

# Improved Concrete Durability Using Ground Granulated Blast Furnace Slag on Seawater Environment

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## ABSTRACT

A study to improve the utilization of waste material as concrete construction material and the durability of concrete was carried out using a Ground Granulated Blast Furnace Slag (GGBFS) material which is the residual material produced by a blast furnace process. This experimental study using 6 normal concrete blocks and GGBFS modified concrete blocks 15x15x75cm sized. Acceleration for corrosion by soaking using seawater that has been modified with the wet dry treatment and addition of 30mg/L NaCl solution. In this study flexural strength testing and corrosion area testing are used. The stiffness of the immersed specimen is smaller than that of the non-immersed specimen. At the time of immersion, concrete with GGBFS has greater stiffness value than normal concrete. The increase in corrosion is seen in the average potential difference that occurs in normal concrete with immersion, namely being 3.57 times and in GGBFS concrete by 2.57 times. The increase in normal concrete corrosion was also seen in the corroded area, namely 5% to 50% active corroded steel, up from 0.52% to 46.88% and 50% to 95% active corroded steel from 0% to 3.12%. It was different with what happened to 40% GGBFS concrete, the active corroded area only increased from 1.04% to 6.43%. The purpose of this study is for better effectiveness concrete in seawater, so it can become one of the alternative solutions for infrastructure development especially for seawater infrastructure in Indonesia.

**Keywords:** Durability, GGBFS, Flexural Strength, Corrosion

## 1. INTRODUCTION

The cement industry has been one of the biggest emitters of CO<sub>2</sub> in the world along with the development of construction science using concrete. Research conducted by Chatham House reported by BBC News America in 2018, the cement industry was able to produce 8% of CO<sub>2</sub> emissions which far exceeded the CO<sub>2</sub> emissions produced by aircraft fuels (2.5%) and only slightly rose of value from CO<sub>2</sub> emissions generated by the global agricultural industry (12%) [1]. Based on this, many studies have been carried out using environmental-based concrete as a base material or what is commonly referred to as green concrete. One of the environmental-based concrete uses is to use Ground Granulated Blast Furnace Slag (GGBFS) which is a derivative of the production of blast furnace waste in the steel industry as a substitute for cement. However, in Indonesia, the use of waste materials as a substitute for cement is still rarely used. In addition, the use of waste, which in this case is GGBFS, cannot be done carelessly [2]. This is stated in Government Regulation Number 101 of 2014 which regulates hazardous waste in Indonesia from specific

sources, derivatives from blast furnace waste is classified as dangerous so that they cannot be directly released into the environment [3]. In addition, based on data from the Ministry of Industry in 2019, currently in Indonesia the demand for steel in Indonesia reaches 17 million tons per year, where 12 million tons are produced domestically and the other 5 million tons are imported from other countries which are generally types of steel that are not produced in Indonesia. The waste from steel processing in Indonesia now produces at least 600,000 tons of slag per year [4]. Based on this, it is necessary to apply the 3R (reuse, reduce, and recycle) in using this concrete waste. One of the applications of 3R on GGBFS is to make it into a composite form, which in this case is concrete. Therefore, concrete that uses GGBFS can also be categorized as environmentally based concrete (green concrete) because it utilizes waste to turn it into another form, which in this case is concrete. In several studies on GGBFS, it was able to increase the compressive strength value of normal concrete and concrete mixed with GGBFS and its resistance to sodium sulfate and magnesium sulfate [5]. In addition, other studies have investigated the effect of GGBFS on mortar withstanding sulfate attack and its

relationship to pore structure and transport properties [6]. Therefore, this study is aimed at increased the durability of reinforced concrete by utilizing GGBFS

material in the seawater environment so that it can be used as a construction material and applied to infrastructure development in seawater.

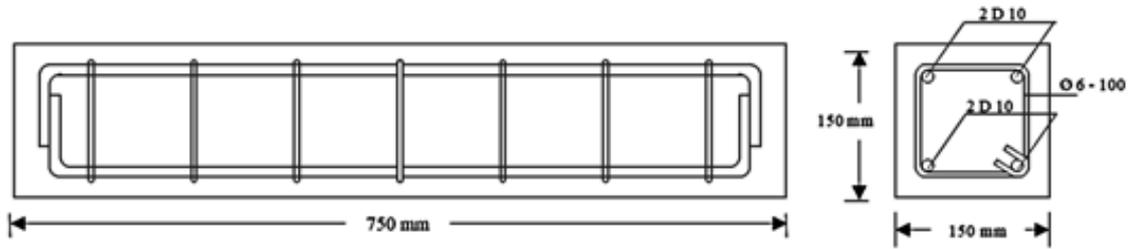


Figure 1 Specimen Dimension

2. RESEARCH METHOD

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

- a. Flexural Strength Testing. This test was conducted to obtain the values of flexural stiffness and ductility. The test standard used in this test is ASTM C78 using a simple beam with third-point loading.
- b. Corrosion Area Testing. This test is carried out to obtain the percentage of corroded area, the difference in the average corrosion point potential and the reinforcement corrosion contours. Testing used the canin+ tool.

2.1. Specimens

The specimens in this study are using normal concretes and modified concretes. Bar cover used is 2 cm. The specimens can be explained as follows: (see Table 1 & Figure 1).

Table 1. Quantity and Object Code of Specimens

Object Code	Quantity
BN	3
BNR	3
BG	3
BGR	3

Information:

- BN : Normal Concrete (0% GGBFS)
- BNR : Soaked Normal Concrete (0% GGBFS)
- BG : Modified Concrete (40% GGBFS)
- BGR : Soaked Modified Concrete (40% GGBFS)

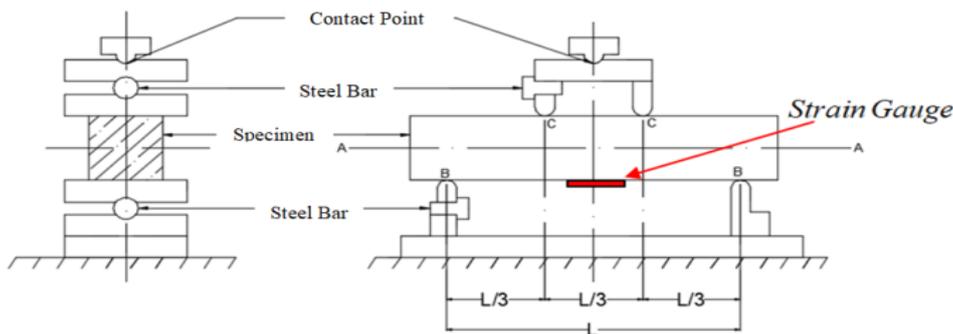


Figure 2 Concrete Flexural Strength Testing Scheme

2.2. Method

The concrete immersion method was carried out using sea water which had increased its concentration using a 30 mg/L NaCl solution [7] in order to maximize the level of damage caused by sea water during immersion. In addition, the acceleration of corrosion was also carried out by wet and dry for 3 days alternately [8]. This soaking was carried out for 6

months before finally being tested for flexural strength testing and corrosion.

2.3. Testing

The testing for flexural strength is using ASTM C78 [9] using a simple beam with third-point loading as standard. This concrete flexural strength testing scheme can be seen in Figure 2. After flexural strength testing done, then the corrosion testing is carried out by using canin+ tool. The tool can be seen in Figure 3.



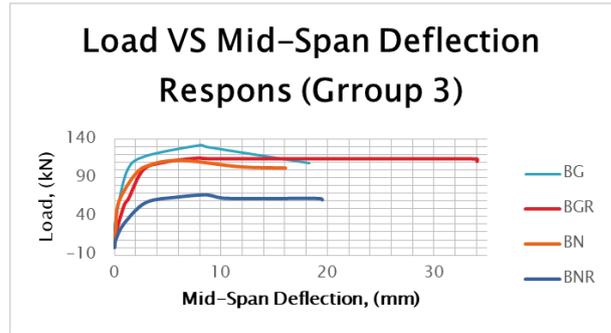
**Figure 3** Canin+ Tool for Corrosion Testing

### 3. RESULT AND DISCUSSION

The following are the results of experimental research that has been carried out:

#### 3.1. Flexural Strength Testing Result

The following are the results of the flexural strength test that has been carried out can be seen at Figure 4a, Figure 4b and Figure 4c.



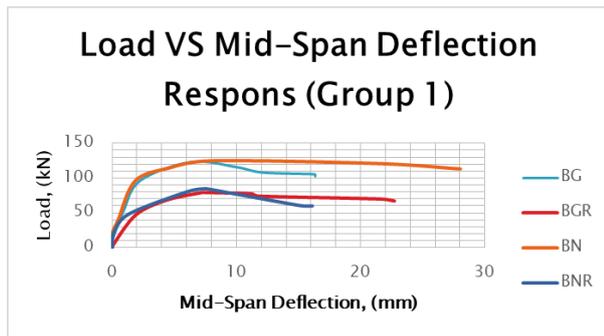
**Figure 4c** Load vs Mid-Span Deflection Response (Group3)

#### 3.2. Corrosion Testing Result

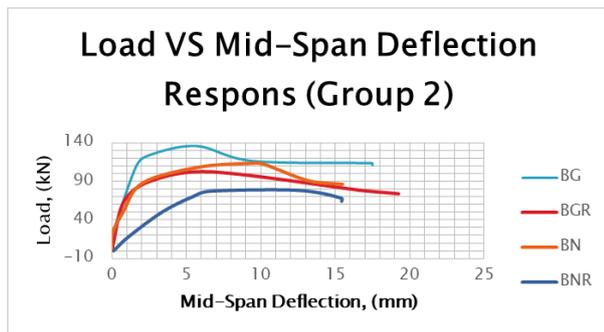
The following are the results of the corrosion testing that has been carried out can be seen in Table 2 and Figure 5.

**Table 2.** Average Potential Differences and per Specimens

Number	Code	Average Potential Difference (mV)	Average per Specimens (mV)
1	BN1	-24.73	-54.09
2	BN2	-50.87	
3	BN3	-86.67	
4	BG1	-47.60	-54.80
5	BG2	-12.67	
6	BG3	-104.13	
7	BNR1	-200.67	-193.42
8	BNR2	-207.87	
9	BNR3	-171.73	
10	BGR1	-113.73	-140.91
11	BGR2	-155.00	
12	BGR3	-154.00	



**Figure 4a** Load vs Mid-Span Deflection Response (Group1)



**Figure 4b** Load vs Mid-Span Deflection Response (Group2)

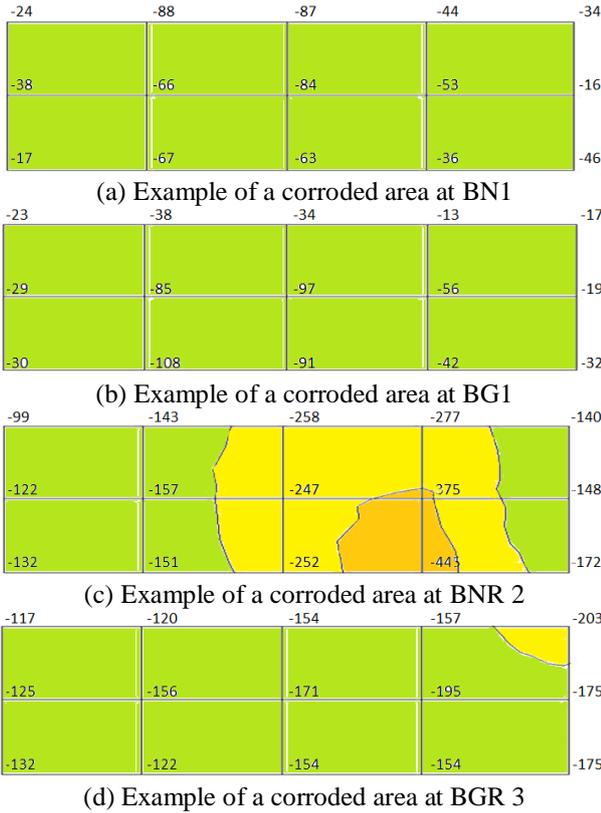


Figure 5 Example of a Corroded Area at BN, BNR, BG, and BGR

Based on ASTM C876-91, the recorded potential differences have the following ranges see Table 3:

Table 3. Corrosion Range by Potential Differences

Measurement (mV)	% of steel being corrosively active	Colour
0 to -200	0 - 5	Lime
-201 to -350	5-50	Yellow
-350 to -500	50-95	Orange

Table 4. Specimens Proportional Stiffness

Specimen Group	Specimen Code	Pmax	δmax	Pprop	δprop	Kprop
		(kN)	(mm)	(kN)	(mm)	(kN/mm)
Group 1	BN	124.906	7.977	49.962	0.742	67.325
	BG	123.113	6.352	49.245	0.898	54.832
	BNR	84.705	7.498	33.882	0.630	53.813
	BGR	79.339	7.434	31.736	1.285	24.692
Group 2	BN	113.803	9.307	45.521	0.685	66.443
	BG	136.494	5.681	54.598	0.683	79.901
	BNR	78.740	6.577	31.496	0.670	47.018
Group 3	BGR	102.691	6.775	41.076	0.416	98.639
	BN	112.560	5.407	45.024	0.196	229.437
	BG	132.739	8.105	53.096	0.460	115.435
	BNR	68.261	8.372	27.305	0.675	40.456
	BGR	116.018	7.895	46.407	0.675	68.792

### 3.3. Discussion

Based on the research that has been done, the stiffness and ductility can be calculated using the following formula:

$$K_{prop} = \frac{P_{prop}}{\delta_{prop}} \tag{1}$$

Information:

K<sub>prop</sub> : Proportional stiffness (N/mm)

P<sub>prop</sub> : Proportional limit load (N)

δ<sub>prop</sub> : Proportional limit deflection (mm)

In determining the value of proportional stiffness (K<sub>prop</sub>), the proportional limit of the load and its deflection is used. Proportional limit is the area where the load and deformation have a proportionality relationship, where each additional load will be followed by a proportional addition of deformation in a linear relationship. According to the Commonwealth Scientific and Industrial Research Organization (CSIRO), the proportional limit is determined from 0.4 P<sub>max</sub>. The results of the proportional stiffness calculation can be seen in the Table 4.

$$\mu = \frac{\delta_u}{\delta_y} \tag{2}$$

Information:

μ : Ductility

δ<sub>u</sub> : Maximum deflection (ultimate)

δ<sub>y</sub> : Deflection at yield

**Table 5.** Specimens Ductility

Specimen Group	Specimen Code	Pu	$\delta u$	Py	$\delta y$	$\mu$
		(kN)	(mm)	(kN0)	(mm)	( $\delta u/\delta y$ )
Group 1	BN	99.925	2.411	55.291	0.928	2.599
	BG	98.490	2.490	56.754	1.123	2.218
	BNR	67.764	4.090	38.880	0.787	5.197
	BGR	63.471	3.592	42.013	1.607	2.236
Group 2	BN	91.042	2.300	52.151	0.856	2.685
	BG	109.195	1.599	64.182	0.854	1.872
	BNR	62.992	2.303	36.465	0.837	2.750
	BGR	82.153	2.216	45.383	0.521	4.258
Group 3	BN	90.048	2.002	48.161	0.245	8.161
	BG	106.191	1.828	67.374	0.575	3.179
	BNR	54.609	2.478	29.051	0.844	2.937
	BGR	92.814	2.264	50.587	0.843	2.685

Based on the results of the proportional stiffness (Table 4), it can be concluded that the stiffness value of the immersed test object is lower even though there are specimens had experience anomalies such as BGR 2 (98.639 kN / mm). In addition, when immersion was carried out, generally the stiffness value of BGR was higher than that of BNR except for BGR 1 (24.692 kN / mm) which was lower than BNR 1 (53.813 kN / mm). This is influenced by the  $\delta_{prop}$  value on BGR 1 which makes the  $K_{prop}$  value small. Ductility is the ability of a building structure to experience large post-elastic deviation repeatedly and back and forth due to earthquake loads above the earthquake load which causes the first melting, while maintaining sufficient strength and stiffness, so that the building structure remains standing, even though was already on the verge of collapse. The ductility value will be very important

for buildings when an earthquake occurs, the ductility will maintain the strength and stiffness of the structure so that the building structure remains standing even though it is on the verge of collapse [11]. The ductility factor is calculated based on the Commonwealth Scientific and Industrial Research Organization (CSIRO). The deformation value at the ultimate load ( $\delta u$ ) is determined from the ultimate load  $P_u = 0.8 P_{max}$  and the proportional limit deformation value ( $\delta y$ ) is  $1.25 \times \delta_{0.4P_{max}}$ . According to Muñoz, the concrete specimen that is included in the ductile state is concrete with a ductility value of  $1.5 < \mu < 4.0$  [12]. Based on the results of tests carried out (Table 5), almost all concrete categorized into the ductile, but some concrete such as BNR 1, BGR 2, and BN3 have ductility values greater than 4. This is influenced by the large  $\delta u$  value (BNR 1) and small  $\delta y$  value (BGR 2 and BN 3).

**Table 6** Specimens Corroded Area

Specimen Code	Corroded Area (%)			Average Corroded Area (%)		
	0 to 5	5 to 50	50 to 95	0 to 5	5 to 50	50 to 95
BN1	100	0	0	99.48	0.52	0
BN2	100	0	0			
BN3	98.44	1.56	0			
BG1	100	0	0	98.96	1.04	0
BG2	100	0	0			
BG3	96.87	3.13	0			
BNR1	40.62	59.38	0	50.00	46.88	3.12
BNR2	25	65.63	9.37			
BNR3	84.37	15.63	0			
BGR1	100	0	0	93.60	6.43	0
BGR2	100	0	0			
BGR3	80.81	19.29	0			

Based on the results of the research that has been carried out, it can be seen an increase in corrosion due to immersion. This can be happened by the acceleration of the seawater content by using 30 mg /L NaCl in the implementation of immersion. In addition, it can be noted that the use of GGBFS in concrete can reduce the corrosion rate by 27.14% better than normal concrete. The increase in corrosion can be seen in the average potential difference that occurs in normal concrete with immersion, namely being 3.57 times and in GGBFS concrete by 2.57 times. In addition, it can also be seen in Figure 5 that the area of corrosion in BGR is significantly reduced when compared to BGR (Table 6). The increase in normal concrete corrosion was also seen in the corroded area, namely 5% to 50% active corroded steel, up from 0.52% to 46.88% and 50% to 95% active corroded steel from 0% to 3.12%. It was different with what happened to 40% GGBFS concrete, the active corroded area only increased from 1.04% to 6.43%. So it can be concluded that the use of GGBFS can reduce the level of corrosion in concrete and the corroded area in concrete. The results of this study are also supported by several studies that have been conducted by several researchers. Song and Saraswathy [13], have also conducted research with the conclusion that the more the percentage of the amount of GGBFS used in cement substitution, the less corroded area will be. Then, the thicker the concrete blanket used to protect the reinforcing concrete, the more corroded areas will be reduced. In addition, the selection of the type of cement used, namely portland cement type 5, is able to work better than portland cement type 1 in reducing the value of the corroded area.

#### 4. CONCLUSION

Based on the results of research and analysis, it can be concluded:

- a. The stiffness value of the immersed test object is lower even though there are specimens had experience anomalies.
- b. The stiffness value of BGR was higher than that of BNR except for BGR 1 which was lower than BNR 1.
- c. Almost all concrete categorized into the ductile, but some concrete such as BNR 1, BGR 2, and BN3 have ductility values greater than 4.
- d. The stiffness of the immersed specimen is smaller than that of the non-immersed specimen. At the time of immersion, concrete with GGBFS has greater stiffness value than normal concrete.
- e. Almost all specimens are in a ductile state. But none of the concrete is in a non-ductile state.
- f. The use of GGBFS in concrete can reduce the corrosion rate by 27.14% better than normal concrete. During immersion time, corrosion increased 3.57 times in normal concrete and 2.57 times in GGBFS concrete.
- g. The use of GGBFS can reduce the level of corrosion in concrete and the corroded area in concrete.

#### ACKNOWLEDGMENT

This work was supported by PT. Krakatau Semen Indonesia (KSI) for GGBFS material.

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