International Journal of Civil Engineering and Technology (IJCIET)
Volume 13, Issue 12, December 2022, pp. 15-29 Article ID: IJCIET_13_12_002
Available online at https://iaeme.com/Home/issue/IJCIET?Volume=13&Issue=12
ISSN Print: 0976-6308 and ISSN Online: 0976-6316
DOI: https://doi.org/10.17605/OSF.IO/SD3QY

THE EFFECT OF BOTTOM ASH AS A MATERIAL FINE AGGREGATE SUBSTITUTION ON THE STRENGTH OF POROUS CONCRETE

Yasnawi Idrus
Doctoral Program in Environmental Science,
Graduate School, Brawijaya University, Malang, Indonesia

M. Bisri
Faculty of Engineering, Universitas Brawijaya, Malang, Indonesia

Wisnumurti
Faculty of Engineering, Universitas Brawijaya, Malang, Indonesia

Hanafi Asad
Faculty of Engineering, Universitas Muslim Indonesia, Makassar, Indonesia

ABSTRACT

Bottom ash is the residual product of coal combustion which can be useful for the utilization of porous concrete mixtures. In this study, bottom ash was used as a substitute for fine aggregate in the manufacture of porous concrete. Bottom ash has a larger and heavier grain size with a characteristic dark gray color. The purpose of this study was to determine the strength of concrete using bottom ash as a fine aggregate substitution material. The percentage of using bottom ash as a fine aggregate substitution material is 0%, 10, 20% and 30%. The research was carried out at the Structure and Materials Laboratory of the Indonesian Muslim University, Makassar, South Sulawesi. The specimens used were 24 cylinders with a diameter of 15 cm and a height of 30 cm. The tests carried out were in the form of compressive strength, split tensile strength and porosity tests with a design concrete quality of 17.5 MPa. From the research results, the results of the compressive strength test obtained the optimum bottom ash composition when using 21.61% bottom ash with a maximum compressive strength of 20.02 MPa at 28 days of age, the split tensile strength test obtained the optimum bottom ash composition when using 21 bottom ash .73% with a maximum split tensile strength of 2.42 MPa at 28 days of age while for the porosity test the optimum bottom ash composition was obtained when using 22.12% bottom ash with a minimum porosity of 17.86%.

From the results of the analysis using the exponential statistical method, the relationship between porosity and split tensile strength is obtained by a minimum porosity of 17.86% and a maximum split tensile strength of 2.47 MPa, for compressive strength a minimum porosity of 17.86% and a maximum compressive strength of 20.02 MPa with an optimum bottom ash composition of 21.61%.

Keywords: Bottom Ash, Porous Concrete, Compressive Strength, Split Tensile Strength, Porosity.

Cite this Article: Yasnawi Idrus, M. Bisri, Wisnumurti and Hanafi Asad, The Effect of Bottom Ash as A Material Fine Aggregate Substitution on The Strength of Porous Concrete, International Journal of Civil Engineering and Technology, 13(12), 2022, pp. 15-29. https://iaeme.com/Home/issue/IJCIET?Volume=13&Issue=12

1. INTRODUCTION

Today, the knowledge of concrete materials has undergone many developments. The basic ingredients in the concrete mixture formulation have changed. Utilization of industrial waste materials is the right choice to obtain quality, economical and efficient concrete. One industry that has great potential to produce this waste is the coal industry. Increasing the production capacity of the coal industry causes an increase in the amount of waste produced. Coal waste has properties that can pollute the environment such as air pollution, water pollution and a decrease in ecosystem quality. If this waste is not utilized optimally, it will have social and environmental impacts on the people of Jepara, such as shortness of breath in humans, the death of plants, and others [1].

The coal industry produces waste in the form of bottom ash in the form of fine aggregate. Bottom ash is bottom ash in the form of ash that is left behind and released under the furnace from the residue of burning coal. Bottom ash has a larger and heavier grain size with a characteristic dark gray color. Semen Tonasa Enterprise Pangkep South Sulawesi produces 0.217 million tonnes/year of bottom ash waste. The relatively large amount of bottom ash requires good management so as not to pollute the environment.

The waste material from burning coal ash (Bottom Ash) used is waste from burning coal from the steam power plant of PT. Semen Tonasa in Pangkajena and Islands Regencies experiencing problems in handling coal-burning waste. The cement of the Portland Composite Cement (PCC) type produced by the Tonasa Cement Factory uses Coarse Aggregate originating from the Production of The Devoted Style of the Kuncio Village, Pangkep Regency. The tests performed were a compressive strength test, porosity test, permeability test and split tensile strength test at 28 days of age. The composition of the Coal Waste used has variations (0%, 10%, 20% and 30%). The quality of the planned material is the quality of the concrete f'c 17.5 MPa and the design of the porous concrete mix design refers to the ACI 522R –10 Report Pervious Concrete regulations. This is because currently Indonesia does not have SNI specifically for porous concrete.

Several similar studies, namely: Investigation of concrete performance utilizing bottom ash waste as a substitute for fine aggregate [2], The effect of coal bottom ash as a partial replacement for sand on the workability and strength properties of concrete [3], the role of coal bottom ash as an alternative to cement [4] , New coal bottom ash waste composites for sustainable construction [5], New environmentally friendly porous concrete made with coal ash and geopolymer binders: Heavy metal leaching characteristics and compressive strength [6], Short-term effects of sulfates and chlorides on ash-containing concrete coal as a complementary material for cement [7]. Effect of coal bottom ash as a substitute for fine aggregate on various properties of concrete: Resource Review, Conservation and Recycling [8].

The study aimed to determine the compressive strength and split tensile strength with the percentage of bottom ash in the concrete mix, using variations in the percentage of bottom ash, namely 0%, 10%, 20%, and 30% using the design f'c concrete quality of 17.5 MPa.

2. RESEARCH METHODS

The research adopted an experimental method in the Laboratory of Structures and Materials, 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), Making porous concrete, Testing specimens, and Analysis of research results.

Mix design and manufacture of test specimens are carried out concerning the ACI (American Concrete Institute) 522R-10 method for porous concrete [1]. To create concretes, it takes a mixture of four materials. To make 1 m^3 of material, 0.094 m^3 of bottom ash is needed with a weight of 123.58 kg (Table 1), while to make 24 test samples with dimensions of 15 x 30 cm, 34.58 kg of bottom ash is needed (Table 2).

Table 1: 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 2: 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

2.1. Compression strength

The compressive strength of concrete is the amount of load per unit area that causes the concrete specimen to be destroyed when it is loaded with a certain compressive force generated by a press machine. Concrete compressive strength is the most important characteristic of concrete quality compared to other properties. The compressive strength of concrete is determined by setting the ratio of cement, coarse and fine aggregates, and water. Mathematically it can be written as follows:

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

Where:

$f'c$ = concrete compression strength (MPa)

P = Axial compressive force (N)

A = Cross-sectional area of the test object (mm^2)

2.2. Splitting Strength

Splitting tensile strength is the tensile strength of concrete which is determined based on the splitting compressive strength of a concrete cylinder pressed on its long side. The splitting tensile strength of concrete is relatively low, and the compressive strength and splitting tensile strength of concrete is not directly proportional. Every effort to improve the quality of compressive strength is only accompanied by a small increase in the value of the tensile strength. Tensile strength is more difficult to measure than compressive strength due to clamping problems in the machine

The test uses a concrete cylinder with a diameter of 150 mm and a length of 300 mm, placed in a longitudinal direction on top of the tester and then the compressive load is applied evenly in a perpendicular direction from above over the entire length of the cylinder. If the tensile strength is exceeded, the specimen is split into two parts from end to end. The tensile stress that occurs when the specimen is split is called split cylinder strength or split tensile strength. The split tensile strength of concrete can be calculated by the formula:

$$Fsp = \frac{2\,P}{\pi\,L\,D} \qquad (2)$$

Where :
Fsp = Splitting Tensile Strength (Mpa)
P = Test limit load (N)
L = Length of Test Object (mm)
D = Diameter of Test Object (mm)

2.3. Porosity

Porosity is the ratio between the volume weight of the cavity in the concrete specimen to the total volume of the concrete specimen. The voids in the concrete are in the form of air or water which are held together by bonds called capillaries. Increasing the pore volume in concrete, it will cause an increase in porosity, which will reduce the strength of the concrete. Based on ASTM C 642 – 90, concrete porosity can be used in formula 3, and based on ASTM D C 642 – 97, concrete absorption can be used in formula (4).

$$n = \frac{C-A}{C-D}\ x\ 100\% \qquad (3)$$

$$n1 = \frac{C-A}{A}\ x\ 100\% \qquad (4)$$

With,
n = Porosity of the test object (%)
A = oven dry weight of the specimen (kg)
C = weight of water-saturated concrete after boiling (kg)
D = weight of concrete in water (kg).
n 1 = concrete absorption (%)

3. RESEARCH RESULTS AND DISCUSSION

3.1. Coarse agregate characteristic

Results showed that all the results of the test 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 (Table 3).

Table 3. Characteristics of coarse agregate

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

3.2. Characteristics of Bottom Ash and Fine Aggregate.

all fine aggregate inspection results 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.

Table 4. Results of inspection of fine aggregate 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

3.3 Cement characteristic

This study showed that all cement inspection results meet the required specifications, so it can be concluded that the tested Portland composite cement is suitable for use in the concrete mixing process.

Table 5. Portland cement measure 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

3.4. Concrete Mix Composition

The need for each concrete mix material per m^3 was presented in Table 6. To create each concrete, it was need 0.814 m^3 in 1 volume of concrete.

Table 6. The need for each concrete mix material per m3

No.	Unit	Result (m3)
1	Water	0.093
2	Cement	0.094
3	Coarse aggregate	0.533
4	Fine Aggregate (Bottom Ash)	0.094
	Total	0.814

Source: Calculation Results of ACI 522R-2010 Job Mix Formula (JMF)

3.5. Compression Press

The increase in average compressive strength of variations in bottom ash at 28 days of age was 17.56 MPA, 19.27 MPa, 20.06 MPa and 19.66 MPa from normal/control compressive strength which was 17.56 MPa. Or there is an increase in compressive strength of 0%, 9.74%, 14.24% and 11.96% respectively against normal porous concrete (control) without the addition of bottom ash (bottom ash 0%) (Table 7).

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

Based on Figure 1, 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:

$Y = - 0.0053 X^2 + 0.2291 X + 17.547$ ....(5)
Written as: $fc = - 0.0053 BA^2 + 0.2291 BA + 17.547$................................ ....(6)

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:

$dfc/dBA = 0$,
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 (6), the optimum compressive strength is obtained as follows:

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

$$fc\ Optimum = -0.0053 (21.61)^2 + 0.2291 (21.61) + 17.547$$
$$= 20.02\ MPa.$$

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 the normal/control compressive strength (0% bottom ash variation). Based on 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 compressive strength after the addition of Bottom Ash is greater than 20%.

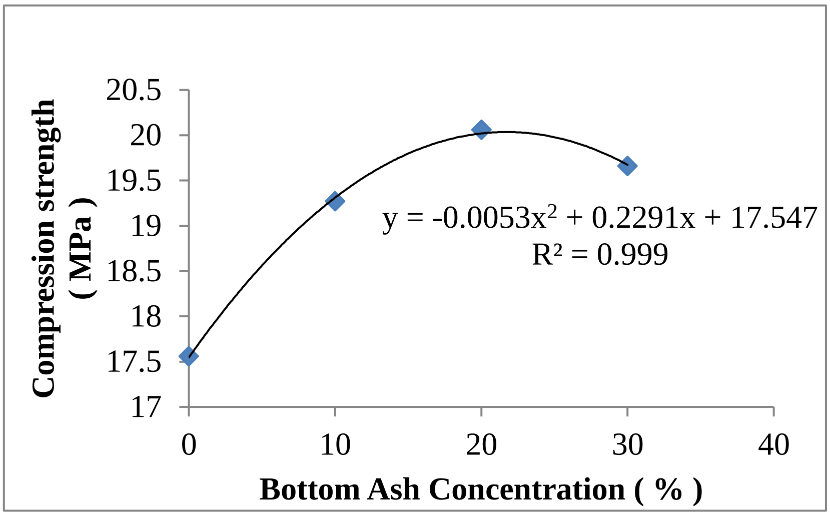


Figure 1. The Relationship Between the Compressive Strength of Porous Concrete and the Variation of Bottom Ash 0 – 30% 28 Days of Age.

Bottom ash used in the study acts as a substitute for fine aggregate (sand) with a percentage of 30%. This value is more than the percentage specified in ACI 522R-10, which is 20%. Based on research results on workability and strength properties, it is recommended to use bottom ash in concrete optimally up to 30% for concrete without superplasticizer and up to 50% with superplasticizer [9].

Bottom ash is a pozzolanic material, which is an additional material originating from nature. Most of these materials contain silica (Si) and alumina (Al) compounds, where pozzolans are able to react to Ca(OH)2 compounds resulting from the hydration reaction between cement and water. Pozzolan itself does not have the properties of cement independently, but contains elements which, when mixed with water at ordinary temperatures, can form elements that 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. Ca(OH)2, which is a by-product of the hydration reaction, reacts again with SiO2 and Al2O3 elements in the pozzolanic material to get more CSH and CAH. The pozzolan reaction to Ca(OH)2 can be seen in equations 7 and 8 below:

$$Ca(OH)2 + H2O + SiO2 \rightarrow CSH \quad (7)$$

$$\downarrow$$

Secondary solids/Pozzolonic effect

$$Ca(OH)2 + H2O + Al2O3 \rightarrow CAH \quad (8)$$

The use of pozzolanic materials in concrete or mortar will result in more water-resistant concrete and mortar. The addition of 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 which causes less permeability. 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 21.67%), but with the addition of 30% bottom ash, the compressive strength decreased to 19.66 MPa. This is because in the puzzolonic reaction the appearance of the element CH which dissolves in water will result in a larger volume of free lime, which can cause volume expansion during setting, which can then lead to cracking and damage to the hardened cement paste and concrete. 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 concrete.

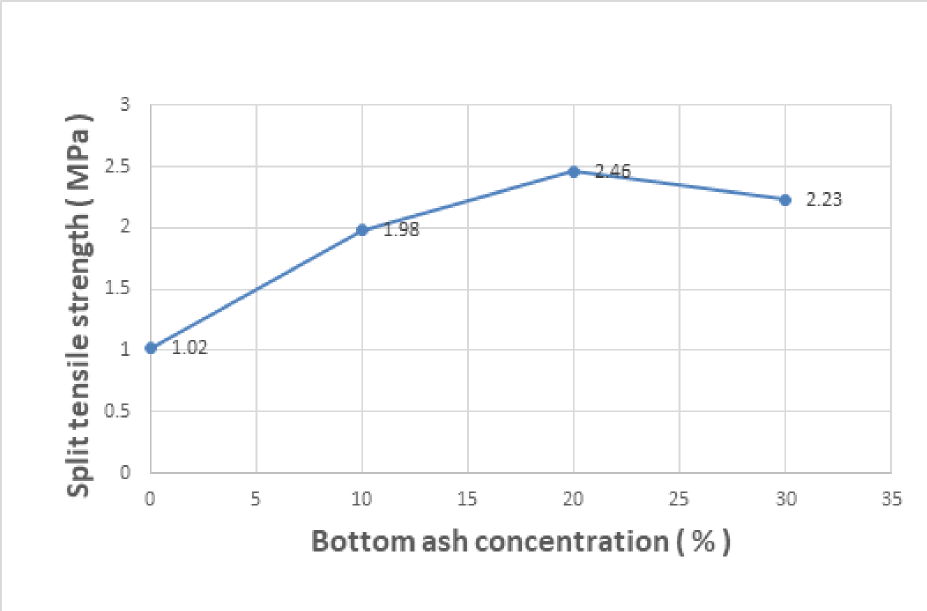
3.6. Split tensile strength

The specimens in the Split Tensile test of porous concrete were 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 at the age of 28 days and 0-30% variation.

Table 8. Results of the Split Tensile Strength Test with the addition of 28-day-old Bottom Ash

Sample code	Weight (Kg)	Height (mm)	Diameter (mm)	Area (mm)	Age (Day)	Pressure (KN)	Compressive Strength (Mpa)	Sample code
1	BA-0%	9.745	300	150	17662.5	28	72.06	1.02
2	BA-10%	9.872	300	150	17662.5	28	139.89	1.98
3	BA-20%	10.321	300	150	17662.5	28	173.79	2.46
4	BA-30%	10.443	300	150	17662.5	28	157.55	2.23

Figure 2 Graph of the split tensile strength test of porous concrete with the addition of 30% bottom ash aged 28 days



Determination of Optimum Bottom Ash Composition and Splitting Strength.

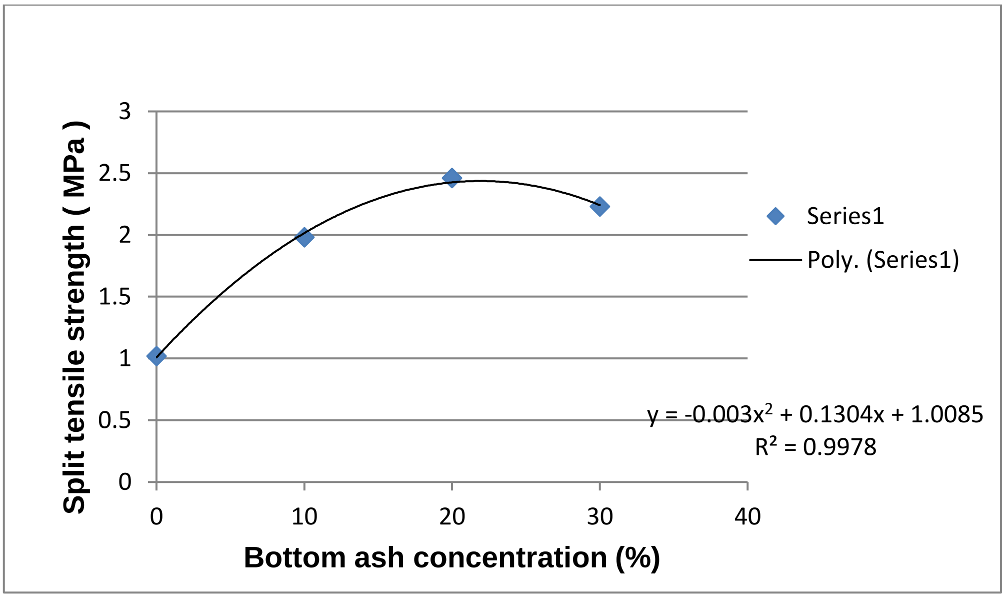


Figure 3. Graph of the Relationship Between the Split Tensile Strength of Porous Concrete and Variation of Bottom Ash

Based on Figure 3, it is known that the relationship between the split tensile strength 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 (2nd Order Polynomial Regression Equation), as follows:

$Y = - 0.003 X^2 + 0.1304 X + 1.0085$ ....(9)

It is written as, $fsp = - 0.003 (BA)^2 + 0.1304 (BA) + 1.0085$....................(10)

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 :

$$dfsp/dBA = 0, \text{ then: } 2 (-0.003) BA + 0.1304 = 0$$

$$-0.006 BA + 0.1304 = 0$$

$$BA = 21.73 \%$$

By inserting the value of BA into equation (10), the maximum split tensile strength of porous concrete is obtained as follows:

$$fsp = - 0.003 (21.73)^2 + 0.1304 (21.73) + 1.0085$$

$$\text{optimum } fsp = - 1.4165 + 2.8336 + 1.0085$$

$$= 2.42 \text{ MPa}$$

So the optimum Split Tensile Strength of Porous Concrete = 2.42 Mpa.

Thus the optimum composition of bottom ash in porous concrete is 21.73% with a maximum split tensile strength of 2.42 MPa and a coefficient of determination $R^2 = 0.9978$ (very strong relationship).

From the experimental results in the laboratory, it was obtained that the maximum Split Tensile Strength of Porous Concrete was 2.46 MPa at the addition of 20% Bottom Ash at 28 days old. And the Split Tensile Strength decreased to 2.23 MPa at the addition of 30% Bottom Ash.

Apart from knowing the compressive strength, what needs to be done to know in utilizing porous concrete as a structural material is tensile strength. This is because concrete is weak in terms of tensile strength (the tensile strength of concrete is only about 10% of its compressive strength). The tensile strength of porous concrete is defined by the modulus of collapse of porous concrete or commonly referred to as flexural strength (Modulus of rupture), which ranges from 11% to 23% of its compressive strength.

There are several approaches that can be taken to determine the magnitude flexural strengh (Modulus of rupture) or Flexural Tensile Strength, which include:

1). The approach is to find the relationship between the compressive strength and the modulus of concrete failure. According to SNI T-15 -1991-03 (Procedures for calculating concrete structures). This approach is expressed by the following equation:

$$fr = 0.7\sqrt{fc} \quad \text{......} \quad (11)$$

Where :

fr = Flexural strength (modulus of rupture), in MPa.

This value ranges from 3 – 5 MPa (Research and Development of Transportation Infrastructure Engineering, Pd T – 14 –2003).

0.70=Constant.

$\sqrt{fc}$= Compressive strength of concrete aged 28 days.

In this study, it was found that fr = 0.70 √20.02 = 3.1321 Mpa > 3 MPa (SNI Pd T-14-2003).

2). Approach by looking for the relationship between Flexural Tensile Strength and Splitting Tensile Strength.

According to SNI 03 – 2491 -1991. This approach is expressed by the following equation:

fr = 1.37.fsp... .(12)

Where :

fr = Flexural Tensile Strength, in Mpa.

Fsp = Tensile Strength of Concrete aged 28 days.

In this study, the flexural tensile strength of porous concrete was obtained, fr = 1.37. 2.42 = 3.3154 Mpa > 3 MPa, fulfills the requirements as an environmentally friendly surface covering material (SNI Pd T-14-2003).

Ibrahim, et al (2015) examined the effect of using coal bottom ash as fine aggregate in self-compacting concrete on split tensile strength. The fine aggregate was replaced with varying percentages of 0, 10, 20, and 30% coal bottom ash using different water-cement ratios of 0.35, 0.40 and 0.45. The split tensile strength and density of self-compacting concrete decrease with higher CBA content [10].

3.7. Porosity

The results of the porous concrete porosity test are shown in table 9 as follows:

Table 9: Results of the 28-day-old porous concrete porosity test

Sample code	Porosity (%)
BA-0%	20.56
BA-10%	18.83
BA-20%	17.75
BA-30%	18.26

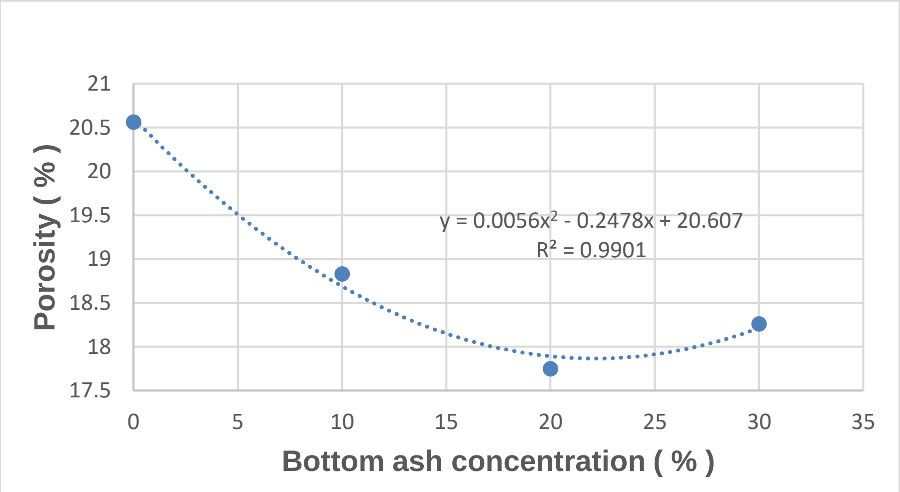


Figure 4. Graph of the Relationship Between Porosity of Porous Concrete and Variation of Bottom Ash 0 – 30% 28 Days Age.

Based on Figure 4, the equation is obtained, as follows:

$Y = 0.0056 X^2 - 0.2478 X + 20.607$ .... (13)

Written as, $P = 0.0056 BA^2 - 0.2478 BA + 20.607$ ....(14)

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

$$dp/dBA = 0, \text{ then: } 2\ (0.0056)\ BA - 0.2478 = 0$$
$$0.0112\ BA = 0.2478$$
$$BA = 22.12\%$$

By inserting the BA value into equation (14), the minimum porosity value for porous concrete is obtained as follows:

$$P = 0.0056\ (BA)^2 - 0.2461(BA) + 20.604$$
$$P\ min = 0.0056\ (22.12)^2 - 0.2478\ (22.12) + 20.607$$
$$= 17.86\ \%$$

So the Minimum Porous Concrete Porosity = 17.86%.

Based on the calculation results, the optimum bottom ash composition is 22.12%. These results have a porous concrete porosity value of 17.86%. This value is greater than the minimum porosity value of 17.77% (20% addition of bottom ash).

3.8. Compression Strength and Porosity Relationship

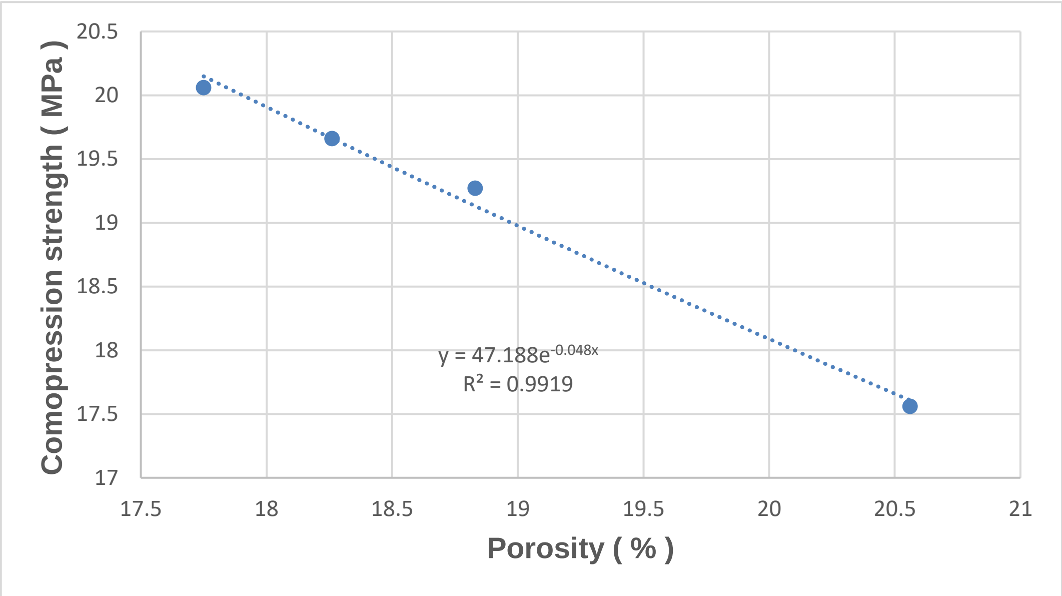


Figure 5. Exponential Regression Graph of the Relationship Between Porosity of Porous Concrete and Compression Strength.

Figure 5 shows the relationship between porosity and compressive strength of porous concrete. This relationship is expressed by the empirical formula as follows:

$$Y\ = 47{,}188\ e^{-0{,}048\ x} \quad \text{…………………………………………………………(15)}$$

Where :

Y = Dependent Variable.

X = Independent Variable

Next is written:

$$f\,c\ = 47{,}188\ e^{-0{,}048\ p} \quad \text{………………………………………………………………………(16)}$$

$R^2 = 0.9919$

Where :

fc = Permeability Coefficient

p = Porosity

R^2 = Coefficient of determination

By substituting the minimum porosity value of P = 17.86% into equation 16, we get:

fc = 47.188 e-0.048 (17.86)

fc = 47.188 e-0.8572

fc = 47.188 (0.4243)

= 20.02 MPa

Based on the results of a minimum porosity value of 17.86%, then a maximum compressive strength value of 20.02 MPa is produced with an optimum bottom ash content of 21.67% and a coefficient of determination of R^2 = 0.9919 (very strong relationship). It can be seen that the ideal compressive strength of porous concrete that utilizes bottom ash is smaller than the highest compressive strength (20.06 MPa).

3.9. Relationship between Porosity and Tensile Strength.

The split tensile strength test is used to evaluate the shear resistance of structural components made of concrete using aggregate.

Splitting tensile strength is often used in the calculation of surface layer rigid pavement design. One of the procedures carried out in the planning of concrete road pavements is to determine the stress ratio factor by dividing the equivalent stress by the flexural tensile strength. Flexural tensile strength can be determined from the results of the concrete split tensile strength test (Pd T – 14 – 2003). The flexural tensile strength that occurs in porous concrete as a surface covering layer is influenced by the level of density and the level of density is affected by the amount of porosity.

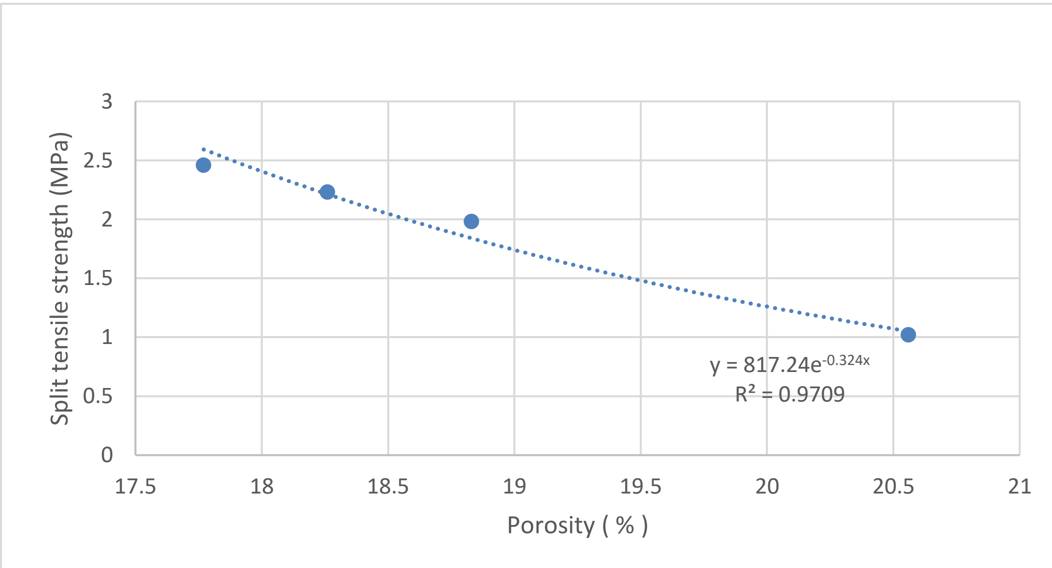


Figure 6. Exponential Regression Graph of the Relationship Between Concrete Porosity and Strong Tensile.

Based on Figure 6, the relationship between porosity and split tensile strength of porous concrete is presented as a result of testing in the laboratory. This relationship is expressed by the empirical formula as follows:

$Y = 817{,}24\ e^{-0{,}324\ x}$ ……………………………………………………………(17)

Where :

Y = Dependent Variable.

X = Independent Variable

Next is written:

$f\ sp = 817{,}24\ e^{-0{,}324\ p}$ ……………………………………………………………(18)

$R^2 = 0.9709$

Where :

fsp = Maximum Splitting Tensile Strength

p = Porosity

R^2 = Coefficient of determination

By substituting the minimum porosity value of P = 17.86% into equation 18, we get:

fsp = 817.24 e-0.324 (17.86)

fsp = 817.24 e-5.7866

fsp = 817.24 (0.0030)

= 2.47MPa

With a minimum porosity value of 17.86%, a maximum split tensile strength value of 2.47 MPa is obtained with an optimum bottom ash content of 21.67%, a coefficient of determination of $R^2 = 0.9709$ (very strong relationship).

4. CONCLUSION

1. Substitution of bottom ash for porous concrete can increase the compressive strength of porous concrete by 14.01% from the design compressive strength of 17.56 MPa to 20.02 MPa.

2. By substituting bottom ash for porous concrete, the quality of porous concrete increases from low quality to medium quality.

3. The relationship between porosity and compressive strength and splitting tensile strength, the mathematical model is obtained as follows:

The relationship between porosity and compressive strength $Y = 47.188\ e^{-0{,}048\ x}$

Where :

Y = Dependent Variable (compressive strength)

X = Independent Variable (porosity)

The relationship between porosity and compressive strength $Y = 817.24\ e^{-0{,}324\ x}$

Where :

Y = Dependent Variable (splitting tensile strength)

X = Independent Variable (porosity)

ACKNOWLEDGEMENT

The author would like to thank the Director of Semen Tonasa Enterprise Pangkep South Sulawesi, Chancellor of the Indonesian Muslim University (UMI) Makassar.

REFERENCES

[1] Qomaruddin, M., & Sudarno, S. Pemanfaatan Limbah Bottom Ash Pengganti Agregat Halus Dengan Tambahan Kapur Pada Pembuatan Paving. *Reviews in Civil Engineering*, **2017***1*(1).

[2] Mangi, S.A.; Wan Ibrahim, M.H.; Jamaluddin, N.; Arshad, M.F.; Memon, F.A.; Putra Jaya, R.; Shahidan, S. A Review on Potential Use of Coal Bottom Ash as a Supplementary Cementing Material in Sustainable Concrete Construction. *Int. J. Integr. Eng.* **2018**, *10*, 28–36.

[3] Singh, N.; Mithulraj, M.; Arya, S. Utilization of coal bottom ash in recycled concrete aggregates based self compacting concrete blended with metakaolin. *Resour. Conserv. Recycl.* **2019**, *144*, 240–251.

[4] Jang, J.G.; Ahn, Y.B.; Souri, H.; Lee, H.K. A novel eco-friendly porous concrete fabricated with coal ash and geopolymeric binder: Heavy metal leaching characteristics and compressive strength. *Constr. Build. Mater.* **2015**, *79*, 173–181.

[5] Ibrahim, M.H.W.; Hamzah, A.F.; Jamaluddin, N.; Ramadhansyah, P.J.; Fadzil, A.M. Split Tensile Strength on Self-compacting Concrete Containing Coal Bottom Ash. *Procedia Soc. Behav. Sci.* **2015**, *195*, 2280–2289.

[6] Kim, H.K.; Lee, H.K. Use of power plant bottom ash as fine and coarse aggregates in high-strength concrete. *Constr. Build. Mater.* **2011**, *25*, 1115–1122.

[7] Hannan, N.I.R.R.; Shaidan, S.; Ali, N.; Bunnori, N.M.; Mohd Zuki, S.S.; Wan Ibrahim, M.H. Acoustic and non-acoustic performance of coal bottom ash concrete as sound absorber for wall concrete. *Case Stud. Constr. Mater.* **2020**, e00399.

[8] Singh, N.; Shehnazdeep; Bhardwaj, A. Reviewing the role of coal bottom ash as an alternative of cement. *Constr. Build. Mater.***2020**, *233*, 117276.

[9] Aydin, E. Novel coal bottom ash waste composites for sustainable construction. *Constr. Build. Mater.* **2016**, *124*, 582–588.

[10] Mangi, S.A.; Wan Ibrahim, M.H.; Jamaluddin, N.; Arshad, M.F.; Putra Jaya, R. Short-term effects of sulphate and chloride on the concrete containing coal bottom ash as supplementary cementitious material. *Eng. Sci. Technol. Int. J.* **2019**, *22*, 515–522.

[11] Teraiya, D, 2015. *Develop Method To Find Out Permeability And Void Ratio For Pervious Concrete*, Institute Of Technology, Nirma University, India.

[12] S. Hesami, S. Ahmadi, M. Nematzadeh, Effects of rice husk ash and fiber on mechani- cal properties of pervious concrete pavement, Constr. Build. Mater. 53 (2014) 680 691.

[13] X. Cui, J. Zhang, D. Huang, X. Gong, Z. Liu, F. Hou, et al., Measurement of permeability and the correlation between permeability and strength of pervious concrete, in: First International Conference on Transportation Infrastructure and Materials, 2016, ISBN:978-1-60595-367-0.