Compressive strength and permeability of concrete by using GGBFS against seawater

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Abstract. One of the causes of cracked reinforced concrete in the seawater environment is direct contact between concrete and sea water. This is because cement as a binding material in concrete does not have a good ability to withstand corrosive conditions in seawater. Ground Granulated Blast Furnace Slag (GGBFS) which in this case is B3 waste can be a solution. From several studies conducted previously, the behaviour of GGBFS concrete against sulfate and chloride attacks showed positive results but relatively little is known about GGBFS material produced by steel mills in Indonesia. Therefore, an experimental study of the characteristics of compressive strength and permeability test using GGBFS (0%, 20%, 30%, 40%, 50%, and 60%) with 72 concrete cylinders in 28 and 40 days. Microstructure of GGBFS concrete test using Scanning Electron Microscopy (SEM) was also studied. The result of this experimental study is GGBFS microstructure, compressive strength and concrete permeability for better effectiveness concrete in seawater, so that it can become one of the alternative solutions for infrastructure development especially for seawater infrastructure in Indonesia.

1. Introduction
One of the causes of reinforced concrete cracks in the water environment is direct contact between concrete and sea water [1]. This causes cement as a binding agent in concrete does not have a good ability in binding which is corrosive to seawater. Ground Granulated Blast Furnace Slag (GGBFS) or commonly called cement slag is a by-product that is reprocessed from the furnace process in an iron and steel plant into one solution. Evident from several studies conducted by many GGBFS researchers can be used for cement substitution such as Bhat [2], Ozbay [3], and Song [4]. But in Indonesia, GGBFS waste is a waste that is categorized as B3 (Hazardous and Toxic Material) [5], therefore 3R (Reuse, Reduce, Recycle) activities are needed in its management before finally being released back to the environment. Based on the problems that occur, this study aims to conduct research on compressive strength and permeability of concrete to the air with GGBFS material so that it can be used as construction material and research is needed that can be used in infrastructure development in sea water.

2. Research methods
In the research to get the intended results, in this study conducted several tests including:

2.1. Material characteristics testing
This test serves to obtain the material characteristics of the material under study namely GGBFS and OPC cement.
2.2. **Concrete compressive strength testing**

This test serves to obtain the compressive strength value of concrete. The specimens used were 36 concrete cylinders, 18 cylindrical concrete pieces aged 28 days and 18 cylindrical concrete pieces aged 40 days with GGBFS substitution content of 0%, 20%, 30%, 40%, 50% and 60% with respectively each substitution level of 3 cylindrical concrete pieces.

2.3. **Concrete permeability testing**

This test serves to obtain the value of concrete permeability. Permeability testing is done in 2 ways, first by immersion of 10-minute cylindrical concrete and 1 day and secondly by permeability testing by applying 5 bar pressure for 3 days. The specimens used were 36 concrete cylinders, 18 cylindrical concrete pieces aged 28 days and 18 cylindrical concrete pieces aged 40 days with GGBFS substitution content of 0%, 20%, 30%, 40%, 50% and 60% with respectively each substitution level of 3 cylindrical concrete pieces.

2.4. **Scanning Electron Microscopy (SEM) testing**

This test serves to obtain microstructure from GGBFS concrete. Along with this test EDX testing is also carried out which serves to determine the composition of concrete. The test specimens used are concrete with 0% and 60% GGBFS content.

3. **Results and discussion**

3.1. Results

3.1.1. **Compressive strength test results.** The results of compressive strength test are presented in graphs in Figure 1.

![Figure 1. Compressive strength graph.](image)

3.1.2. **Permeability test results.** The results of permeability test by soaking and with 5 bar pressure are presented in graphs in Figure 2.
3.1.3. Scanning electron microscopy test results. The results of scanning electron microscopy and EDX test are presented in Figure 3. and Figure 4.

3.2. Discussion
Based on the results of testing the characteristics of GGBFS, the silica content in GGBFS is more than that of ordinary OPC cement. It can be seen that the comparison of silica in GGBFS is 36.27% and silica
in OPC cement is 22.86%. The amount of silica content in the GGBFS exceeds silica levels in cement in general. Besides that, GGBFS has a whiter color than OPC cement, which is also caused by silica which has a white color. Besides that, the fineness of GGBFS granules which is coarser than OPC cement is 332 m$^2$/kg for GGBFS and 375 m$^2$/kg causing the heat of hydration to be lower. This lower assumption of hydration heat is due to the small grain cross-sectional area, so that the contact area with water becomes smaller. Therefore there is a possibility that the initial strength is low and the final strength will be large [6]. In addition, lower hydration heat also gives advantages when thermal concrete cracks that can be a problem in making concrete are reduced [7].

After compressive strength testing, it can be noted that there is an increase in the compressive strength value of concrete at 40 days with GGBFS. The addition of GGBFS at 28 days significantly reduced the compressive strength of concrete. However, the 40 days compressive strength test was found to have a maximum compressive strength of 30% GGBFS (30,339 MPa). The biggest increase in compressive strength with GGBFS substitution of 30% (12.17%). With this it is concluded that mixing with GGBFS to maximize compressive strength is with a mixture of 30% GGBFS. The phenomenon of the slow increase in compressive strength of the GGBFS concrete can also be explained by the grain size which is more rough compared to concrete with OPC cement only. Rougher grain size causes lower hydration heat so that the increase in the final compressive strength is higher and the increase in the initial compressive strength is low.

For the 28-day concrete marinade the smallest weight value was obtained at 50% GGBFS substitution (1.078% 10 minutes and 5.868% 1 day) and the 40-day concrete marinade the smallest weight value obtained at 30% GGBFS substitution (1.340% 10 minutes and 6.102% 1 day) where both of them have fulfilled the requirements stated in SNI Water Resistant Concrete, 2.5% 10 minutes and 6.5% 1 days [8]. For permeability testing with 5 bar pressure with the smallest value is 50% GGBFS substitution at 28 days and 40% GGBFS substitution at 40 days. However, what meets the criteria stated in the SNI Water Resistant Concrete (SNI 03-2914-1992) is a 40% GGBFS substitution (minimum water height 50 mm for moderate aggressiveness). Therefore, the best mix for waterproof concrete is GGBFS 30% to GGBFS 40% substitution.

After SEM-EDX testing the results of the study can be analysed as follows.

- It can be seen that the 60% GGBFS concrete granules (531.5 nm smallest) are smaller than the 0% GGBFS concrete (881.8 nm smallest) which can be compared in Figure 3. and Figure 4. Smaller grain size has better density than larger ones. Even so it cannot be said that concrete with GGBFS 60% is better because in some of the tests above, 60% GGBFS concrete is in fact no better than 0% GGBFS concrete.

| Table 1. EDX test results. |
|--------------------------|
| Element | Atomic (%) | 0% | 60% |
| Si | 8,35 | 11,47 |
| O | 70,08 | 70,89 |
| Ca | 14,45 | 7,68 |
| Al | 3,37 | 7,45 |
| S | 0,45 | - |
| Na | 0,38 | 1,28 |
| Fe | 1,72 | 1,23 |
| Mg | 1,21 | - |
| Total | | 100 | 100 |

- Based on EDX testing, it can be concluded that both of them have high O (Oxygen) content (can be seen in Table 1). This is because in general in OPC cement and GGBFS in general other elements are found to be interlocking with O such as: CaO, SiO$_2$, Fe$_2$O$_3$, MgO, and SO$_2$. 
- Si element (silicon) in concrete with GGBFS is higher (11.47%) compared to OPC cement concrete (8.35%). This causes an increase in compressive strength (as evidenced by compressive strength testing of 20% and 30% GGBFS 40 days), giving a whiter color than normal concrete. This is because the compressive strength is strongly influenced by C\(_2\)S and C\(_3\)S compounds where an increase in S is likely to increase the compressive strength [9].

- Element Ca (Calcium) in concrete with GGBFS is lower (7.68%) compared to OPC cement concrete (14.45%). This causes a decrease in compressive strength (as evidenced by the 40%, 50% and 60% concrete compressive strength testing of 40 days GGBFS). Although the use of GGBFS can increase compressive strength, the addition of too much GGBFS will reduce the Ca element. Therefore, C\(_2\)S and C\(_3\)S are affected by Ca so that the reduction in Ca element causes a decrease in compressive strength.

- Element Al (Aluminum) in concrete with GGBFS is higher (7.45%) compared to OPC cement concrete (3.37%). This results in the GGBFS concrete being able to harden faster because the C\(_3\)A compound affects the binding of the concrete at the beginning (<1 day) [10].

In its application in developed countries (such as Docklands and Jack Lynch Tunnel in Dublin, Ireland), the use of GGBFS often occurs because it is known that GGBFS has the ability to protect concrete against sulfate and chloride attacks and even now effectively replaces the use of SRPC type cement (Sulfate-Resistance Portland Cement). But the most effective use for increasing durability based on the standard they use is 50% GGBFS substitution. Of course this is slightly different from the use of GGBFS recommended by the results of this study (ie 30% - 40%). The existence of these differences researchers assume that the processing of GGBFS carried out abroad and the processing of GGBFS in Indonesia is likely to have differences. In addition, the use of OPC cement used by researchers may also influence. Therefore the research produced is also different. Apart from the analysis of the chemical properties used, there are also physical properties that affect the sea water environment (Properties of Indonesia seawater test results can be seen in Table 2). It is known that concrete with GGBFS has lower hydration heat so that the possibility of microcrack will occur is low. Microcrack is able to reduce the porosity of concrete and if porosity decreases, sea water is able to enter and disrupt the strength of the concrete. GGBFS concrete which has microcrack potential will certainly increase durability in the seawater environment.

| Parameter          | Unit            | Testing Method | Results  |
|--------------------|-----------------|----------------|----------|
| Hardness           | mg/L            | APHA-2340-C    | 5786     |
| Calcium Titration  | mg/L            | APHA-3500-Ca-B | 784      |
| Magnesium Titration| mg/L            | APHA-3500-Mg-B | 918      |
| Chloride           | mg/L            | APHA-4500-Cl-B | 17369    |
| Natrium            | mg/L            | APHA-3500-Na-B | 8300     |
| pH                 | -               | APHA-4500-H++-B| 7.58     |
| Sulfate            | mg/L            | APHA-4500-SO4-E| 1131     |

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

- GGBFS has more Si element than OPC, it can affect compressive strength but and the fineness of OPC was better. Lower fineness makes GGBFS concrete has low hydration heat that can prevent microcrack better.

- The optimum substitution for compressive strength is 30%. The phenomenon of reducing the compressive strength of concrete using GGBFS at 28 days and increasing the compressive
strength of concrete using GGBFS at the age of 40 days. This is probably caused by low heat of hydration which causes low compressive strength at the beginning and an increase in compressive strength at the end.

- The optimum substitution for compressive strength is 30% - 40%. The lowest average water penetration is 49.42 mm at 28 days concrete age and 49.45 mm at 40 days concrete age. In addition, some of the test results, the value of immersion weight was in accordance with the requirements listed in SNI (for a maximum of 10 minutes soaking 2.5% and for 1 day immersion a maximum of 6.5% oven dry weight) especially for 40-day-old concrete. Therefore, based on the results of tests that have been carried out, GGBFS concrete has met the requirements to be in a medium aggressive water environment (sea water).

Acknowledgement
The author would like to thank UPPM State Politeknik Negeri Bandung for research funding assistance and PT. Krakatau Semen Indonesia has provided GGBFS material assistance so that this research can be completed well.

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