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Properties of Concrete Using Bottom Ash N107 Cured in The Tidal Zone

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Abstract: In Indonesia, around 9.89 million tons of Fly Ash and Bottom Ash (FABA) waste is generated annually from burning coal in steam power plants (PLTU). One type of FABA waste categorized as Non-B3 which is Bottom Ash with a waste code of N107. If this waste not utilized, it will only become a waste product. With the Indonesia Government Regulation No. 22 of 2021, this waste utilization process becomes more manageable and has the opportunity to be optimized. One of the recommended alternative uses of Non-B3 FABA is substituting raw materials for infrastructure materials, especially for coastal areas where it is difficult to obtain fine aggregate. In the process of development, coastal areas are often in contact with sea air. Seawater has a high salt content which can undermine the strength and durability of concrete, so this study focuses on discussing the effect of using Bottom Ash as a fine aggregate substitute on concrete strength of the M24 concrete, which is influenced by the sea's tides. By using the ACI 211.1-91 concrete mix design method, experimental concrete samples were made by substituting fine aggregate with bottom ash N107 with a percentage of 0%, 20% and 30% and a maximum coarse aggregate size of 20 mm, the treatment of concrete samples was carried out in freshwater and in the tidal zone. From the sample of concrete with 20% and 30% bottom ash, it is known that the porosity of the concrete immersed in the tidal zone is higher than that of the concrete immersed in fresh water. For concrete that was given maintenance treatment in the tidal zone, the compressive strength decreased at 56 days.

Keywords: Bottom Ash N107, properties, fine aggregate substitution, concrete, compressive strength, voids, density

1. Introduction

Fly Ash and Bottom Ash (FABA) is the solid waste from burning coal in a steam power plant (PLTU). Three types of coal combustion are known in the electricity industry: dry bottom boilers, wet bottom boilers, and cyclone furnaces. The most commonly used type is the dry bottom boilers type. This type of combustion produces ash, approximately 80% in the form of fly ash, that flows into the gas funnel and is collected by a precipitation mechanism. The remaining 20% is in the form of bottom ash which remains at the bottom of the furnace [1]. Of the various types of FABA waste produced, the FABA waste categorized as Non-B3 is FABA waste with code N106 for Fly Ash and N107 for Bottom Ash [2].

Fusing FABA waste in other countries has been massive, and almost reach 100%. For example, India has utilized up to 67% in 2018, Netherlands 100%, Denmark 90%, Germany 79%, Belgium 73%, France 65%, UK 70%, Japan 92%, China 100%, and Vietnam 60% [3]. [4] said that FABA can be reused for road construction as materials for cement, concrete, slope concrete, structural fillers, road base materials, synthetic aggregates, snow and ice control, reclamation as commonly used in ex-open pit reclamation, reclamation in active open pit mines, remediation, and control of land subsidence, agricultural applications as soil ameliorant, farm yard hardener, straw storage mats, manufacturing as aggregate, paint, cement industry, filler material in plastic, rubber and alloy industries), civil engineering as brick, paving blocks, media, waste stabilizer.

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Around 49% of power plants in Indonesia use coal as their energy source. In 2019, coal consumption at several steam power plant in Indonesia was recorded at around 98.9 million tons, with the potential for FABA production of around 10% or 9.89 million tons. If FABA not utilized it will only become a waste product [5]. The reuse of non-B3 FABA waste in Indonesia is supported by Indonesia Government Regulation No. 22 of 2021, which no longer categorizes FABA, especially from steam power plants as hazardous waste. The FABA utilization process becomes more manageable and has the opportunity to be optimized [5]. According to the Director General of Electricity, Rida Mulyana, with the release of FABA from B3 waste, it will be more widely open to using FABA to provide benefits for the country and reduce environmental problems due to the number of FABA stockpiles and making conventional concrete, and providing an efficient infrastructure development budget of Rp. 4.3 trillion until 2028, and has the potential to absorb labor in small and micro businesses [5].

In the management of non-B3 FABA, environmental principles must be applied. The use of non-B3 FABA has several advantages in terms of the environment (reduction of waste emissions, reduction of landfill land), the economic side (reduction of waste processing costs and selling value), and the product side (as a material mix / increase the strength of the material) [5]. In addition, based on [2], one alternative to the recommended use of Non-B3 FABA is substituting raw materials for infrastructure materials. Several studies on FABA have been carried out. Some studies focus on using Fly Ash or Bottom Ash alone or researched simultaneously, combining the use of Fly Ash and Bottom Ash as a substitute for building materials such as building houses, roads, and bridges.

FABA Non-B3 can be used as a substitute for clay in manufacturing bricks by having 30-40% greater compressive strength and 5% better flexibility [7]. At the same time, the effect of the addition FABA to the base layer mixture can increase the bearing capacity, with the results of the CBR immersion test that goes against the standard (90%), which is 162% [8]. For concrete mixtures, adding FABA 2.5% to 17.5% to the weight of the aggregate, giving results in a higher quality of concrete [9].

According to [10], the substitution of base ash by weight of fine aggregate with percentages of 10%, 20%, 30%, 40%, and 50% with a control concrete mixture using 100% fine aggregate shows that 30% WBA replacement was found to be the optimal amount for obtaining good strength and a good pattern of strength development during aging. However, on the use of coal bottom ash (CBA) and fly ash as partial replacement of fine aggregate and cement in the range of 0, 5, 10, 15 & 20% (same percentage), the yield of compressive strength at curing 7, 28, 56 & 90 days presented due to the pozzolanic reaction; Other properties investigated include physical properties, properties of fresh concrete and specific gravity, the results showed that for grade 35 concrete with a combination of CBA and fly ash can produce 28 days of strength above 30 Mpa [11].

Utilizing soil CBA as a complementary material for cementing concrete, the original CBA dried in an oven was ground for 20 hours to achieve the required fineness, using a concrete mixture with a proportion of CBA 10, 20, and 30% by weight of cement, the compressive strength and tensile strength of the resulting concrete. Decreased with the addition of ground CBA, but with a 10% replacement, it met the targeted compressive strength at 28 days [12]. A follow-up study (10% CBA) used various percentages (5% to 15%) of lime content used by the weight method. Compressive, tensile, and flexural strength at 7 and 28 days decreased when the cement replacement rate increased. The compressive strength, split tensile, and flexural strength decrease as the cement replacement rate increases, but the strength increases with increasing maintenance life [13].

Besides applying regular treatments using fresh water, research by applying curing using seawater was also carried out to determine the effect of seawater on concrete properties. The compressive strength of the concrete treated with seawater was higher than that of the freshwater-treated concrete for a 7-day treatment period. In comparison, for the 14-day and 28-day treatment periods, the compressive strength of the concrete treated with seawater was lower than that treated with fresh water. This shows that the concrete that has been treated with seawater has a higher initial strength than the concrete that has been treated with fresh water [14].

Concrete with water cement factors 0.45; 0.50; and 0.55 gave a significant difference in the effect on the compressive strength of concrete with either seawater or clean water treatment, while the variation in the duration of curing with seawater for one day, two days, and three days did not give a significant difference in the compressive strength of the concrete. Variations influence absorption that occurs in concrete in seawater curing duration and variations in water-cement factors. The longer the curing period and the greater the water-cement factor, the greater the absorption that occurs [15]. Likewise, in the immersion of M22.5 grade concrete with seawater, there is a decrease in the compressive strength of the concrete with a percentage decrease, namely for seawater 5.89% against normal concrete for 28 days, 7.62% for 90 days, and 15.19% for 150 days old [16].

In high-strength concrete with variations in the percentage of fly ash as a fine aggregate substitution 0%, 10%, 20%, and 30%, as well as variations in curing using fresh water and seawater, sample treatment is carried out for up to 28 days, the relationship between fly ash substitution as a fine aggregate substitution the compressive strength has a significant correlation, the higher the percentage of fly ash, the higher the compressive strength of the concrete, both freshwater, and seawater curing, besides that the compressive strength of high-quality concrete using fly ash substitution as a fine aggregate substitution with fresh water curing treatment is greater than the seawater curing treatment [17].

In the process of development, coastal areas are often in contact with seawater. Seawater has a high salt content (CL) and is aggressive which can undermine the strength and durability of concrete [14]. Therefore, for the development of previous research, this study focuses on discussing the effect of using Bottom Ash as a fine aggregate substitute on the compressive strength of concrete influenced by tides.

2. Materials and Experimental Works

2.1 Materials

In this study, the cement generally used in construction on the Riau Province is Portland Composite Cement (PCC) which meets ASTM C1157, fine aggregate, and coarse aggregate with a maximum nominal size of 20 mm. Bottom Ash (BA) non-B3 N107 was taken from a waste processing company in PT. Dumai Hijau Abad, Dumai, Indonesia. Bottom Ash which is used first, is separated by using a No. Sieve. 4 (4.75mm), the part that passes the No. Sieve. 4 is considered fine aggregate and is used as a partial substitute for fine aggregate in concrete. To determine the particle size, a sieve analysis was carried out following ASTM C 136; its specific gravity is determined by a pycnometer based on ASTM C127 for the specific gravity of coarse aggregate and ASTM C128 for the specific gravity of fine aggregate; dry volume weight of aggregate based on ASTM C 29/C 29 M – 97, aggregate moisture content based on ASTM C566-97 and the color was assessed by visual observation. The properties of the materials used can be seen in table 1 below.

Table 1 - Material Inspection Results

No	Checking type	Results		
		Coarse Aggregate	Fine Aggregate	Bottom Ash (BA)
1	Fineness Modulus	-	2.88	2.54
2	Specific gravity			
	a. Apparent specific gravity	2.63	2.65	1.37
	b. Bulk specific gravity on Dry	2.60	2.61	1.03
	c. Bulk specific gravity on SSD	2.57	2.62	1.23
	d. Absorption	0.87	0.5	18,90
3	Water content (%)	0.44	12.81	0.5
4	Dry Volume Weight (kg/m3)			
	a. Congested	1548,10	1705.38	966.85
	b. Loose	1403.08	1591.46	857.30
5	Sludge levels (%)	0.2	0.9	-

Based on table 1, it is known that the fine modulus of fine aggregate and bottom ash has met the requirements of ASTM C33 (2.3 – 3.1), but for water absorption testing, coarse aggregates and fine aggregates have qualified water absorption of < 2.3% while water absorption for bottom ash > 2.3%. From the specific gravity test, the coarse aggregate and fine aggregate used are included in the normal weight aggregate category, while the bottom ash used is included in the light aggregate category.

2.2 Mix Proportion

2.3 Experimental Work

Based on the material properties of table 1, a concrete mixture sample was made with a water to binder ratio (w/(c+p)) of 0.54 and a slump value of 75-100 mm and tested at the age of 7, 28 and 56 days, where the method of replacement bottom ash by volume of fine aggregate. The concrete samples were immersed in fresh water and sea water, while the proportions of the concrete mixture are as given in Table 2.

Table 2 - Concrete mix proportions

Sample Design	PCC (kg)	Coarse Aggregates (kg)	Water (kg)	Repl. (%)	Fine Aggregates		Bottom Ash (m3)
					(kg)	(m3)	
Contro Mix	376,27	933,64	202 kg	0	827,95	0,315	-
20% BA	376,27	933,64	202 kg	20	662,36	0,252	0,063
30% BA	376,27	933,64	202 kg	30	579,56	0,221	0,095

Based on ASTM C 192/C 192 M-95, concrete mixing is carried out through a rotating drum mixer with a maximum capacity of 75 liters and is operated for 5 minutes. The specimens were removed from the mold after 24 hours of casting and immersed in a water tank for 7 days of curing. The first batch of concrete samples were prepared for casting control specimens without bottom ash, then in the second batch, the fine aggregate samples were replaced with bottom ash using the volume method with a percentage of 20% to 30%. ASTM C 143/C 143M – 03 is used for the slump test, ASTM C39-

99 is used as the basis for evaluating compressive strength, ASTM C 642 – 06 is used to obtain density and voids in hard concrete. For each assay, three specimens were prepared, and average values were obtained to represent the determined proportions. In this study the number of specimens that were printed for the first time was 18 concrete cylinder test objects aged 7 days, 28 days and 56 days which were immersed in fresh water and sea water with 3 specimens each, for testing the two specimens consisting of 18 cylinders. 20% Bottom Ash concrete with 3 specimens each and the third specimen consisting of 18 30% Bottom Ash concrete cylinders with 3 specimens each. Table 3 shows the number of samples for each test.

Table 3 - Number of sample

Sample Design	Curing in fresh water			Curing in sea water			Number of sampel
	7 days	28 days	56 days	7 days	28 days	56 days	
Control Mix	3	3	3	3	3	3	18
10% BA	3	3	3	3	3	3	18
20% BA	3	3	3	3	3	3	18

3. Results and Discussions

The slump test results are shown in Figure 1; by using a slump value of 75-100 mm, the concrete mixture get lack of water along with the addition of bottom ash. This is because the bottom ash is used in dry conditions and has a high absorption rate of bottom ash, which is 18.9%. In order to maintain workability, water is added, and the amount of water added for each concrete sample. Figure 2 shows the curing of concrete carried out in the tidal zone as a simulation of concrete used as a building material in coastal areas.

Fig. 1 - Slump test of concrete with 10% bottom ash

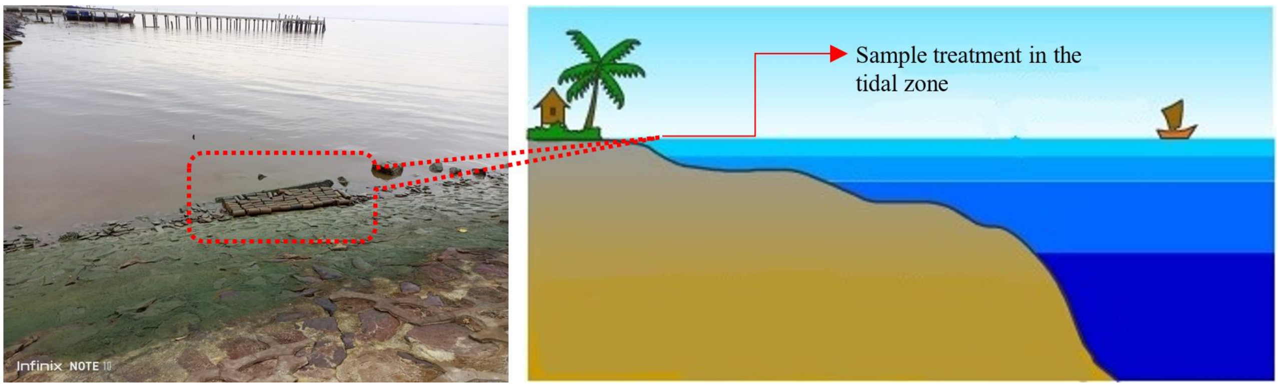

Fig. 2 - Curing sample in tidal zone sea water

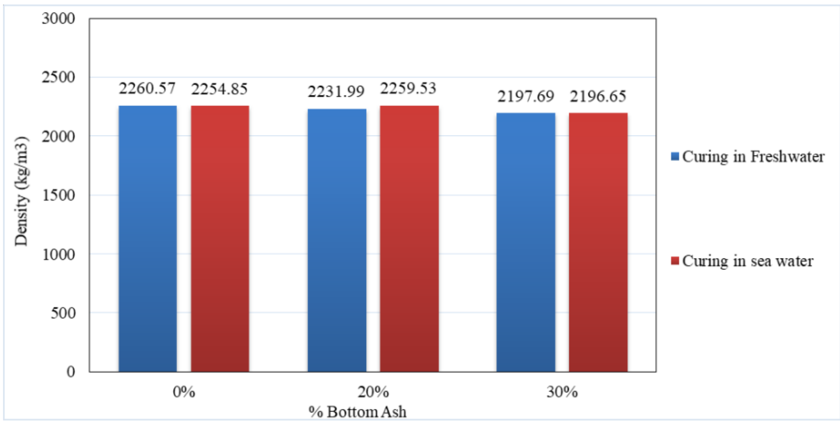

Fig. 3 - The relationship of density sample of 28 days old concrete to % bottom ash

Based on Figure 3, the density of the concrete volume decreases with the addition of bottom ash, and this is because the bottom has a specific gravity and density smaller than fine aggregate. However, the decrease in density is not significant. When using the bottom ash, 20% and 30% immersed in fresh water decreased in density by 1.26% and 2.78%, respectively. The same thing also happened to immersion in the tidal zone, with a decrease of 0.05% in used of 20% bottom ash and 2.83% decrease in using a 30% bottom ash.

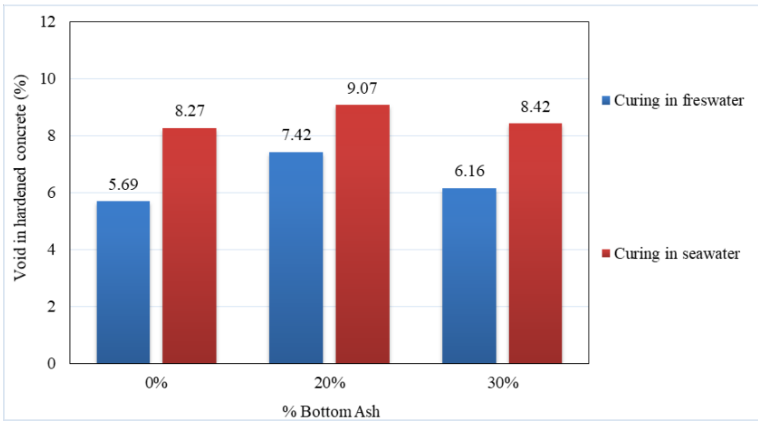

Fig. 4 - The relationship of % bottom ash to void of 28 day

From the perspective of the void in hardened concrete (Figure 4), the porosity value of concrete immersed in the tidal zone is higher than that of concrete immersed in fresh water. The decrease in porosity is 45.41% for concrete with 0% bottom ash concrete, 22, 21% for concrete with 20% bottom ash, and 36.67% for concrete with 30% bottom ash.

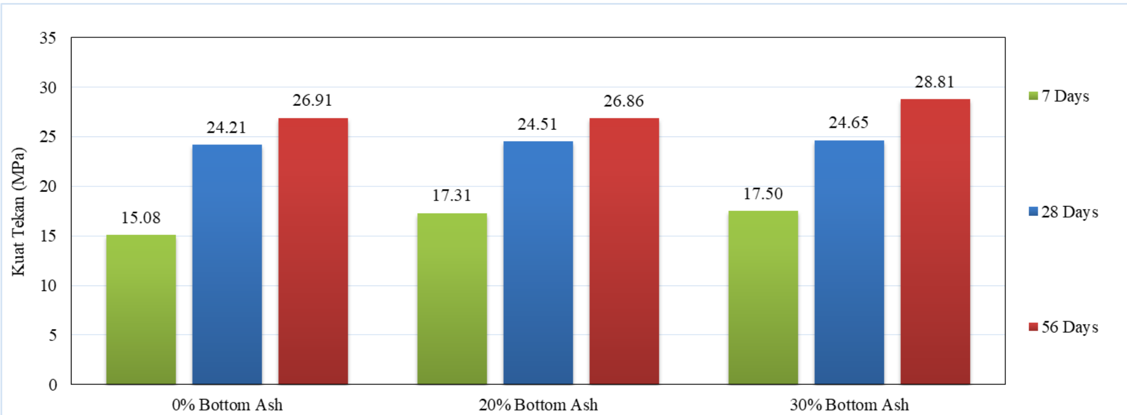

Fig. 5 - The relationship of compressive strength of concrete to age and % bottom ash on curing in freshwater

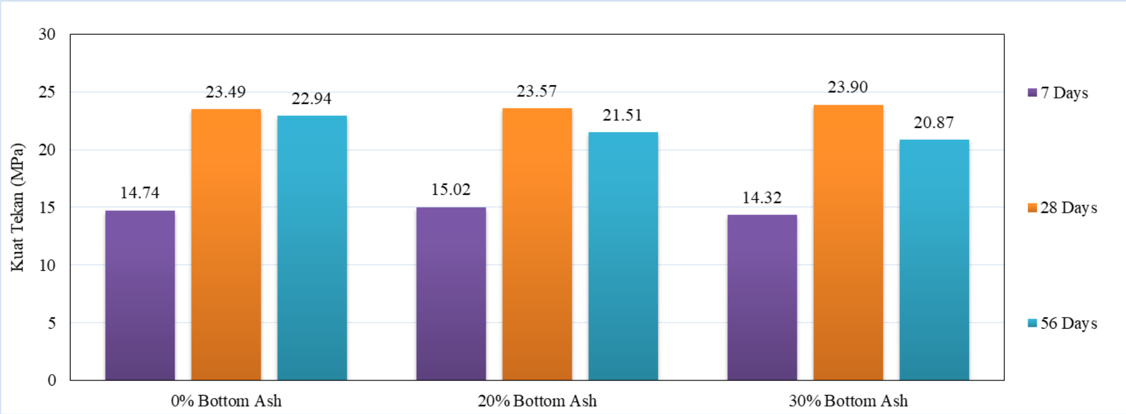

Fig. 6 - The relationship of compressive strength of concrete to age and % bottom ash on curing in seawater

The results of the control concrete compressive strength test (0% Bottom Ash) of 15.08 MPa were used as a reference for the compressive strength of concrete with a mixture of bottom ash. The results of the compressive strength test at the age of 28 days (Figure 5) for concrete curing in fresh water have the same trend as the test result with the addition of 20% and 30% bottom ash, the compressive strength value of concrete curing in fresh water is higher if compared to the strength of the concrete sample that was curing in the tidal zone of seawater at the level of bottom ash usage at the same percentage. If we look at the development of 7 days, 28 days, and 56 days (Figure 6), concrete curing in freshwater has a trend of increasing concrete quality with increasing age of concrete, but for concrete curing in the tidal zone, there is a decreasing trend at the age of 56 days, because seawater has a high salt content (CL) and is aggressive which can undermine the strength and durability of concrete.

4. Conclusions

The results of research and discussion of the effect of using a combination of non-B3 bottom ash as a substitute for fine aggregate on the compressive strength of concrete can be concluded as follows.

1. The use of non-B3 bottom ash as a substitute for fine aggregate with a proportional percentage has an optimum compressive strength at usage of 20% - 30% bottom ash.
2. The density of concrete decreases as the percentage of bottom ash increases as a substitute for fine aggregate.
3. The porosity of the curing concrete in the tidal zone is higher than that of the curing concrete in fresh water.
4. The effect of substituting fine aggregate using non-B3 bottom ash into the concrete mixture is that it can increase the compressive strength of concrete, as evidenced by the results of testing the compressive strength of concrete with a mixture of 20%, and 30% which has a compressive strength value higher than regular concrete at the age of 28 days, with the highest compressive strength value in the sample with a mixture of 30%.
5. For concrete that was given maintenance treatment in the tidal zone, the compressive strength decreased at 56 days because seawater has a high salt content (CL) and is aggressive which can undermine the strength and durability of concrete.

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