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Utilization of bottom ash in porous concrete as an environmentally friendly surface covering material

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Abstract
Concrete is a material that is widely used as a surface covering, because it not only has reliability in terms of strength, durability and ease of implementation, but also has high economic value. Therefore, with the current development of concrete technology, efforts are being made to improve the performance of concrete to be more effective and efficient as a surface covering material by creating a porous concrete structure that allows surface runoff to infiltrate into the soil. Covering the surface of porous concrete is a form of innovative approach that is unique in rainwater management and is effective in tackling environmental problems and supporting development based on ecosystem data collection in land development and stormwater management. Increasing the amount of concrete used in the world of construction will increase the demand for concrete materials and result in natural limitations in providing concrete-forming materials as well as causing a decrease in the amount of natural resources available for concreting purposes. environmental pollution. As in the cement factory Semen Tonasa enterprise, it produces bottom ash waste of 0.217 million tons/year, where such large waste requires special handling. The two main benefits of using bottom ash in civil construction are the reduction of greenhouse gas emissions and the generation of solid waste by coal-fired thermal power plants. In addition, bottom ash contains high amounts of SiO2, Al2O3 and Fe2O3 which increase the pozzolanic effect, mixed interlock and properties such as strength. It is hoped that the use of bottom ash can improve the performance of porous concrete as an environmentally friendly surface covering material. Overall, based on the results of permeability and compressive strength tests on porous concrete as an environmentally friendly surface covering by using bottom ash as a substitute for fine aggregate, the optimum bottom ash composition is obtained at 21.61% with a maximum compressive strength of 20.02 MPa and an effective permeability of 0 .5653 cm/s.

Keywords: Bottom Ash, Porous Concrete, Compressive Strength, Permeability, Environmentally friendly Surface Cover

1. Introduction

One of the weaknesses of conventional concrete as a surface covering layer is its impermeability, causing surface water to stagnate and producing it is suspected of causing environmental problems. Porous concrete is an innovation made to conventional concrete that allows surface water to infiltrate into the ground.
One of the weaknesses of porous concrete to be utilized in the manufacture of infrastructure, including as a surface covering layer is its relatively low compressive strength. So an effort is needed to increase the compressive strength and relate it to the effective ability to pass surface water.

From various studies that have been carried out, including: Research on environmentally friendly porous concrete made using coal bottom ash. Bottom ash is used as a substitute for coarse aggregate and geopolymer is used as a binder [3]. Research on the effect of using bottom ash as fine aggregate in self-compacting concrete on split tensile strength [4]. Research on the chemical and physical composition of bottom ash particles to determine its feasibility as a substitute for fine and coarse aggregates in high strength concrete [5]. Bottom ash as a substitute for cement [6]. Research on replacing a certain percentage of cement with bottom ash to increase resistance to carbonation, chloride penetration, acid and sulfate attacks [7]. Research on the use of bottom ash as a substitute for cement to produce environmentally friendly building materials [8]. Research on the short-term impact of replacing cement with bottom ash on sulfate and chloride attacks [9].

Utilization of bottom ash in porous concrete as an environmentally friendly surface covering material is intended to obtain a surface covering material that has maximum compressive strength (ability to carry maximum load) and effective permeability coefficient (effective ability to pass water). To ascertain how porous concrete that utilizes conditional bottom ash is used as an environmentally friendly surface covering material, it is necessary to find an effective relationship between: Compressive Strength and Permeability.

2. Materials and methods

2.1. Research Phase Design

The research method was experimental in the Structures and Materials Laboratory, Faculty of Engineering, Indonesian Muslim University, Makassar. This research was carried out through several stages, namely: procurement and inspection of materials, making mixed designs (Mix designs) based on making porous concrete, testing specimens, and analysis of research results.

2.2. Test material

Materials used in tghis study included coarse aggregate, Portland Composite Cement (PCC), water and bottom ash.

2.3. Press hard

Compressive strength is the ability of concrete to accept a broad unit compressive force. Compressive strength is one of the mechanical properties of concrete, concrete compressive strength identifies the quality of a structure. The higher the desired level of structural strength, the higher the quality of the concrete given. The compressive strength value of concrete is obtained through standard testing procedures, using a testing machine by applying a multilevel compressive load to a concrete cylinder test object (diameter 150 mm, height 300 mm) until it crumbles. SNI 2011 is used for the standard compressive strength test. Because there is a compressive load P, a compressive stress occurs in the concrete 〖(f〗^' c) equal to the load (P) divided by the cross-sectional area of the concrete (A), so the formulation is:

$$f'c = \frac{P}{A} \quad (1)$$

Where

f'c: Compressive Strength (MPa)

P: Maximum Load (N)

A: Surface area of the specimen (mm2)

Compressive strength testing procedure

1. Prepare tools and materials
2. Prepare a cylindrical specimen that has been cured and data on diameter, height and weight have been taken.
3. Place the concrete cylinder test object on the Compression Strength Machine.
4. Set the needle (Compression Strength Machine) exactly at zero position.
5. Turn on (Compression Strength Machine) then
6. Record the value of the maximum compressed concrete.
7. Read the load pointer until the test object is destroyed.
8. Record the value of the maximum compressed concrete.

2.4. Permeability

Based on research conducted by Teraiya [10], with a Constant Head Permeability test tool, based on ACI 522R – 10. The final value of water permeability in porous concrete can be calculated by the formula:

$$k = \frac{A}{t} \quad (2)$$

Where:

A is constant = 92.595 mm

K: Permeability Coefficient (mm/s)

T: Time of lowering the water level from h1 to h2 (s)

To find the value of A, a calculation of formula was done as follows:

$$k = 1 + \frac{A1 \times h}{A2 \times t} \log \frac{h1}{h2} \quad (3)$$

Where:

k: Permeability Coefficient (mm/s)

A1: Cross-sectional area of the test object (mm²)

A2: Pipe cross-sectional area (mm²)

h1: Initial height of the water surface (mm)

h2: Final height of the water surface (mm)

t: Time of lowering the water level from h1 to h2 (s)

h1: Height of test object (mm)

$$k = \frac{[1/4\,\pi\,(101.6\text{ mm})^2]\ 150\text{ mm}}{[1/4\,\pi\,(101.6\text{ mm})^2]\ t} \log\left[\frac{290\text{ mm}}{70\text{ mm}}\right]$$

$$k = \frac{150\text{ mm}}{t}\ 0.6173 = \frac{92.595}{t}\text{ mm/s} = \frac{0.0926}{t}\text{ m/s}$$

$$k = \frac{0.0926}{t}\text{ m/s}$$

$$k = \frac{A}{t}$$

A = 0.0926 m

Permeability testing procedure

1. The process of testing the permeability of the sample is carried out the day before the compressive strength testing process of porous concrete.
2. Prepare a falling head permeability tool, with the tap closed.
3. Measure the diameter of the pipe falling head

permeability tool, and the diameter of the test object.
4. Then record the water level of the pipe.
5. Install the test object on the rubber ring in the falling head permeability set-up.
6. Enter the water in the falling head permeability set-up pipe at the specified height.
7. Open the water tap in the falling head permeability set-up, at the same time turn on the stopwatch, measure the time until the water level is parallel to the surface of the test object in the falling head permeability set-up, record the time.

3. Result and discussion

3.1. Coarse Aggregate Characteristics

Coarse aggregate is crushed gravel or natural rock where the size is larger than 5 mm. In this study, several characteristic checks were carried out, along with the results of the measurement of the characteristics of the coarse aggregate inspection.

Table 1: Results of inspection of coarse aggregate (crushed stone)

No	Coarse aggregate measure characteristics	Result	Standard
1	Fineness modulus	6.68	6.0-7.1
2	Water content (%)	0.45	-
3	Solid content mass (kg/L)	1.469	1.2 – 1.75
4	Loose bulk (kg/L)	1.316	1.2 – 1.75
5	Specific gravity	2.569	2.4 – 2.9
6	Absorption (%)	1.882	≤ 3
7	Sludge levels (%)	0.28	≤ 1
8	Wear (%)	17.07	≤ 40

Based on table 1 above, all the results of the inspection of coarse aggregate meet the required specifications, so it can be concluded that the coarse aggregate that has been tested is suitable for use in the concrete mixing process.

3.2. Cement quality

Cement is a hydraulic material, that is, an inorganic material that is finely ground and when mixed with water, using reactions and hydration processes forms a paste that binds and hardens.

Table 2: Cement measurement results

No.	Cement characteristic	Result	Standard
1.	Specific gravity of cement	3.019	3.05 - 3.25
2.	Cement fineness #NO.100	100	>90
3.	Cement fineness #NO.200	90	>90
4.	Filling mass (solid) (kg/L)	1.208	1.1-1.4
5.	Mass content (loose) (kg/L)	1.127 kg/L	1.1-1.4
6.	Normal consistency (%)	23	22 - 30
7.	Initial binding time	45 minutes	Minimum 45 minutes
8.	Final binding time	120 minutes	Maximum 375 minutes

It can be seen from table 2 above that all cement inspection results meet the required specifications, so it can be concluded that the cement that has been tested is suitable for use in the concrete mixing process.

3.3. Bottom Ash Examination

Bottom ash is a waste material or residue from the process of burning coal in power plants. Bottom ash has very porous particle grains on its surface. Bottom ash particles range in size from gravel to sand.

Table 3: Examination results (Bottom Ash)

No.	Examination characteristics	Bottom Ash	Fine aggregate
1.	Fineness modulus	3.10	2.68
2.	Water content (%)	0.60	5.045
3.	Solid content mass (kg/L)	1.382	1.593
4.	Loose bulk (kg/L)	1.276	1.490
5.	Specific gravity	2.63	2.767
6.	Absorption (%)	6.38	2.670
7.	Sludge levels (%)	1.2	3.810
8.	Organic Content	No.1	No.2

It can be seen from table 3 above that all the bottom ash inspection results meet the required specifications, so it can be concluded that the bottom ash that has been tested is suitable for use in the concrete mixing process.

3.2. Mix planning results (Job Mix Formula)

Mix planning in the manufacture of concrete is carried out after all the data from the results of characteristic inspection regarding coarse aggregate, cement and bottom ash are obtained. From these data it can be seen that the required material composition and the ratio between cement, coarse aggregate, and water needed in a concrete mix, with the quality planned using the ACI (American Concrete Institute) method. The results of concrete mix planning can be seen in the following table:

Table 4 showed the material requirements for 1 m^3 of porous concrete, while Table 5 presented the material requirements for 24 test objects (cylinders 15 x 30 cm). These results are determined based on the calculation of the job mix formula using the ACI (American Concrete Institute) method using previously tested material data.

Table 4: Material requirements for 1 m^3 of porous concrete

No	Material	Volume (m3)	Weight (Kg)
1.	Water	0.093	92.8
2.	Cement	0.094	290
3.	Coarse aggregate	0.533	1341.02
4.	Bottom Ash	0.094	123.58

Table 5: Material requirements for 24 test objects (cylinder 15 x 30)

No.	Material	Weight (Kg)
1.	Water	51,94
2.	Cement	162,3
3.	Coarse aggregate	763,10
4.	Bottom Ash	34,58

Mix planning in the manufacture of porous concrete is carried out after all the data from the results of characteristic inspection regarding coarse aggregate, cement and bottom ash are obtained. From these data it can be seen that the required material composition and the ratio between cement, coarse aggregate, and water needed in a porous concrete mixture, with the quality planned using the ACI (American Concrete Institute) method.

Table 6: Material requirements for 4 test objects (cylinder 10 x 15).

No.	Material	Weight (Kg)
1.	Water	0,488
2.	Cement	1,532
3.	Coarse aggregate	7,080
4.	Bottom Ash	0,326

Table 6 above shows the material requirements for 4 test objects (cylinder 10 x 15). These results are determined based on the calculation of the job mix formula using the ACI (American Concrete Institute) method using previously tested material data.

3.3. Compression strength

The compressive strength test specimen was carried out on a cylinder with a base size of 150 mm in diameter and 300 mm in height. Where the test was carried out when the concrete was 28 days old.

Table 7: Results of the compressive strength test of concrete with the addition of bottom ash aged 28 days

Sample code	Weight (Kg)	Height (mm)	Diameter (mm)	Area (mm)	Age (Day)	Pressure (KN)	Compressive Strength (Mpa)
BA-0%	9.745	300	150	17662.5	28	310	17.56
BA-10%	9.872	300	150	17662.5	28	340	19.27
BA-20%	10.321	300	150	17662.5	28	354	20.06
BA-30%	10.443	300	150	17662.5	28	347	19.66

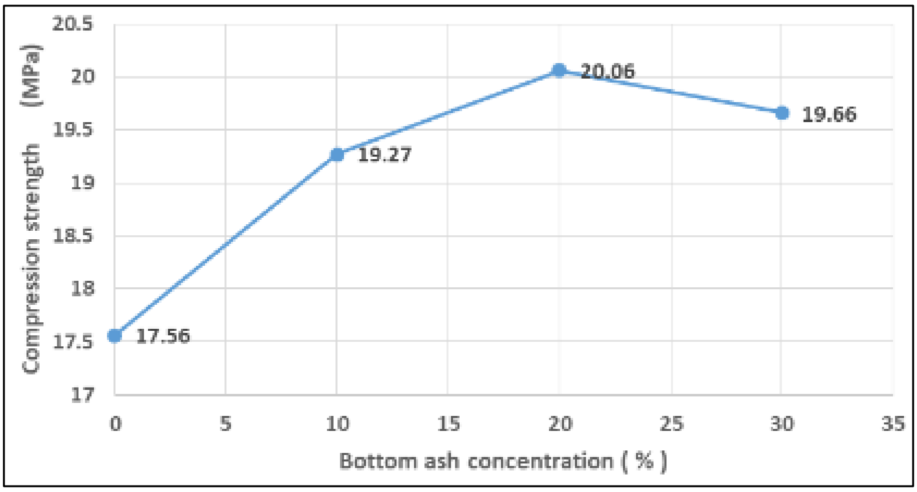

Fig 1: Graph of compressive strength testing of porous concrete with the addition of bottom ash aged 28 days

Based on table 7 and figure 1, the compressive strength test results of porous concrete at 28 days without the addition of bottom ash were 17.56 MPa (the lowest), while the results of the porous concrete compressive strength tests at 28 days with the addition of 20% bottom ash were 20.06 MPa (highest).

Determination of Optimum Bottom Ash Composition and Compressive Strength.

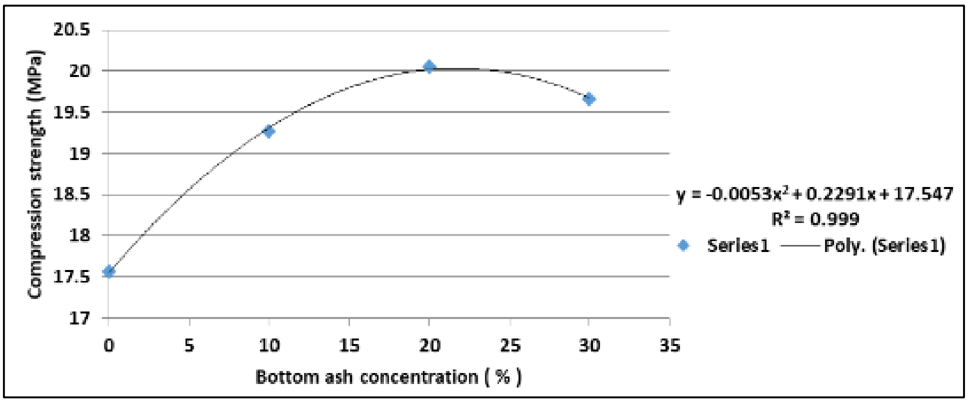

Fig 2: Graph of the Relationship Between the Compressive Strength of Porous Concrete and the Variation of Bottom Ash 0 – 30% 28 Days of Age.

Based on Figure 2, shows the relationship between the compressive strength of porous concrete and the percentage of variations in the addition of bottom ash 0 – 30% at 28 days of age, where the relationship pattern tends to follow the parabolic equation, as follows:

$$Y = - 0.0053\, X^2 + 0.2291\, X + 17.547 \quad (4)$$

Written as: $f'c = - 0.0053\, BA^2 + 0.2291\, BA + 17.547$ (5)

Based on the maximum / minimum theorem that the maximum / minimum value is obtained if the differential of the equation is equal to zero.
So that:

$$dfc/dBA = 0, \text{ then: } 2\,(-0.0053)\,BA + 0.2291 = 0$$

$$-0.0106\,(BA) + 0.2291 = 0$$

$$-0.0106\,BA = -0.2291$$

$$BA = 21.61\ \%$$

By inserting the value of BA into equation (5), the optimum compressive strength is obtained as follows:

$$fc = -0.0053\,(BA)^2 + 0.2291\,(BA) + 17.547$$

$$fc\ \text{Optimum} = -0.0053\,(21.61)^2 + 0.2291\,(21.61) + 17.547$$

$$= 20.02\ \text{MPa.}$$

Thus the optimum composition of bottom ash in porous concrete is 21.61% with a maximum compressive strength of 20.02 MPa and a coefficient of determination $R^2 = 0.999$ (very strong relationship). Here there is an increase in the compressive strength of porous concrete by 14.01% from normal/control compressive strength (0% bottom ash variation).

From the test results in the laboratory it was found that the Bottom Ash variation 0-30% aged 28 days, showed an increase in compressive strength from the addition of 0% Bottom Ash to the addition of 20% which resulted in an optimum compressive strength value of 20.02 MPa and a decrease in strength Press after adding Bottom Ash is greater than 20%.

The very basic drawback of porous concrete is its low compressive strength, due to the many pores of ACI 2010), so that its use is very limited to structures with low compressive strength. porous with maximum compressive strength and effective water permeability. For this reason, the remaining coal combustion (Bottom Ash) was chosen as a material that can fill pores and at the same time improve the compressive strength of porous concrete, with the following considerations:

1. Particle size and characteristics of bottom ash which have similarities with sand.
2. The chemical composition of bottom ash is pozzolonic. Even though this pozzolonic property is not too dominant because the particle size of bottom ash is relatively large. This is in accordance with what has been determined by ASTM C-618 and SKSNI SNI S-04 – 1989 – F.
3. The use of coal as an energy source to replace fuel oil on the one hand is very profitable, but on the other hand it creates problems, namely combustion waste (fly ash and bottom ash). Which are hazardous and toxic materials.

Bottom ash as a substitute for fine aggregate (sand) used in this study, is presented at 30%, above the percentage based on ACI 522R-10, which is 20%. According to Singh and Siddique (2016), based on research results on workability and strength properties, it recommends the optimum use of bottom ash in concrete up to 30% for concrete without superplasticizer and up to 50% with superplasticizer.

Bottom ash is a pozzolanic material, which is an additional material originating from nature, which mostly contains silica (Si) and alumina (Al) compounds, where pozzolan is able to react to Ca(OH)2 compounds resulting from the hydration reaction between cement and water. According to Mulyati (2012), Pozzolan itself does not have cementitious properties independently, but contains elements which, when mixed with water at ordinary temperatures, can form elements which have the characteristics of cement, namely calcium-silica-hydrate.

The reaction of cement compounds with water forms CSH and Ca(OH)2 compounds which then Ca(OH)2 compounds will react with pozzolans to form CSH and CAH.

The pozzolan reaction to Ca(OH)2 can be seen in equations 6 and 7 below:

$$Ca(OH)2 + H2O + SiO2 \rightarrow CSH \quad (6)$$

$$\downarrow$$

Secondary solids / Pozzolonic effect

$$Ca(OH)2 + H2O + Al2O3 \rightarrow CAH \quad (7)$$

The use of pozzolanic materials in concrete or mortar will result in more water-resistant concrete and mortar. Silica in a certain amount can act as a filler between the particles forming the material, so that in the presence of silica, the porosity of the concrete or mortar will become smaller and then the impermeability of the concrete and mortar will increase so that the permeability decreases. This can cause the strength of the material to increase. As in this study, the strength of porous concrete increased from 17.56 MPa (bottom ash 0%) to 20.02 MPa (bottom ash 21.61%), but with the addition of 30% bottom ash, the compressive strength decreased to 19.66 MPa. This is due, among other things:

1. In a puzzolonic reaction the appearance of the element CH which dissolves in water will result in a larger volume of free lime, so that it can cause volume expansion during setting, which in turn can cause cracks and damage to the hardened cement paste and concrete and can cause a decrease in the strength value of concrete. The CH element can also be a source of corrosion in concrete due to sulfates, which is caused by the formation of the element ettringite (C6AS3H32) from the reaction of CaSO4, C3A and water which can cause volume expansion and damage to concrete.
2. The presence of friable particles, generally in dry bottom ash, namely the coal crust which is shaped like a flower (pop-corn particles). These particles are easily destroyed due to compaction and are very porous, so they have a high absorption rate. This also indicates that using a certain amount of bottom ash (30%) in a porous concrete mixture will increase the porosity value. This will reduce the strength of porous concrete.

Fadel. M, *et al* (2019) conducted research on lightweight concrete with substitution of bottom ash as a substitute for sand with a percentage of replacing sand with bottom ash of 10%, 20% and 30%. The maximum compressive strength obtained was 9.776 MPa at 20% addition and decreased to 9.026 MPa at 30% addition.

3.4. Permeability

(1). Permeability Test Results of Porous Concrete

The test object for permeability testing of porous concrete was carried out on a cylinder with a base size of 100 mm in diameter and 150 mm in height. Where the test was carried out on porous concrete specimens aged 28 days and 0-30% variation.

Table 8: Results of permeability testing of porous concrete aged 28 days at bottom ash variations of 0-30%.

No	Bottom ash concentration (%)	Time (s)	Debit (cm3/s)	Permeability coef.
1	0	10.5	224.28	0.8819
2	10	14.3	164.68	0.6475
3	20	16.5	151.93	0.5612
4	30	15.5	142.73	0.5974

Note: In the constant measurement used 9.26; the volume of water is 2355 cm3, the height of the sample is 15 cm, the area of the pnp is 78.5 cm2 and the height of the water is 30 cm

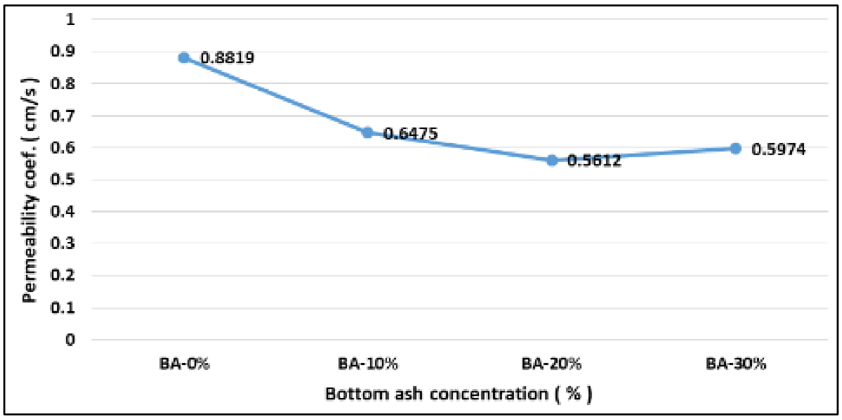

Fig 3: Graph of the results of testing the permeability coefficient of porous concrete aged 28 days at bottom ash variations of 0-30%.

Based on table 8 and figure 3, it shows that the results of testing the permeability coefficient (k) of porous concrete at the age of 28 days for a 0% variation of 0.8819 cm/s, in the addition of a 10% bottom ash variation the value of k decreased to 0.6475 cm /s, with the addition of 20% bottom ash variation, the value of k drops even further to 0.5612 cm/s. At the time of adding 30% bottom ash variation, the value of k increased to 0.5974 cm/s.

The largest permeability coefficient (k) value that can be achieved by porous concrete is 0.8819 cm/s (with a variation of bottom ash 0%) and the lowest permeability coefficient (k) value that can be achieved by porous concrete is 0.5612 cm/s (With a variation of bottom ash 20%).

From the results of tests conducted at the Laboratory, it appears that the use of bottom ash in porous concrete is able to pass water quickly.

(2) Determination of Optimum Bottom Ash Composition and Permeability

Permeability, namely the ability possessed by porous concrete to pass fluids or liquids through interconnected pores that have hardened.

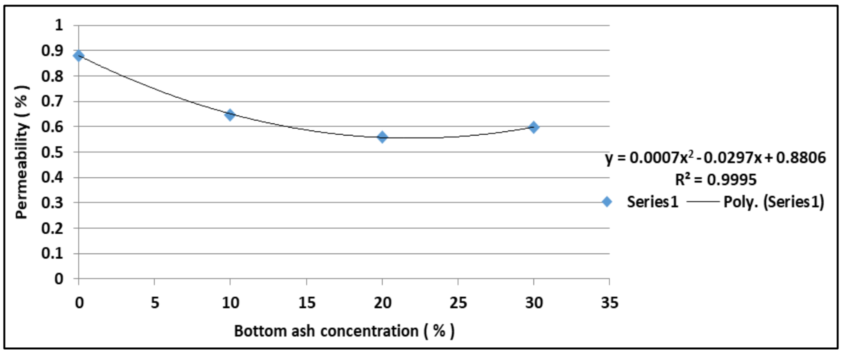

Fig 4: Graph of the Relationship between Permeability of Porous Concrete and Variation of Bottom Ash 0 – 30% 28 Days Age.

Based on Figure 4, it shows the relationship between the permeability of porous concrete and the percentage of addition of bottom ash at 28 days of age, where the relationship pattern tends to follow the parabolic equation, as follows:

$$Y = 0.0007 X^2 - 0.0297 X + 0.8806 \quad (8)$$

It is written as $k = 0.0007 (BA)^2 - 0.0297 (BA) + 0.8806$ (9)

Based on the maximum / minimum theorem that the maximum / minimum value is obtained if the differential of the equation is equal to zero.

So that:

$dk/dBA = 0$, then: $2 (0.0007) BA - 0.0297 = 0$

$$0.0014 BA - 0.0297 = 0$$

$$0.0014 BA = 0.0297$$

$$BA = 21.21\%$$

By plugging the BA value into equation (9), the minimum permeability coefficient value = k is obtained, as follows:

$$k = 0.0007\,(BA)^2 - 0.0297\,(BA) + 0.8806$$

$$k\ min = 0.0007\,(21.21)^2 - 0.0297\,(21.21) + 0.8806$$

$$= 0.3149 - 0.6299 + 0.8806$$

$$= 0.5653\ cm/second$$

So the Minimum Permeability of Porous Concrete = 0.5653 cm/s.

Thus the optimum composition of bottom ash in porous concrete is 21.21% with a minimum permeability value of 0.5653 cm/s. On the addition of 30% bottom ash, the permeability value decreases to 0.5974 cm/s and the coefficient of determination R^2 = 0.9995 (very strong relationship). The optimum bottom ash composition in porous concrete is 21.61%, which is determined from the value of strength because the compressive strength of concrete is generally used as a reference to determine the quality or quality of a concrete material. All test results comply with ACI 522R-10 standard.

3.5. Compressive Strength and Permeability Relationship Analysis.

Conventional concrete is a material that is widely used as a surface covering, because it not only has reliability in terms of strength, but also ease of implementation. One of the weaknesses of conventional concrete as a surface covering layer is its impermeability, causing surface water to stagnate and producing it is suspected of causing environmental problems. Porous concrete is an innovation made to conventional concrete that allows surface water to infiltrate into the ground.

One of the weaknesses of porous concrete to be utilized in the manufacture of infrastructure, including as a surface covering layer is its relatively low compressive strength. So an effort is needed to increase the compressive strength and relate it to the effective ability to pass surface water. From various studies that have been conducted, including Jang *et al* (2015), examined environmentally friendly porous concrete made using coal bottom ash. Bottom ash is used as a substitute for coarse aggregate and geopolymer is used as a binder. The combination of coal bottom ash and geopolymer produces porous concrete with higher compressive strength compared to porous concrete made from recycled aggregates and cement paste.

Utilization of bottom ash in porous concrete as an environmentally friendly surface covering material is intended to obtain a surface covering material that has maximum compressive strength (ability to carry maximum load) and effective permeability coefficient (effective ability to pass water). To ascertain how porous concrete that utilizes conditional bottom ash is used as an environmentally friendly surface covering material, it is necessary to find an effective relationship between: Compressive Strength and Permeability.

Looking for an effective relationship between compressive strength and permeability in porous concrete that utilizes bottom ash as an environmentally friendly surface covering material, the exponential regression equation is used, which can be written as follows: The general form of the exponential regression equation model is:

$$Y = b \times e^{ax} \tag{10}$$

Where:
Y = Dependent Variable
a, b = Constants.
X = Independent Variable:

3.6. The relationship between compressive strength and permeability.

To ensure that porous concrete that utilizes bottom ash meets the requirements as an environmentally friendly surface coating, this can be determined by determining how strong the porous concrete is (compressive strength) and its relationship to its ability to allow water to pass through (permeability). The relationship between the compressive strength of porous concrete and permeability is a non-linear relationship. So that the relationship is analyzed with exponential regression method. The relationship between compressive strength and permeability is shown in Figure 5.

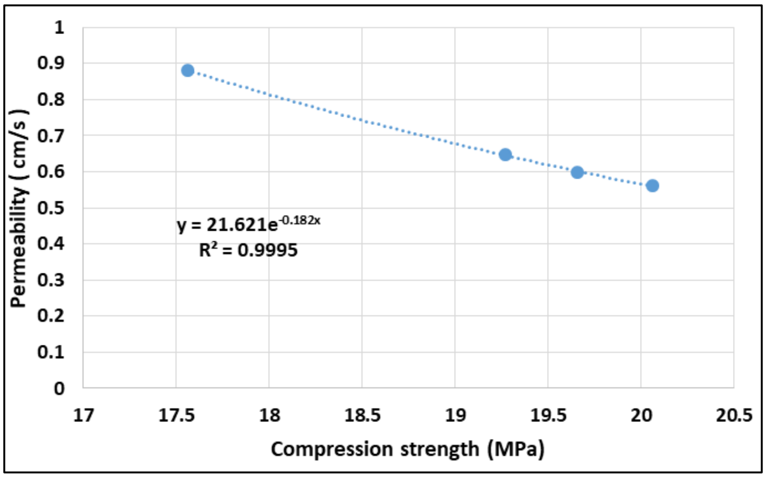

Fig 5: Graph of the Relationship Between the Compressive Strength of Porous Concrete and Permeability.

From Figure 5, an exponential equation is obtained for the relationship between the compressive strength of porous concrete and permeability (variation of bottom ash 0 – 30%, age 28 days), as follows:

$$Y = 21.621\ e^{-0.182\ fc} \tag{11}$$

Where
Y = Dependent Variable.
X = Independent Variable

Next is written

$$k = 21.621\ e^{-0.182\ fc} \qquad (12)$$

$R^2 = 0.9996$

Where
k = Permeability Coefficient
fc = Maximum Compressive Strength
R^2 = Coefficient of determination

By substituting the compressive strength value of, fc = 20.02 into equation 12, we got:

k = 21.621 e-0.182 (20.02)
k = 21.621 e-3.6436
k = 21.621 (0.02615)
= 0.5653 cm/s.

With a maximum compressive strength value of 20.02 MPa, an effective permeability coefficient of 0.5653 cm/s is obtained with $R^2 = 0.9996$, indicating a negative correlation. It was found that an increase in permeability will decrease the compressive strength up to a certain point. Hesami *et al* [11], when the permeability increases, the strength decreases. Furthermore, Cui *et al* [12], found that the strength of porous concrete is negatively correlated with its permeability. The results of the relationship analysis: Compressive Strength, Strength and Permeability can be seen in table 9.

Table 9: Relationship Analysis Results: Compressive Strength and Permeability With the Addition of Bottom Ash

Bottom Ash concentration (%)	Result	Compression strength (MPa)	Result	Permeability (cm/s)	Result
0				0.8819	
10		19.27		0.6475	
20		20.06		0.5612	
21.61	Optimum	20.02	Maximum	0.5653	Effective
30		19.66		0.5974	

In utilizing bottom ash in porous concrete as a surface covering material, the maximum compressive strength value of the permeability value needs to be related to:

1. Traffic Vehicle Loading System
To calculate the traffic load due to the weight of the vehicle, the load T is used, namely the load which is a truck that has a dual wheel load of 10 tons, as follows:

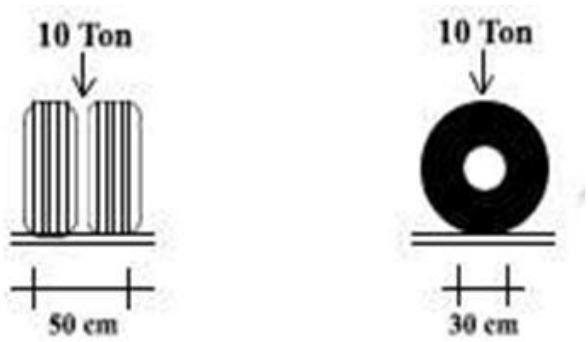

Fig 6: Loading System Due to Vehicle Loads

From Figure 6 above, the area of the depressed area will be obtained as shown in Figure 7.

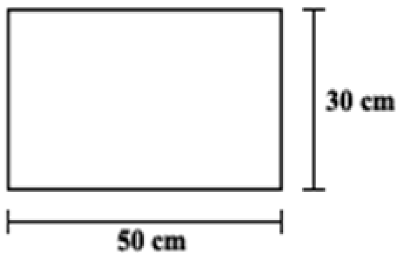

Fig 7: Area of Depression.

The calculation of the compressive strength test of porous concrete test objects against vehicle loads is as follows:

1). Calculation of contact area
L = 50 cm X 30 cm.
= 1500 cm2
= 232.5 in2
2). Vehicle load calculation.
Vehicle Load = 10 Tones = 20000 pounds

$$\text{Compression strength} = \frac{\text{vehicle load}}{\text{compression area}} \qquad (13)$$

$$= \frac{20000}{232.5}$$

Compressive Strength = 86.0215 psi (1 psi = 0.006895 Mpa).
So compressive strength due to vehicle loads = 0.5931 Mpa.

When compared between the compressive strength of porous concrete (20.02 MPa) and the compressive strength due to vehicle loads (0.5931 MPa), porous concrete as a surface covering material is safe for vehicles weighing 10 tons to pass through. From the results achieved in this study, namely by utilizing bottom ash of 21.61% in porous concrete, it meets the requirements for use as an environmentally friendly surface covering material with light to moderate traffic loads (RSNI – T – 12 – 2004).

2). Surface runoff management system
In line with the development of a comprehensive mindset in the field of drainage, where water does not merely have to be disposed of but rather as an environmental asset that must always be maintained in quantity, quality and sustainability. In several developed countries, new drainage applications have developed in various concepts. Some of them are Low Impact Development (LID) in the United States and Canada, Sustainable Urban Drainage Systems (SUDS) in Great Britain, Water Sensitive Urban Design (WSUD) in Australia, and Low Impact Urban Design. and Development (LIUDD) in New Zealand and Ecodrain in Indonesia.

The results of the implementation of this new concept are quite encouraging. Some of the best practices for this eco-drainage application include, in Frederick Country, Maryland, United States which uses the LID system and provides bonuses to its residents through tax reductions when applying the LID system, it is proven to be able to handle 31% of city runoff. City of Boulder, Colorado which is capable of handling runoff up to 80% with the same principle. Even in Los Angeles, the application of a rainwater collection system from a home scale and continued with shelter through retention and detention ponds both on the surface and underground, is claimed to be able to handle flash floods for a period of 100 years. Because the new drainage system is in line with the principles of environmental harmony, it handles flooding in a way that is friendlier to flora, fauna and the environment.

In principle, there are four stages that must be implemented in dealing with floods and inundation from upstream to downstream areas as follows:

1. The first principle is to collect as much water as possible and then use it or better known as rainwater harvesting. (rain harvesting). The most effective harvesting of rainwater is carried out at the household scale, by collecting rainwater in water reservoirs in each resident's house and industrial area as well as planting trees and plants in residential areas. Water storage is estimated to be able to reduce runoff load on each resident's house by up to 40%, while planting trees is estimated to be able to reduce runoff by 14%, so that the remaining runoff from the household level that must be handled is only 48%. The rest of the runoff can be handled using conventional principles such as reusing reservoirs, swamps, lakes and so on.
2. The second principle is to absorb as much water as possible into the soil through various media such as biopores, absorption wells and recharge wells. However, keep in mind that the selection of this type of absorbent structure must be based on engineering principles. For example, the use of biopori in areas with clay or alluvial soils is not suitable because the ability to absorb water is small and different from sandy soils, for example.
3. The third principle is to flow water through various aqueducts, both macro and micro.
4. And the fourth principle is maintaining water. If the three principles above focus on the quantity of water, then the fourth principle focuses on maintaining water quality, so that water can be utilized as optimally as possible so that flora and fauna can continue to live side by side with humans. It is on this principle that the use of technologies such as bioremediation, phytoremediation, waste filtering and the ban on disposing of waste in canals is enforced.

Paying attention to the 4 (four) ecodrain principles, shows that porous concrete with bottom ash utilization of 21.61% effectively reduces surface water stagnation and fills soil infiltration as an environmentally friendly surface covering material.

4. Conclusion

1. Strength and Permeability of porous concrete using Bottom Ash as an environmentally friendly surface covering material, namely:

a. Strong Press

With the utilization of bottom ash of 21.61%, an increase in compressive strength of 14.01% was obtained from 17.5 MPa to 22.02 MPa (Maximum Compressive Strength).

b. Permeability

With the utilization of bottom ash of 21.61%, a porous concrete material is obtained that is able to pass water effectively with a Permeability Coefficient of 0.5653 cm/s.

The relationship between compressive strength and permeability is obtained in a form that can be written in the form of the following equation:

$$k = 21.621\ e^{-0.182\ fc}$$
$$R^2 = 0.9996$$

Where

k = Effective Permeability Coefficient

fc = Maximum Compressive Strength

R^2 = Coefficient of determination

2. By utilizing bottom ash in porous concrete as a layer material for environmentally friendly surface coverings, a layered pavement structure is obtained for light to medium traffic loads.

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