

# Long-Term Durability of Bio-Polymer Modified Concrete in Tidal Flooding Prone Area: A Challenge of Sustainable Concrete Materials

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## Article

# Long-Term Durability of Bio-Polymer Modified Concrete in Tidal Flooding Prone Area: A Challenge of Sustainable Concrete Materials

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**Abstract:** The need for durable concrete in marine environments such as areas prone to tidal flooding is important due to its ability to deteriorate the structures. This led to the design of a durable and strong Polymer-Modified Concrete (PMC) using natural or bio-polymer modified concrete. However, the use of biopolymer-modified concrete is very limited. Therefore, this research developed a bio-polymer modified concrete using *Gracilaria* sp., *Moringa oleifera*, and honey (GMH) for column retrofitting. The research aimed to retrofit and improve the compressive strength and durability of broken columns submerged by tidal flooding by applying bio-polymer modified concrete with GMH. A field application of column retrofitting was conducted in areas prone to tidal flooding. The retrofitted columns performance was observed for 14 months and validated by non-destructive and destructive tests. The result showed that the compressive strength of the retrofitted column achieved 32.37 MPa, which is a 92.34% increase compared to the baseline. This research provides answers to the challenge of concrete materials sustainability by promoting bio-polymer modified concrete that significantly increased its performance and long-term durability using GMH.

**Keywords:** durability; bio-polymer; concrete; tidal flooding; sustainability



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## 1. Introduction

The deterioration of concrete structures caused by tidal flooding is one of the major causes of coastal infrastructure damage. Therefore, it is important to ensure concrete structures' durability in an aggressive environment, such as areas prone to tidal flooding. Some of the major causes of concrete deterioration are chemical attack of seawater constituents during the hydration process of cement, alkali-aggregate expansion, crystallization pressure of salts, frost action in cold climates, and corrosion of reinforced steel embedded in concrete structures. Others include physical erosion, such as wave and floating objects contacted to the concrete structures, as well as the carbonic acid attack that leaches away the calcium from hydrated cement [1,2]. Hence, it is necessary to ensure that concrete materials have good performance and durability.

Several research have reported the durability of concrete structures in the marine environment, including long-term investigation of concrete performance exposed to seawater [3–6]. Furthermore, concrete mixed with seawater achieved a good mechanical properties performance even though it was slightly lower than those using plain water [7–9]. It is also reported to provide a more resistant product against deterioration and higher compressive strength at an early age. Preliminary reasearch also conveyed the improved durability and bond strength of concrete structures in the marine environment was achieved due to the development of Polymer-Modified Concrete (PMC) by mixing

a polymer material into Portland Cement [10–13]. According to [11,12], thermoplastics, such as epoxy resins, elastomers or rubbers, natural polymers cellulose, lignin proteins, latex, re-dispersible polymer powder, water-soluble powder, liquid resins, SF (Silica Fume), RHA (Rice Husk Ash), and SF with nano-silica were used in PMC. There were also several studies reported the advantage of PMC for marine environment i.e., [14–19]. However, research on the utilization of natural or bio-polymer modified concrete and mortar are still very rare irrespective of the advantages such as increased compressive strength and durability [20–24].

This research aims to implement column retrofitting in tidal flooding areas with bio-polymer modified concrete using *Gracilaria sp.*, *Moringa oleifera*, and honey (GMH). It was conducted by field application of columns retrofitting in areas prone to tidal flooding for 14 months and validated by non-destructive and destructive tests. The result showed that the bio-polymer modified concrete using GMH increased concrete columns’ performance and long-term durability.

**2. Materials and Methods**

This research was conducted by field application as well as non-destructive and destructive tests in sites prone to tidal flooding. The methods and stages are outlined in subsequent sub-sections.

• **On-site column retrofitting and control column construction**

Two broken columns were retrofitted in the site, and a control column was constructed, as shown in Table 1. Each specimen identity was represented by one column.

The column retrofitting and construction was carried out by grouting it with bio-polymer modified concrete. Furthermore, *Gracilaria sp.* powder, an agar-agar product sold in the marketplace, *Moringa oleifera* powder from its seeds and honey were added to the mixture, as shown in Figure 1, Tables 2 and 3. The concrete mix composition of Mix I and Mix III were implemented in producing concrete bricks [23]. All concrete columns were designed for compressive strength of  $f'_c = 30$  MPa with a dimension of 15 cm × 15 cm × 100 cm. The concrete mixture was calculated by Indonesian National Standard for Procedure of Concrete Mixing Design (SNI 03-2834-2000). However, bio-polymers did not add the Mix-Normal process shown in Table 2.

**Table 1.** Detail of Column Retrofitting and Construction.

No	Specimen Code	Status	Mix Composition
1	K1 *	retrofitted column	Mix I *
2	K3 *	retrofitted column	Mix III *
3	K	control column	Mix-Normal

\* the mix composition and specimen code referred to author’s previous study of [23].

**Table 2.** Mix composition of bio-polymer.

Mix Composition	Specimen Code	% of Cement Weight		
		<i>Gracilaria sp.</i>	Honey	<i>Moringa Oleifera</i>
Mix I *	K1 *	0.05	0.03	0
Mix III *	K3 *	0.025	0	0.075
Mix-Normal	K	—	—	—

\* the mix composition and specimen code referred to author’s previous study of [23].

**Table 3.** Mix composition of concrete for 1 column production.

Cement	Sand	Crushed Stone	Water	Bio-Polymer
(kg)	(kg)	(kg)	(l)	(% of Cement Weight)
8	8	8	3.6	see Table 1



**Figure 1.** The materials used in columns production as bio-polymers modified concrete: (a,b) *Gracilaria* sp. Powder, which is an agar-agar product sold in marketplace; (c) raw *Moringa oleifera* seeds with skin; (d) raw *Moringa oleifera* seeds without skin; and (e) honey which is also honey product sold in the marketplace.

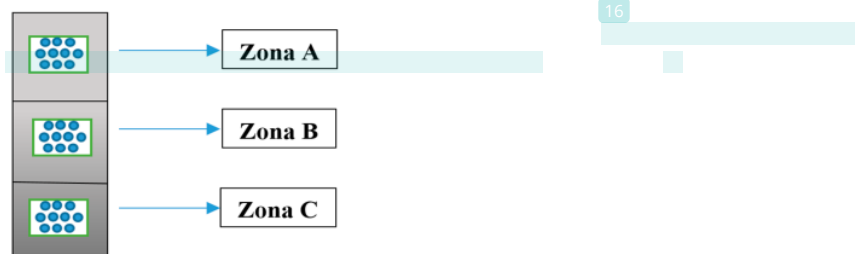
- **Non-destructive test for retrofitted and control columns**

This stage was conducted on-site, which led to the construction of the control columns after the broken sections were retrofitted. The Rebound Hammer test was carried out as a non-destructive test to analyze the columns compressive strength with Matest 2H1Q17. All columns were tested at 7, 14, and 28 days, while some were retested at 12, 13, and 14 months with mix K3, which contains *Moringa oleifera* and mix-normal.

The non-destructive procedure used in this test followed ASTM C 805-Standard Test Method for Rebound Number of Hardened Concrete, as shown in Figure 2. Several shootings were applied to the clean and flat surfaces of zone A, B, and C. Each zone was shot ten times, as shown by Figure 3.



**Figure 2.** Hammer Test Matest 2H1Q17 used in this research as non-destructive test equipment.



**Figure 3.** The zones for shooting at column surface for Rebound Hammer Test.

The Rebound Value was read by the equipment and then corrected for inclination as indicated in Table 4. After the corrected Rebound Value was calculated as R, the concrete ( $W_m$ ) strength that referred to the cubes was calculated in accordance with the age, as shown in Table 5.

**Table 4.** Correction of the Test Hammer Indications for Non-Horizontal Impacts (Manual Book Hammer Test Matest 2H1Q17).

Rebound Value R $\alpha$	Correction for Inclination Angle $\alpha$			
	Upwards		Downwards	
	+90°	+45°	−45°	−90°
10			2.4	3.2
20	−5.4	−3.5	2.5	3.4
30	−4.7	−3.1	2.3	3.1
40	−3.9	−2.6	2	2.7
50	−3.1	−2.1	1.6	2.2
60	−2.3	−1.6	1.3	1.7

**Table 5.** Cube Compressive Strength ( $W$ , in kg/cm<sup>2</sup>) as a function of the Rebound Number R Type N.

R	Age of Concrete			
	14 to 56 Days		7 Days	
	$W_m$	$W_{min}$	$W_m$	$W_{min}$
20	101	54	121	74
21	113	64	132	83
22	126	75	145	94
23	139	86	157	104
24	152	98	169	115
25	166	110	183	127
26	180	122	196	138
27	195	135	210	150
28	210	149	225	164
29	225	163	239	177
30	241	178	254	191
31	257	193	269	205
32	274	209	285	220
33	291	225	300	234
34	307	240	315	248
35	324	256	331	263
36	342	273	348	279
37	360	290	365	295
38	370	307	381	311
39	395	324	398	327
40	413	341	416	344
41	432	359	434	361
42	450	377	451	378
43	469	395	470	396
44	488	414	488	414
45	507	432	507	432
46	526	450	526	451
47	546	470	546	570
48	565	489	565	489
49	584	508	584	508
50	604	527	604	527
51	623	546	623	546
52	643	565	643	565
53	663	584	663	584
54	683	603	683	603
55	703	622	703	622

- **Destructive test for retrofitted and control columns**

After the Rebound Hammer test, the inner concrete's compressive strength was obtained using the Core Drill method. This technique was purposed to obtain compressive strength of the drilled core of concrete using the ASTM C 42/C 42M-04 and SNI 03-2492-2002 Standard test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete. A versatile diamond drilling system with a diameter of 3 mm and a HILTI DD 150-U machine was also used to obtain the core of concrete specimens. The Core Drill method was applied only to columns K3 at 14 months. The samples were drilled from the inner columns at points A, B, and C, as shown in Figure 4. The drilled concrete cylinder with a diameter and height of 70 mm and 140 mm used the ASTM code to test for compressive strength. This is in addition to the use of Computer Control Servo Hydraulic Concrete Compression Testing Machine and Hung-Ta serial HT 8391PC to obtain compressive strength of concrete cylinder as shown in Figure 5.

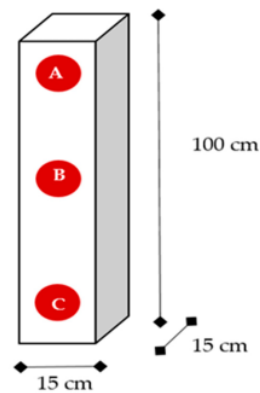


Figure 4. Column dimension and using HILTI DD 150-U machine.



Figure 5. The Computer Control Servo Hydraulic Concrete Compression Testing Machine, Hung-Ta serial HT 8391PC.

The zones A, B, and C are for drilling concrete cores with versatile diamond drilling. Calculation of compressive test followed the expression of Equation (1).

$$\sigma = \left\{ \left( \frac{P}{A} \right) \cdot f_l \cdot f_{dia} \cdot f_d \right\} \quad (1)$$

where  $\sigma$  is characteristic compressive strength (MPa),  $P$  is compressive load (N),  $A$  is compressive area ( $\text{mm}^2$ ),  $l$  is the height of sample (mm),  $d$  is the diameter of the sample (mm),  $f_l$  is

correction factor of core diameter, and  $f_d$  is correction factor of damage caused by drilling. The correction factor of core diameter referred to as ASTM C 42/C 42M-04 and ACI 214.4R-03, while the correction factor of damage caused by drilling is referred to as ACI 214.4R-03.

### 3. Results

#### 3.1. On-Site Column Retrofitting and Construction

This research retrofitted two broken columns marked by red rectangles, as shown in Figure 6a. Those two columns were used to pin the broken masonry wall and observed that the concrete's cover as well as most parts of the columns were peeled off, while the steel reinforcement was corroded. After some months, almost half of the left column collapsed, as shown by Figure 6b.



**Figure 6.** The broken columns which were retrofitted by applying bio-polymer modified concrete, (a) Situation at the time the left column still existed, and (b) Situation in the next few months after the left column had almost collapsed.

Figure 7a shows that the first step in column retrofitting is conducted by peeling the cover of old concrete and unnecessary debris and applying the formwork of 1 m from the base floor. The next step of the activities was grouting the column with bio-polymer modified concrete consisting of *Gracilaria* sp., *Moringa oleifera*, and honey. After the retrofitted column stiffness increased, it was wrapped by jute sack, and curing was applied for about a week by watering it, as shown in Figure 7b.

Figure 8 shows a control column constructed in conjunction with columns retrofitting. The procedure included: mixing the concrete materials consisting of cement, split (crushed stone), sand, and water referred to as Mix-Normal. This is in addition to conducting steel reinforcement and framework curing.

#### 3.2. Non-Destructive Test for Retrofitted and Control Columns

The non-destructive test examined the retrofitted and control columns to investigate their compressive strength. A Rebound Hammer Test was also used by shooting at the necessary points (A, B, C) in the house submerged by tidal flooding at 28 days, as shown in Figures 9–11. A year later, the retrofitted and control columns were tested at 12, 13, and 14 months as shown by Figures 10 and 11.



(a)



(b)

**Figure 7.** The column retrofitting activities: (a) Peeling, formwork, grouting with bio-polymer modified concrete consisting of *Gracilaria* sp., *Moringa oleifera*, and honey (GMH); (b) Curing by watering the column for a week.

The baseline of the Rebound Hammer Test was conducted by shooting the old broken column at points A, B, C to obtain the baseline of compressive strength before column retrofitting procedures, as shown in Figures 12 and 13. It was found that the baseline compressive strength of the old broken columns was 17.3 MPa, 18.63 MPa, and 16.6 MPa at points A, B, and C, respectively.





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Figure 8. Construction of control column.



Figure 9. Rebound Hammer Test that was conducted on the retrofitted columns at 7, 14, and 28 days.



Figure 10. Rebound Hammer Test that was conducted on the retrofitted columns at 12, 13, and 14 months.

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Figure 11. Rebound Hammer Test that was conducted on the control column at 14 months.



Figure 12. The Rebound Hammer Test was conducted on the points marked by red circles.

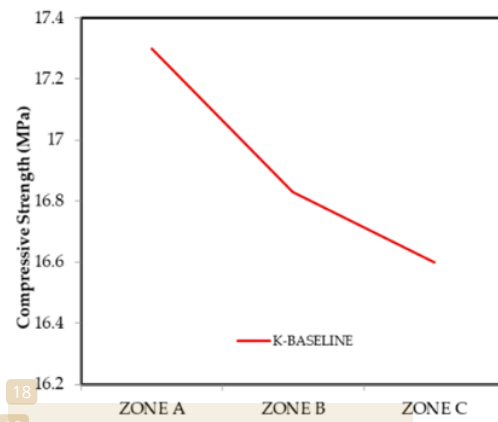


Figure 13. Compressive strength of the old broken column that became the baseline value.

The Rebound Hammer Test result observed that the retrofitted column of K1 had lower compressive strength compared to K3 at point A, but was higher at B and C at 7, 14, and 28 days as indicated in Figure 14. Furthermore, a very high compressive strength value was obtained at point B within 14 months compared to the lower value in the retrofitted

column, as shown in Figure 15. The research also found that the compressive strength of K1 at point C was decreased at all ages, as shown in Figure 16. Rebound Hammer Test results also noted that at 14 months, the compressive strength values of retrofitted and control columns decreased, as shown in Figure 17.

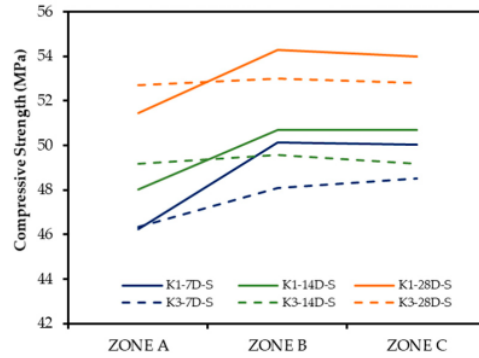


Figure 14. Compressive strength of retrofitted columns of K1 and K3 at 7, 14, 28 days.

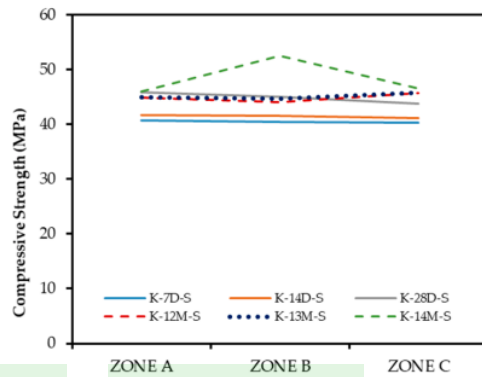


Figure 15. Compressive strength of control column at 7, 14, 28 days, and at 12, 13, 14 months.

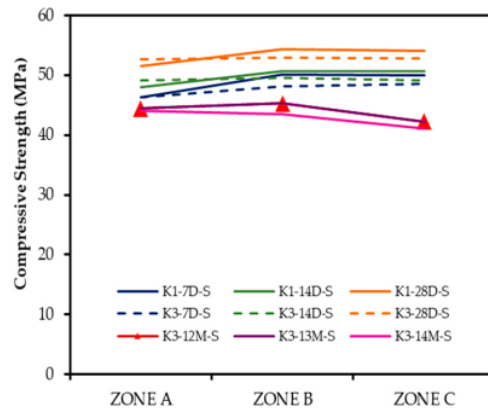
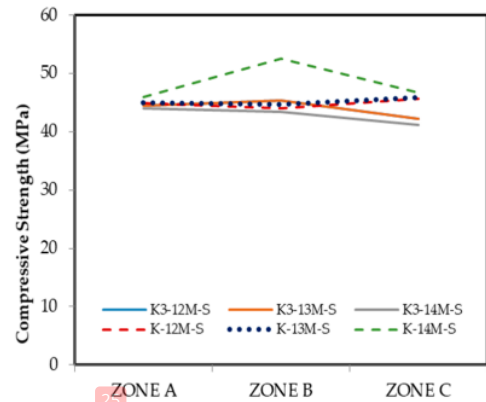


Figure 16. Compressive strength of retrofitted columns of K1 at 7, 14, 28 days, and K3 column at 12, 13, 14 months.



**Figure 17.** Compressive strength of control.

### 3.3. Destructive Test for Column Specimens

The research applied a Destructive Test to investigate the compressive strength of retrofitted and control columns by the Core Drill method. Figures 18 and 19 describe the Core Drill implementation process needed to obtain the core's concrete sample using concrete cylinders. Figure 20 illustrates that the retrofitted column of K3 has stable compressive strength at all points (A, B, C) with 30 MPa. Point B has a slightly higher compressive strength value, which did not occur on the control column. The research found that the compressive strength at point A was very high (52.44 MPa) but low at points B and C (42.76 MPa and 45.98 MPa).



**Figure 18.** Core Drill method of retrofitted and control columns conducted to obtain samples used for the compressive strength test.



Figure 19. A drilled concrete cylinder tested for compressive stress.

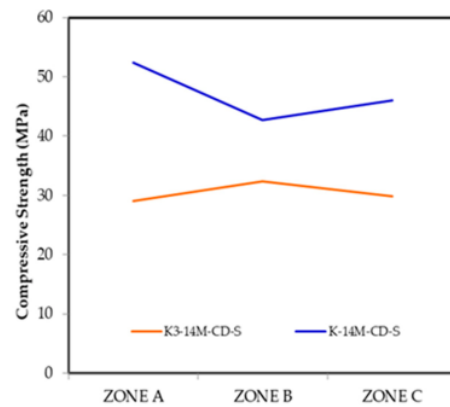
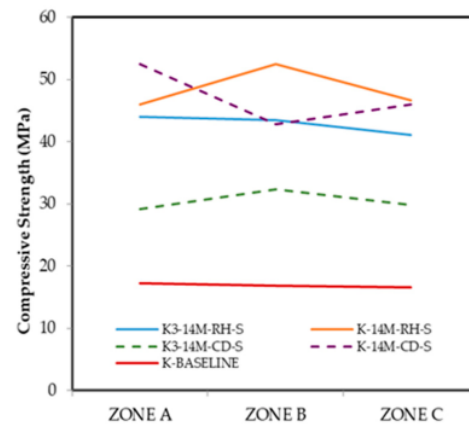
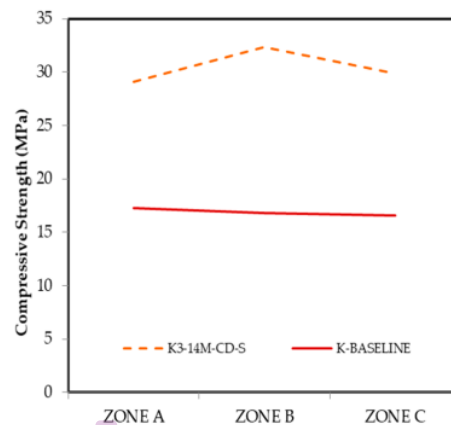


Figure 20. Compressive strength of drilled concrete cylinders of retrofitted and control columns at 14 month.

This research found that the destructive test result of the compressive strength at 14 months has the ability to control column surface by Rebound Hammer Test (K-14M-RH-S). The values were higher than the retrofitted column (K3-14M-RH-S), especially in the middle of point B. However, the retrofitted column has shown average compressive strength along with the column height (at points A, B, and C), as shown in Figure 21. The inner columns compressive strength of the Core Drill Test (K-14M-CD-S and K3-14M-CD-S) had lower results than Rebound Hammer Test. The baseline value of the compressive test of the column before it was retrofitted (K-Baseline) was the lowest (16.91 MPa) compared to the test results of Rebound Hammer and Core Drill. Figure 22 illustrates an increase in compressive strength at point B of the retrofitted column of Core Drill Test (K3-14M-CD-S), where it was 92.34% higher (32.37 MPa to 16.83 MPa) at point B than at K-Baseline.



**Figure 21.** Compressive strength of retrofitted and control columns were obtained from Rebound Hammer Test and Core Drill method.



**Figure 22.** Compressive strength of baseline column was obtained from Core Drill method.

#### 4. Discussion

One of the most effective ways to increase concrete durability and bond strength in areas prone to tidal flooding is using PMC (Polymer Modified Concrete) [10]. Research by [11] found that the application of Styrene-Butadiene Rubber (SBR) latex into PMC and fiber-reinforced polymers (FRP) increased the concrete compressive strength by 72% and 86.64%, respectively. The experiment conducted by [13] on the addition of SF, RHA, and SF with nano-silica into concrete as polymer proved an increase in the compressive strength of the PMC by 82.9 MPa.

Subsequently, concrete durability in tidal-prone areas plays an important role in achieving sustainable concrete. According to research conducted by [4], Indonesia's climate has relative humidity ranging from 70% to 90%. The corrosion in carbonated concrete has become a serious problem in concrete sustainability in the marine environment and areas prone to tidal flooding. Therefore, concretes designed with a life span of 50 years when subjected to a marine environment, such as BS 6349-1, need to be stronger and durable with compressive strength of 25–40 MPa [4]. Previous research reported the retrofitting of concrete structure elements using polymer-modified concrete bonding with adhesive agents [21], premixed mortar additive [20], and concrete-bricks production with a mix of K1 and K3 [23]. It was found that the columns designed with premixed mortar additive

as polymer achieved compressive strength at age 28 days of 60.69 MPa. The compressive strength was 34.87% higher than the control (45 MPa). It was also reported that the compressive strength of the center of brick-wall surface tested by Rebound Hammer and Core drill had a compressive strength of 42.3 MPa [20] and 58.60 MPa at 14 months [23].

Research on the use of natural or bio-polymer to mix concrete, such as PMC is still rare, especially when applied to areas prone to tidal flooding. In this research, the innovation of biopolymer modified concrete using GMH were applied to the old-broken columns retrofitting to get a more durable and resistant concrete structure. The field application results and column tests found that the compressive strength of the retrofitted column achieved 32.37 MPa, increasing 92.34% compared to the baseline.

All columns in the research were submerged by tidal flooding intensively for 14 months because the aggressive environment contributes to the concrete's structure degradation. Research by [3] reported that concrete compressive strength with ordinary, normal Portland Cement exposed to the marine environment for 20 years is likely to significantly drop in the 10th year from approximately 50 MPa to 30 MPa.

## 5. Conclusions

In conclusion, it is necessary to develop concrete materials that are strong and durable in a marine environment prone to tidal flooding. This research proved that the bio-polymer modified concrete using GMH significantly increased concrete columns' performance and long-term durability. The findings also showed that the compressive strength of the retrofitted column achieved 32.37 MPa, a 92.34% increase compared to the baseline. Therefore, the challenges of getting sustainable concrete materials for areas prone to tidal flooding can be fulfilled by using bio-polymer modified concrete with *Gracilaria* sp., *Moringa oleifera*, and honey (GMH).

**Author Contributions:** Conceptualization, Rr.M.I.R.S. and I.I.; methodology, Rr.M.I.R.S.; validation, Rr.M.I.R.S., I.I. and B.S.; formal analysis, Rr.M.I.R.S.; investigation, I.I. and B.S.; resources, B.S.; data curation, Rr.M.I.R.S.; writing—original draft preparation, Rr.M.I.R.S.; writing—review and editing, I.I.; visualization, B.S.; supervision, I.I.; project administration, B.S.; funding acquisition, Rr.M.I.R.S. All authors have read and agreed to the published version of the manuscript.

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