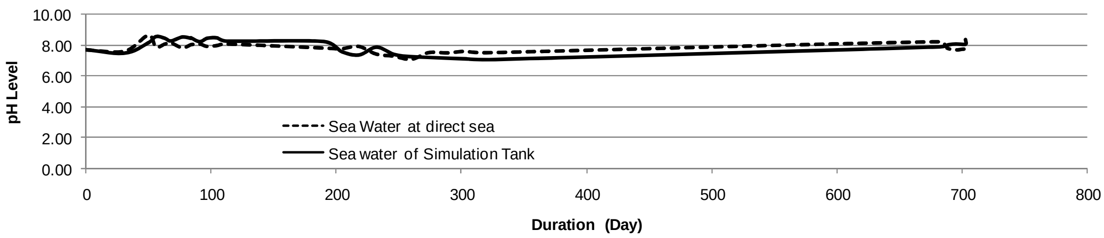

Fig.6 Control of pH Level of Sea Water

2.2. Experimental Results

The loading test was aimed to identify experimentally the flexural capacity of beams after exposure. Strengthened concrete beam specimens were tested under four points flexural loading periodically based on the duration of exposure. Exposing duration was decided for 1, 3, 6, 12 and 24 months, respectively. Flexural tests were conducted using a flexural loading frame with capacity of 150 ton. The load was applied using a hydraulic jack connected to the computerized control panel. The applied load measured using a load cell. The applied load was increased gradually up to the final failure of the beams. The ultimate load was noted for further analysis. Fig.7 present summary of the ultimate flexural capacity of the beams loaded under static loading after exposing to sea water in the simulation pool for 1, 3, 6, 12 and 24 months, respectively. Investigating on the ultimate capacity, results indicated that there was a tendency that the ultimate load was affected by the sea water exposure duration. Using average value of the ultimate capacity and compared to the control specimen (before exposing to sea water), the ultimate capacity of the specimen exposed for six month decreased for about 3.90%, exposing for 12 months, the ultimate capacity decreased for about 4.52% and after exposing for 24 months, the ultimate capacity decreased for about 5.24%, respectively. It was noted that all specimens failed under debonding of the GFRP sheet as shown in Fig.8. Prior to final failure, there were sounds indicated locally debonding of GFRP sheet. Final debonding of GFRP sheet caused the load drop suddenly.

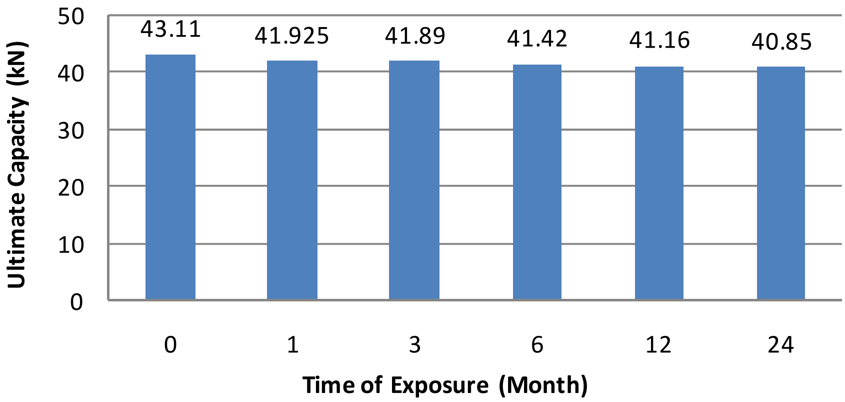

Fig.7 Ultimate Capacity of Beam Specimens

Fig.8 Debonding Failure of GFRP Sheet

3. Relationship Model of the Sea Water Effect

Table 1 presents the ratio the ultimate flexural moment capacity of the specimens exposed to the sea water (Mu_t) and the ultimate moment capacity of un-exposed specimens (Mu_o) for each exposing duration of the specimens. The data indicated that the ultimate moment capacity of the specimens exposed to the sea water (Mu_t) decreased as increasing of the exposure time, as presented in Fig.9. After exposing for 24 months, the moment capacity of the beams was approximately 95% of the moment capacity of control beam specimens.

Table 1.Ratio of the Ultimate Moment capacity after exposure to the un-exposed specimens

Time of Exposure (month)	0	1	3	6	12	24
Muo (kN.m)	25.86	-	-	-	-	-
Mut (kN.m)	-	25.16	25.14	24.86	24.70	24.51
Mut/*Muo*	1.000	0.973	0.972	0.961	0.955	0.948

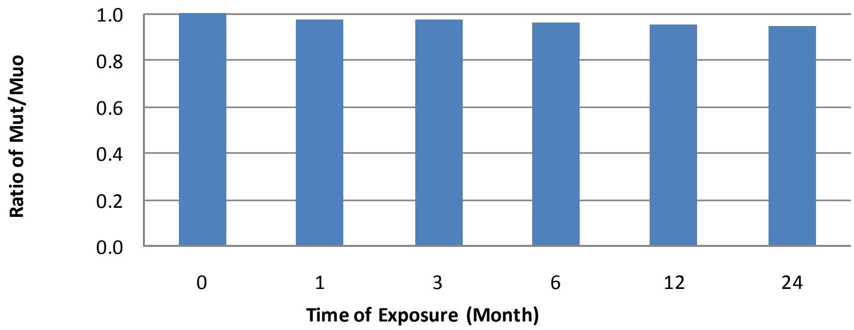

Fig.9 Ultimate Capacity of Beam Specimens

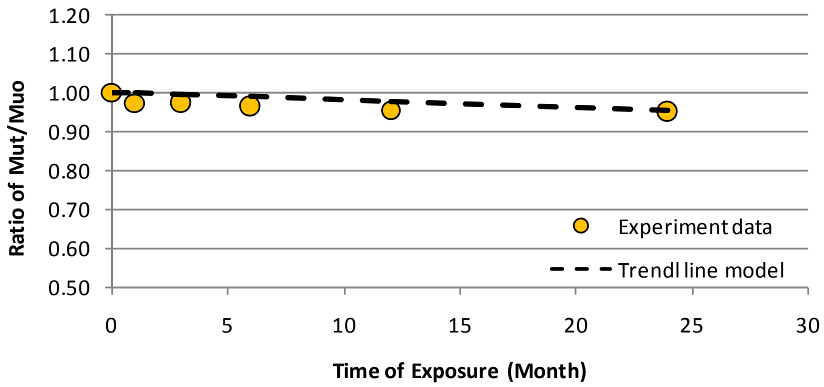

Fig.10. Trend of the Mu_t/Mu_o to the Time of Exposure

The decreasing of the ultimate capacity of the beams for the certain time of sea water exposure may be predicted using the experimental data for 24 months of exposure duration. For practical application, the model was developed based the relationship between the moment capacity after exposure and the coefficient due to exposure effect (α) to the beam specimens. The relationship model was derived based on the ultimate flexural moment capacity of the specimens exposed to the sea water (Mu_t) and the ultimate moment capacity of the un-exposed specimens (Mu_o). In order to develop a mathematical relationship model of the effect of the sea water exposure to the ultimate capacity, the non-dimensional ultimate moment ratio ($Mu_t/(Mu_o$) of experimental result is correlated to the exposure time, as presented in Fig.10. Based on the experimental data plotted on the Fig.10 for each time of exposure then the trend line of the plotted data may be achieved by the mathematical equation as follows :

$$y=e^{-0.002x} \quad (1)$$

If y is ratio of the ultimate moment capacity of the specimens exposed to the sea water (*Mut*) and the ultimate moment capacity of the un-exposed specimens (*Muo*), and x is the time of exposure T (month), then the Eq.(1) may be rewritten to be:

$$(Mu_t/Mu_o)=e^{-0.002T} \quad (2)$$

or,

$$Mu_t=Mu_o\, e^{-0.002T} \quad (3)$$

or

$$Mu_t= \alpha\, Mu_o \quad (4)$$

and

$$\alpha=e^{-0.002T} \quad (5)$$

where Mu_t (kN.m) is the moment capacity after exposure for T month, Mu_o (kN.m) is the unexposed moment capacity, α is the coefficient of the sea water exposure effect to moment capacity and T (month) is the duration of exposure to sea water, respectively. Table 2 shows the comparison between experimental moment capacity and the estimated capacity using Eq.(3). As it can be observed that the estimated value shows a good agreement to the experimental data. Predicting of the ultimate moment capacity of the specimens after exposure for 20 and 40 years as shown in Table 2, the ultimate moment capacity may decrease up to 60% from the initial moment capacity after 40 years of exposure. It was noted that the Eq.(3) is still necessary to be validated using long term data. It should be noted that it was reported that the stress level in the application should be limited to 25% for GFRP due to possibility environment effect degradation as well as insufficient of long-term data [16].

Additionally, the value estimating using proposed model may be used to predict the safety factor. For example, by assuming that the structure safety factor (SF) of unexposed structures is 3 then the safety factor for 40 years of structure under exposing of sea water should be designed equal to nine. Meaning that at the end of 40^{th} year, the safety factor of the structure is still remain approximately 3.

Table 2. Predicting of Ultimate Moment capacity after sea water exposure

Time of Exposure (x12 month)	0	2	10	20	40
Experimental Mut (kN.m)	25.86	24.51	-	-	-
Model Mut (kN.m)	-	24.51	20.35	16.00	9.90
Model/Exp.		95%	79%	62%	38%

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References

[1] Emmanuel Vougioukas, Christos A.Z, and Michael D.K., Toward safe and efficient use of fiber-reinforced polymer for repair and strengthening of reinforced concrete structures, ACI Structural Journal. 102(4) (2005) 525-534

[2] Shin, Y.S and Lee, C., Flexural Behavior of Reinforced Concrete Beams Strengthened with Carbon Fiber –Reinforced Laminates at Different Levels of Sustaining Loads, ACI Structural Journal. Vol.100 No.2 Mar-Apr. (2003) 231-239

[3] Rudy Djamaluddin, Kohei Yamaguchi, Shinichi Hino. Mechanical behavior of the U-anchor of super-CFRP rod under tensile loading. Journal of Composite Material, Vol.48 (15) (2014) 1875-1885

[4] Teng, J.G, Chen J.F, Smith S.t and Lam.L, FRP-Strengthened RC Structures, John Wiley & Sons, West Succex, UK, 2003.

[5] Rudy Djamaluddin, Abdul Madjid Akkas, Akristin Eko S, Application of GFRP sheet for strengthening of yielded reinforced concrete beams, Proceeding the 6th Civil Engineering Conference in Asia Region, Jakarta , (2013) TS10-9 – TS10-16

[6] Rahimi H., and Hutchinson, A., Concrete Beams Strengthened with Externally Bonded FRP Plates, Journal of Composites for Construction, ASCE V-5 No.1 (2001) 44-55.

[7] Balaguru.P, Nanni A, Guancaspro J, FRP Composites for Reinforced and Prestressed Concrete Structures : A guide to fundamentals and design for repair and retrofit, Taylor & Francis, 2009.

[8] Lorenzis, L.D, Miller, B, and Nanni A, Bond of Fiber-Reinforced Polymer Laminates to Concrete, ACI Material Journal V-98 No.3 May-June (2001) 256-264

[9] Dong-Uk Choi, Thomas H.K.Kang, Sang-Su Ha, Kil Hee Kim and Woosuk Kim., Flexural and bond behavior of concrete beam strengthened with hybrid carbon-glass fiber reinforced polymer sheet. ACI Struct. J., 108(1) (2011) 90-98.

[10] M.S.Alam, T. Kanakubo and Yasojima, Shear-Peeling Bond Strength between Continuous Fiber Sheet and Concrete, ACI Structural Journal V-109, No.1, Jan.-Feb. (2012) 75-82

[11] Mehdi T.K., and Chris J.B., Fiber-Reinforced Polymer Bond Test in Presence of Steel and Cracks, ACI Structural Journal V-108, No.6, Nov.-Dec. (2011) 735-744.

[12] Arduini, M., and Nanni, A. Parametric study of beams with externally bonded FRP reinforcement. ACI Structural Journal. 94(5) (1997) 493-501.

[13] Dong-Uk Choi, Thomas H.K.Kang, Sang-Su Ha, Kil Hee Kim and Woosuk Kim. Flexural and bond behavior of concrete beam strengthened with hybrid carbon-glass fiber reinforced polymer sheet. ACI Struct. J., 108(1) (2001) 90-98.

[14] Mahmoud T.E., and Joseph W.T. Analysis of reinforced concrete beams strengthened with FRP laminates. Journal of Structural Engineering, ASCE, 126(6) (2000) 684-691.

[15]Mehdi T.K., and Chris J.B. Fiber-reinforce polymer bond test in presence of steel and cracks. ACI Structural Journal, 108(6) (2011) 735-744.

[16] V.M.Karbhari, J.W.Chin, D.Hunston, B.Benmokrane, T.Juska, R.Morgan, J.J.Lesko, U.Sorathia, and D.Reynaud, Durability Gab Analysis for Fiber Reinforced Polymer Composites in Civil Infrastructure. Journal of composites for Construction, 7(3), (2003) 238-247.