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ORIGINAL ARTICLE

Investigation of Bottom Ash and Fly Ash in Porous Concrete as Replacement for Coarse Aggregate and Cement

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ABSTRACT - The porous concrete helps to reduce stormwater runoff and recharge groundwater. In this study, bottom ash (BA) aggregate was used as coarse aggregate. Granite is the coarse aggregate for porous concrete. Both aggregates were sieved between size of 10 mm to 14 mm. A total of 4 different mixed design (specimens PC1, PC2, PC3 and PC4) were used with 0%, 20%, 40% and 60% of bottom ash as coarse aggregate. A control mix with 100% coarse aggregate and cement paste was used to compare the results with the other mixes. A partial cement replacement of 5% by fly ash (FA) was used for each mix design. The 5% of FA is considered as the optimum cement replacement. Some tests were carried out to check the properties of the aggregate, namely the water absorption test, the aggregate crushing value test (ACV) and Los Angeles (LA) abrasion test. The compressive strength test was performed to determine the maximum strength of the concrete, while the water permeability test was performed to test the flow rate of water passing through the porous concrete. Microstructure analysis by using a digital microscope with 10x magnification was conducted to observe the surface texture of the aggregate and the bond between the aggregate and cement paste. The aggregate-cement ratio used is 1:3.6, while the water-cement ratio is 0.31. The acceptable range of compressive strength is between 5.8 and 13.8 MPa, while the optimum value for water permeability is 22.6 mm/s. The determined compressive strength is between 7.5 N/mm^2 and 12.3 N/mm^2, reaching the acceptable range of 5.8 MPa to 13.80 MPa and allowing the material to be used as a pavement. The porosity of porous concrete containing bottom ash and fly ash specimens for specimens of PC3 and PC4 are 19.16% and 21.07% which are within the acceptable range of 18% to 35%. While, the optimum level of water permeability is 22.6 mm/s whereby water permeability of PC2, PC3 and PC4 specimens with the water permeability of 23.25 mm/s, 28.28 mm/s and 30.51 mm/s respectively are acceptable.

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INTRODUCTION

The porous concrete is commonly used in road paving, sidewalk and pathways, parking lots as well as the drainage of retaining walls to solve the problem of storm water runoff drainage effectively [1]. Besides that, reduce the installation of impermeable surface and replace it with porous concrete can solve the problem as well [2].

Fly ash is known as a waste material which is produced from combustion of coal. It is usually collected from the chimneys of the power generation facilities. The material usually used as a supplement for ordinary Portland cement for producing concretes [3]. Fly ash is considered as a promising source material in the manufacturing of concrete. Due to the fineness of fly ash, it is high in silica and alumina content. The nature of material and type of liquid can determine the strength of concrete [4]. The fly ash has many benefits and improves the concrete performance. It also improves the strength and durability of

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the hardened concrete. The ordinary Portland cement can be reduced by using fly ash. The fly ash can produce additional cementitious compounds when it reacts with available lime and alkali in concrete [5].

There are voids in porous concrete which allows the concrete to drain water. It is produced as an environmental-friendly material which can be used as permeable pavement, water purification, thermal insulation and acoustic absorption. The void content of porous concrete ranges from 15% to 35%. The compressive strength of the porous concrete lies between 2.8 MPa and 28 MPa depending its void ratio content. The high porosity of concrete can be achieved by interconnected void content. High porosity can allow water to be drained naturally and removes normal surface-water drainage infrastructure [6].

Bottom ash is a type of waste material from combustion of coal in thermal power plant which have to be disposed in an environment friendly way. The chemical composition and physical properties of bottom ash differ from those of fly ash, and bottom ash generally contains more heavy metals as compared to fly ash [7]. Therefore, the usage of bottom ash aggregate as a replacement for coarse aggregate is considered as a good selection in terms of environmental and economic considerations [1]. Bottom ash aggregate is known as aggregate which is high in porosity and low density. According to J.G Jang et al [8], the recycling bottom ash as road base material, sub-base aggregate, and structural fill material is still at earlier stage, therefore, the proper recycling of bottom ash is urgent several studies have found that the solidification of bottom ash with cementitious materials reduces the amount of heavy metals which leach from it to below many environmentally acceptable criteria by both physical and chemical means [9].

In this study, porous concrete was fabricated with bottom ash aggregates and the partial cement replacement was fixed at 5% and aims to investigate the compressive strength of porous concrete at various percentages used for aggregates replacement.

MATERIALS AND METHODOLOGY

In this study, fly ash (FA) and bottom ash (BA) were obtained from Mukah Coal-Power Plant, Sarawak as shown in Figure 1. The bottom ash was used to replace the natural aggregates and was sieved between sizes of 10 mm to 14 mm to produce the porous concrete. The physical properties of the aggregates were determined before mixing the concrete. For this research, the properties of aggregates are determined by conducting the water absorption test, Los Angeles abrasion test, and Aggregate Crushing Value (ACV) test. The granite as natural aggregates and bottom ash aggregates physical properties are shown in Table 1. The chemical composition of the FA used in this study is shown in Table 2.

(a) (b)

Figure 1. (a) Bottom ash and (b) Fly ash

Table 1. Aggregates properties

Aggregates Type	Aggregate size (mm)	Water absorption (%)	ACV Value (%)	Abrasion value (%)
Granite	10-14	0.5	21.02	23.84
Bottom ash	10-14	5.5	32.88	48.52

Table 2. Fly ash sample chemical composition

Elements	**Fly As Mukah, Sarawak (%)**
SiO_2	45.33
Al_2O_3	18.11
Fe_2O_3	8.89
CaO	12.42
TiO_2	0.67
K_2O	1.86
SO_3	1.69
MgO	5.77
TiO_2	0.67
P_2O_5	0.20
Na2O	4.89
SrO	0.17
BaO	0.00

Porous Concrete Mix Proportions, Mixing and Casting

The mould size of 100 mm diameter × 200 mm height was used in this research. The specimen size was according to BS 12390-1:2009 [10]. The inner surface of the mould must be cleaned in order to obtain a better bonding strength. The inner surface of the mould was applied with grease to prevent damage while removing the concrete from the mould. The porous concrete is wrapped with a piece of cling wrap to prevent loss of moisture.

The mixing of porous concrete was done manually in a pan as shown in Figure 2. The porous concretes were mixed with a metal shovel and poured into cylindrical moulds and compacted immediately. The volume and density of the concrete decreased when air is trapped. The concretes were filled into the mould in three equal layers. When the concrete was poured into the mould, each of the concrete layers was tamped with 25 blows using a metal rod. The tamping of the concrete mixture was done with a weight to compact the top of the porous concrete at the final stage. It was used for the compaction of porous concrete. The moulds were then covered with plastic wrap, as shown in Figure 3(a), to prevent moisture loss in the concrete. The porous concrete specimens were removed from the moulds after 24 hours and then cured in a water tank as shown in Figure 3(b) and leave it for 7 and 28 days at the temperature of 27±1 °C. The procedure was conducted according to BS EN 12390-2:2000 [10]. Porous concretes were taken out from the curing tank and leave it dry before compressive test.

Sulphur capping method was done before conducting compressive test for porous concrete. The capping method is based on ASTM C617-1998 [11]. Porous concrete must be in dry condition to produce a good sulphur capping. The function of sulphur capping is to provide the top of the concrete with a smooth and flat surface which is suitable to apply the load during compressive test. The heating of sulphur is shown in Figure 4(a). The temperature controller was set to “Full” while melting sulphur. After the sulphur melted, the temperature was lowered down to “Universal”. This is because the Sulphur must be handled with care as it can get into flame if the temperature is too high. After melting the sulphur, the top side of porous concrete was covered with a layer of sulphur and capped it at the top side of the concrete as shown in Figure 4(b).

Table 3. Mix proportions of porous concrete

Specimens	Binder		Water to cement ratio	Binder to Aggreates ratio	Bottom Ash Agg. (kg/m3)	Normal Agg. (kg/m3)	Number of specimens	
	OPC (kg/m3)	FA (kg/m3)					7 days	28 days
NPC	380.97	-	0.40	1:3	1480	1336.73	3	3
PC1	361.92	20.15	0.42	1:3	1480	1336.73	3	3
PC2	361.92	20.15	0.42	1:3	1480	1336.73	3	3
PC3	361.92	20.15	0.42	1:3	1480	1336.73	3	3
PC4	361.92	20.15	0.42	1:3	1480	1336.73	3	3

Figure 2. Bottom Ash and Normal Aggregates mixed manually on a pan

(a) (b)

Figure 3. (a) Moulds covered with with cling wrap, and (b) Water curing

(a) (b)

Figure 4. (a) Sulphur heating, and (b) Porous concrete capped with sulphur

Testing Details

Porosity and water permeability

After conducting water permeability test, the porous concrete has undergone porosity test to test for porosity as shown in Figure 5. The test was done before sulphur capping. A bucket was used for the test. Water was filled into the bucket until sufficient water level for porous concrete. The volume of water (L) was measured by weight (kg). The porous concrete was submerged in water and marked the initial water level. The porous concrete was then taken out, initial weight (W_1) was obtained and marked the final water level. The water level was filled to the initial water level and the final weight (W_2) was obtained. The increment of water level is known as increment of water volume. The weight (W_1 and W_2) was converted to m^3. The equation for the porosity test is as shown in equation (1):

$$P = \left(1 - \frac{W_2 - W_1}{V \cdot \rho_w}\right) \times 100 \quad (1)$$

where P = Porosity of porous concrete (%)

W_1 = Weight of porous concrete (kg)

W_2 = Weight of the water saturated specimen (kg)

ρ_1 = Density of water (kg/m^3)

V = Volume of the specimen (m^3)

Water permeability test is important to determine the flow rate of water passing through porous concrete. The permeability is an important parameter for porous concrete because it is designed for drainage layer in pavement structures [6]. The water permeability of the concrete was tested by using falling head method as shown in Figure 6. The apparatus needed for the test are transparent plastic pipe, roll cling wrap and rubber membrane. The water permeability test must be conducted before conducting compressive test.

The test was conducted by allowing the water to flow through the cylindrical concrete until the standpipe reach a given lower limit. There were three different time intervals taken for the test. The time intervals were taken from heights of 200 mm to 150 mm, 200 mm to 100 mm and 200 mm to 50 mm. The limiting values of the properties of porous concrete as recommended by ACI [12] is 0.14 cm/s to 1.2 cm/s. The water permeability rate of porous concrete was determined by using the equation as shown in equation (2):

$$K = \frac{QL}{HAt} \quad (2)$$

Where;

K = the coefficient of water permeability (cm/s)

Q = the quantity of water collected (cm^3) over time t (s)

L = the length of specimen (cm)

H = the water head (cm)

A = the cross sectional area of specimen (cm^2)

Figure 5. Porosity test

Figure 6. Water permeability set-up

Compressive strength

Compressive strength was carried out to determine the maximum strength of porous concrete. The porous concrete size of 100 mm diameter and 200 mm height with the age of 7 and 28 days were tested. A total of 30 specimens were required for the research. Figure 7 shows the ELE International compression test machine with the specification number of ADR-AUTO V2.0 3000. The machine is compression test machine with maximum load capacity of 3000 kN. The test is based on BS EN 12390-3:2009 [10].

The porous concretes were taken to carry out the test after 7 and 28 days for testing. The specimens were wiped dry by using a cloth before the test. The specimens were weighed and measured before curing. The plate of the compressive machine was ensured clean with suitable height before placing the concrete in it. The concrete was placed at centre of the plate and apply loading until it fails.

Figure 7. Compressive strength test

Microstructure Observation

The bottom ash aggregate and coarse aggregate were observed under magnification of digital microscope. The aggregate from porous concrete failure were chosen for magnification based on its size and texture surface. The enlargement of the magnification on the aggregates is 10X. The physical characteristics of the aggregates and its effects on the performance of porous concrete were observed under the digital microscope. The roughness on the aggregate surface, aggregate porosity and bonding between aggregates and cement binder can be seen clearly through the digital microscope. Figure 8 shows the digital microscope used for the research.

Figure 8. Digital microscope

RESULTS AND DISCUSSION

Porosity and Density

Porosity test was conducted to determine the percentage of air-filled voids in the porous concrete. The results are shown in Table 4 and Figure 9. Based on Table 4 and Figure 9, the PC1 specimens have the lowest porosity whereas PC4 specimens have the highest porosity which are 12.79% and 21.07%, respectively. PC3 and PC4 specimens are within the acceptable range of 15% to 35% in accordance with ASTM C1754 [13].

However, the lowest porosity of the PC1 specimens, containing 5% fly ash and made with completely normal aggregates, is lower porosity than that of normal porous concrete. This is due to the fact that the addition of fly ash as a partial cement replacement reduces the interconnecting voids due to the higher fineness and thickness of the transition zone between the binder and the aggregate [14], [15]. The porosity of the PC2, PC3 and PC4 specimens increased with the increase in the percentage of replacement of coarse aggregate replacement to 20%, 40%, and 60% of bottom ash aggregates, respectively. As shown in Figure 10, the binder paste adhered to aggregates at PC2, PC3, and PC4 created more voids compared to NPC and PC1. As shown in Table 4, the lower density of the porous concrete with bottom ash which is related to the binder paste adhering to the aggregate, increases the porosity of the material compared to porous concrete with normal coarse aggregate. Moreover, the porosity of porous concrete containing fly ash as a partial cement replacement increases with the addition of bottom ash.

Table 4. Porosity and density test results

Specimen	Density (kg/m³)	Porosity (%)
NPC	1906.676	13.43
PC1	1924.502	12.79
PC2	1811.183	16.61
PC3	1712.507	19.16
PC4	1644.389	21.07

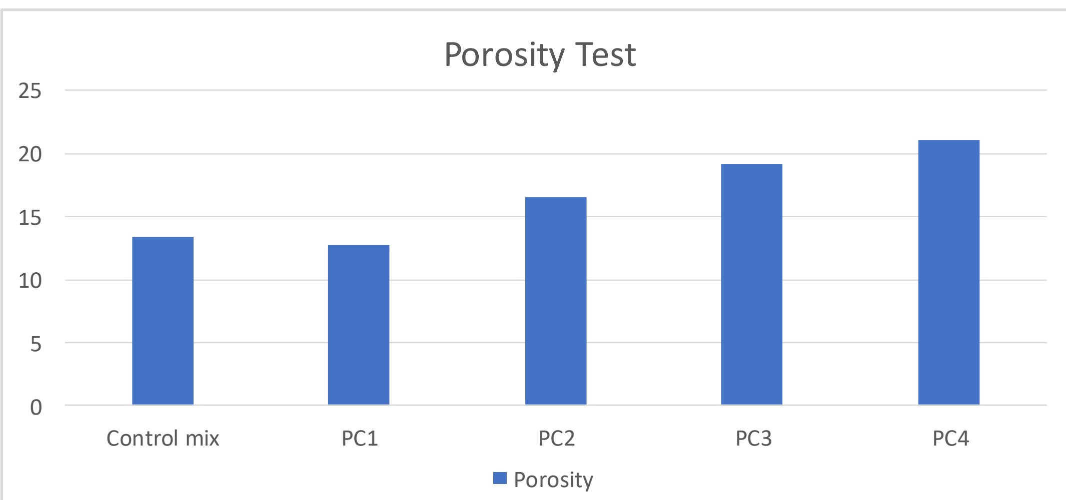

Figure 9. Porosity of porous concrete

a) Control mix

b) PC1

c) PC2

d) PC3

e) PC4

Figure 10. Binder Paste and Aggregates: a) NPC, b) PC1, c) PC2, d) PC3 and e) PC4

Water Permeability

Water permeability test was conducted to determine the water flow rate which passed through the porous concrete for each mix design. Three porous concrete specimens were chosen to conduct the test and the mean permeability rate was obtained. There were three different time intervals conducted for the test which are from the height of 200mm to 150mm, 200mm to 100mm and 200mm to 50mm.

Based on Table 5 and Figure 11, PC4 have the highest water permeability rate of 30.51 mm/s whereas PC1 have the lowest water permeability rate of 17.34%. This is due to low porosity of PC1 which caused the water having difficulty to flow through the porous concrete. As shown in Figure 10, the bottom part of the PC1 specimens shows partially filled voids which stops the water to flow through. PC2, PC3 and PC4 specimens have higher water permeability rate as compared to porous concretes with 100% coarse aggregates. This is caused by the specimens with better interconnected voids between the aggregates and better water absorption. PC4 specimen with the highest water permeability rate shows the highest porosity of 21.07% as shown in Table 4 and 5. The water permeability corresponded to compressive strength of the porous concrete. The water permeability increases as the compressive strength increases. Interconnected cavity or voids of porous concrete is important for water to flow through.

The compaction of concrete affects the water permeability rate as well. Well compaction of porous concrete increases the density of porous concrete. Based on Table 4 and 5, the density of porous concrete decreases as the water permeability increases except for PC1 specimens which caused by low porosity of porous concrete. This shows that compaction can affect the water permeability rate whereby the size of voids decreases as the porous concrete gets more compact and denser. As the porous concrete gets denser, there is loss in interconnected cavity in the concrete.

Porosity is important for water permeability of the porous concrete. High water permeability rate shows high porosity but high porosity does not mean to have high water permeability. This is because high porosity with low water permeability means the voids in the porous concrete might filled by cement paste. Based on Table 4 and Figure 9, the porosity of PC2 to PC4 specimens increased correspond to the water permeability rate.

Table 5. Water permeability test results

Specimen	Water Permeability Rate, mm/s				Total Mean, mm/s
	Height Interval (mm)	Permeability rate			
		Sample 1	Sample 2	Sample 3	
NPC (Control)	200 to 150	14.50	15.47	21.10	19.80
	200 to 100	16.94	18.64	23.63	
	200 to 50	21.23	23.79	28.92	
	Mean	17.56	19.30	24.55	
PC1	200 to 150	14.50	14.21	15.47	17.34
	200 to 100	15.68	15.82	18.04	
	200 to 50	19.62	19.73	22.98	
	Mean	16.60	16.59	18.83	
PC2	200 to 150	18.32	21.76	19.89	23.25
	200 to 100	20.46	23.96	21.78	
	200 to 50	25.81	30.22	27.06	
	Mean	21.53	25.31	22.91	
PC3	200 to 150	26.78	24.86	21.76	28.28
	200 to 100	28.92	28.92	23.30	
	200 to 50	34.95	35.31	29.69	
	Mean	30.22	29.70	24.92	
PC4	200 to 150	25.78	23.21	33.15	30.51
	200 to 100	27.50	25.81	32.89	
	200 to 50	34.95	32.26	39.01	
	Mean	29.41	27.09	35.02	

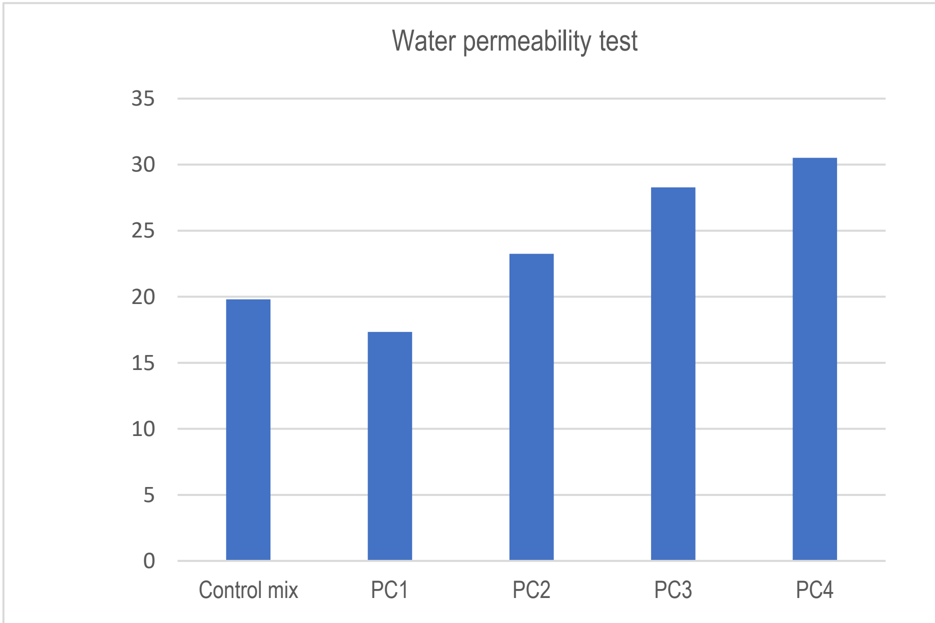

Figure 11. Chart of water permeability of porous concrete

Compressive strength

The results of compressive strength test for each mix designs after 7 and 28 days are recorded in Table 6. The test is to determine the strength of porous concrete. Three specimens form each mix design were tested for 7-day and 28-day concrete. The average weight of each mix design was recorded to obtain density of the porous concretes.

According to Table 6 and Figure 12, NPC and PC1 have similar results with 11.1N/mm^2 for 7 days and 12.3N/mm^2 and 12.2N/mm^2 for 28 days, respectively. All of the mix designs achieve the compressive strength range of 5.8 MPa to 13.80 MPa as mentioned by Muthaiyan and Thirumalai [16]. Both control mix and PC1 contains 100% coarse aggregates but PC1 contains 5% partial cement replacement with fly ash. PC1 have slightly higher density than control mix. Based in the results, this shows that 5% partial cement replacement with fly ash is considered as the optimum level and it is suitable for partial cement replacement. The compressive strength of porous concrete decreases as the density decreases. Abdulsalam Arafa et al. [6] stated that the compressive strength of porous concrete decreases as the porosity increases. The porosity of the porous concrete and aggregate can affect the density of the concrete and affects the compressive strength as well. This is due to the aggregate crushing value (ACV) for bottom ash aggregate is higher compared to coarse aggregate. The bottom ash aggregate content increased from PC1 to PC4 with 20% increment for each mix design. PC4 have the most bottom ash aggregate content which is 60% and it has the lowest compressive strength compared to other mix designs.

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Based on Table 6 and Figure 12, PC3 and PC4 porous concretes have similar strength for 7-day and 28-day porous concrete. This is due to failure in aggregates in which the bottom ash aggregate is expected has lower specific gravity as the porous concrete contained with bottom ash has lower density than that of normal porous concrete. This condition was proven with high ACV value and abrasion value of bottom ash aggregate. As shown in Figure 13(a), the surface texture of the bottom ash aggregate has more voids as compared to coarse aggregate. This cause the bottom ash aggregate to be low in strength. There are two types of concrete failure which are failure in cement paste and failure in aggregate. Figure 14(a) and Figure 14(b) shows failure in cement paste whereas Figure 13(a) is considered as aggregate failure.

Figure 15 shows maximum packing density where coarse aggregate are packed tightly to each other. Figure 14(b) shows an example of interlocking action on porous concrete. When there are no foreign particles in between it, the coarse aggregates will slide against each other and this leads to interlocking action between aggregate [17]. Loading is transferred from top to bottom by good structure and packing density of aggregate on porous concrete to achieve high compressive strength. The large voids on porous concrete and bottom ash aggregate can break the transfer loading thus causing failure of concrete. Coarse aggregate can transfer loading better than bottom ash aggregate due to lower ACV and abrasion value of coarse aggregate. Low ACV and abrasion value of aggregate means that the aggregate is harder and higher strength and this leads to good loading transfer. As shown in Figure 16, bottom ash aggregate was found in between coarse aggregate. The weaker strength of bottom ash aggregate caused the porous concrete to fail as the bottom ash aggregate failed to transfer loadings during interlocking with coarse aggregate.

Granite which used as coarse aggregates have good interlocking mechanism provides higher compressive strength to the porous concrete due to angular and elongated shape of granite as shown in Figure 13(b). The shape of the aggregates tended to resist the compaction force during compaction and this caused the porous concrete more difficult to compact. However, the bottom ash aggregates have irregular shape but less elongate as compared to coarse aggregates as shown in Figure 13(a). The different shape of aggregates caused the porous concrete to have large voids when the two different aggregates mixed together as shown in Figure 17. This shows the poor workability of concrete casting during compaction. The different shapes of aggregates caused the low workability as it is more difficult to interlock against one another. Besides that, low cement-aggregate ratio caused the cement paste to be thicker and this also contributed to low compaction workability. Figure 18 shows the PC1 specimen with well compaction. This is because the shapes of coarse aggregates are more consistent compared to the mixed aggregate porous concrete and easier to interlock against each other.

The difference in aggregate shape affects the compressive strength of the porous concrete and caused PC3 and PC4 specimens to have similar strength after 28 days. Since the bottom ash aggregates are high in porosity, the aggregates start to fail and crack after it reach certain limit during compressive test. Based on Figure 19 and 20, the failure in bottom ash aggregate and cement failure between coarse aggregate and cement paste caused the porous concrete to fail. As the compressive test conducted for a few more seconds, the porous concrete with 60% bottom ash aggregate in Figure 21 crushed as compared to normal porous concrete which is still intact as shown in Figure 22. The bottom ash aggregate which is easy to fail caused PC3 and PC4 specimens where 28-day specimens to have similar results with 7-day specimens.

Table 6. Compressive strength test results

Specimen	Average Weight (kg)	Density (kg/m³)	Compressive Strength (N/mm²)			
			7 days		28 days	
			Strength (N/mm²)	Average Strength	Strength (N/mm²)	Average Strength
NPC (Control)	2.995	1906.676	11.6 10.3 11.5	11.1	12.1 13.1 11.8	12.3
PC1	3.023	1924.502	11.2 10.4 11.8	11.1	10.7 14.3 11.6	12.2
PC2	2.845	1811.183	8.3 10.5 8.1	9.0	9.6 10.6 9.7	10.0
PC3	2.69	1712.507	6.9 8.2 7.6	7.6	8.0 7.0 8.0	7.7
PC4	2.583	1644.389	6.5 8.4 6.3	7.1	6.5 7.5 7.9	7.3

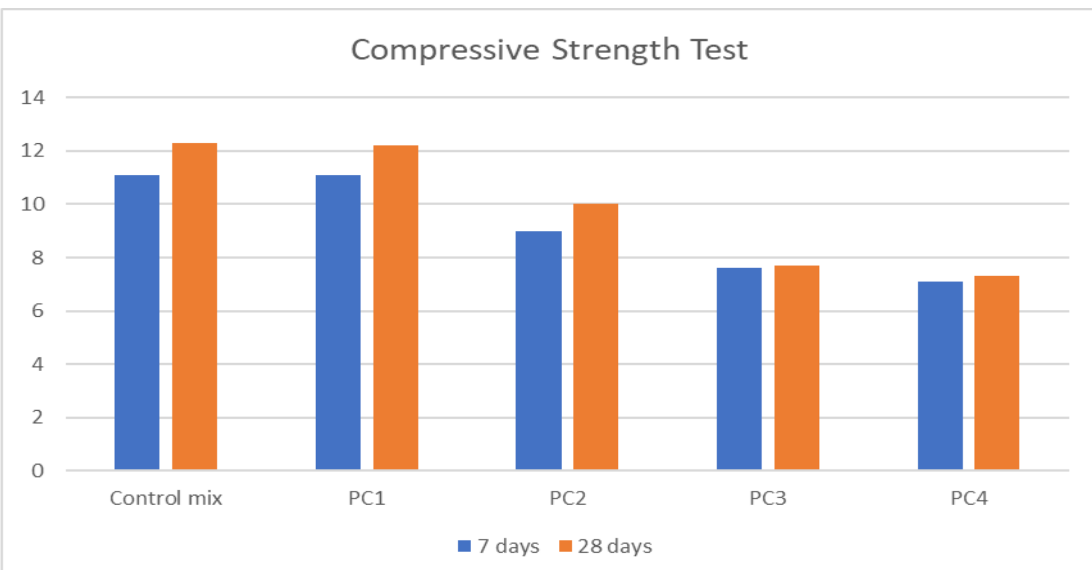

Figure 12. Chart of compressive strength test of porous concrete

a) Bottom Ash Surface b) Granite Surface

Figure 13. a) Bottom Ash Surface; and b) Granite Surface

a) Failure on cement paste b) Failure on aggregate

Figure 14. a) Failure on cement paste and b) Failure on aggregate

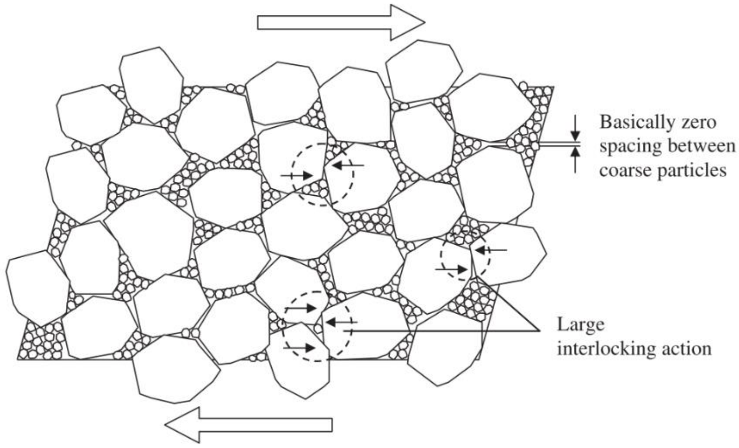

Figure 15. Maximum packing density of aggregate [17]

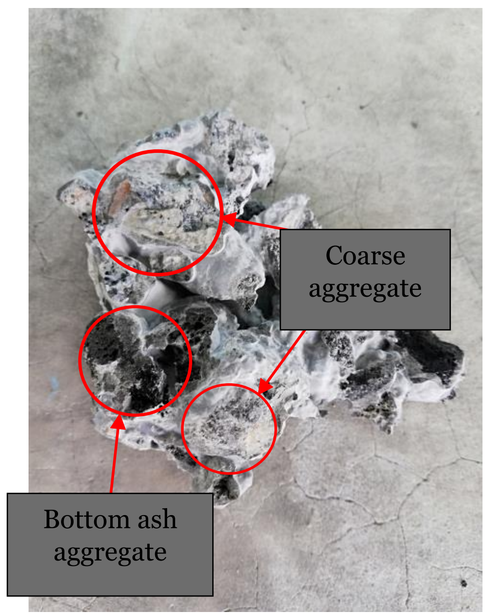

Figure 16. Piece of crushed concrete

Figure 17. Porous concrete with large voids (PC3)

Figure 18. Well compaction of porous concrete

Figure 19. Failure of bottom ash aggregates (PC4)

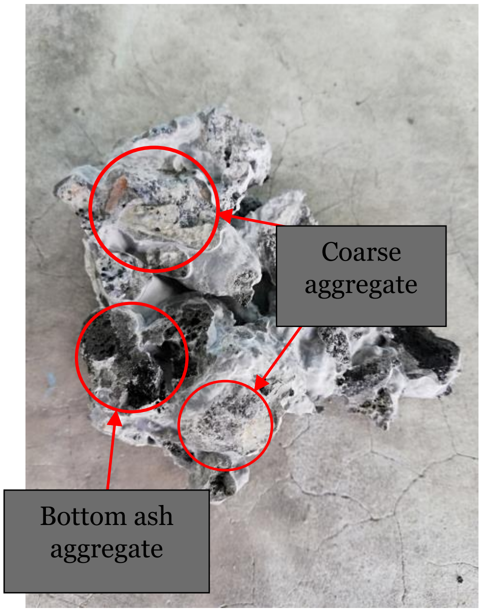

Figure 20. Piece of crushed concrete

Figure 21. Crushed porous concrete (PC4)

Figure 22. Intact normal porous concrete after compressive test

Microstructure

Microstructure analysis has been conducted in this research. The bonding between aggregates and cement pastes as well as the surface texture of the aggregates has been examined under the magnification of digital microscope. Both coarse aggregates and bottom ash aggregates were examined. The analysis observed the properties of aggregates which affects the strength of porous concrete. The aggregates were examined by using 10X magnification lens of digital microscope.

Coarse Aggregate

The surface of the coarse aggregate appears to be smooth as shown in Figure 23. Smooth surface of coarse aggregate provides poor bonding with cement paste as compared with rough surface. The poor bonding between the aggregate and cement paste contributes to cement paste failure of porous concrete as shown in Figure 14(a) and Figure 14(b). However, the porous concrete with higher coarse aggregate content shows higher compressive strength. This is due to lower aggregate crushing value (ACV) of coarse aggregate which can withstand greater loading and have better loading transfer.

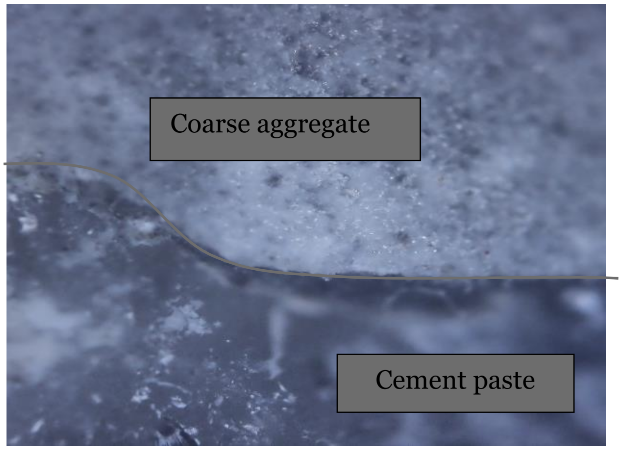

Figure 23. Bonding of coarse aggregate with cement paste

Bottom Ash Aggregate

Based on Figure 24, bottom ash aggregate shows rough surface as compared to coarse aggregate. Void can be seen on the surface of the aggregate. The bonding between bottom ash aggregate and cement paste can be considered as good. However, the ACV test shows higher ACV value of bottom ash aggregate as compared to coarse aggregate. This contributed to lower compressive test of porous concrete which caused by failure in aggregate as shown in Figure 19 and 20. There is less failure between bottom ash aggregate and cement paste due to good bonding. Although the bottom ash aggregate have better cement bonding than coarse aggregate, the compressive strength of porous concrete with bottom ash aggregate appeared to be lower due to higher ACV and abrasion value of aggregate.

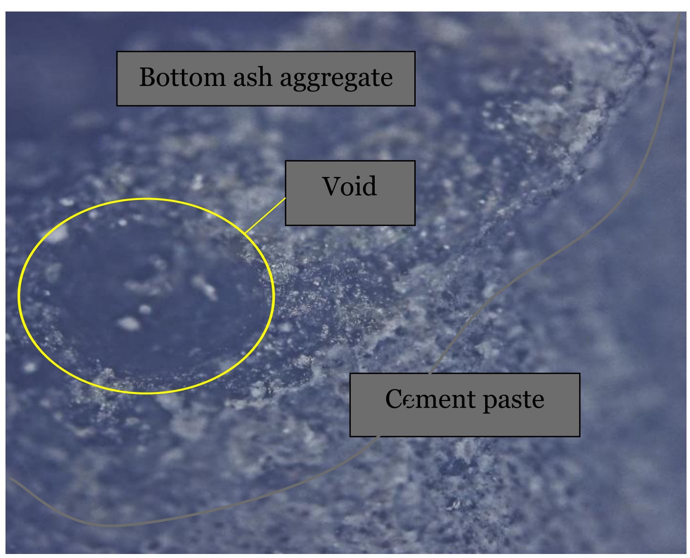

Figure 24: Bonding of bottom ash aggregate with cement paste

Aggregate size used for the research is 10mm. Based on the results in Table 1, bottom ash aggregate has the higher water absorption compared to coarse aggregate which is 0.5% and 5.5%. This is due to higher porosity of bottom ash aggregates as shown in Figure 13(a). From the ACV value test as shown in Table 1, the high porosity of bottom ash aggregate shows higher ACV value compared to coarse aggregate. The ACV value of bottom ash aggregates is 32.88% whereas the coarse aggregates have the value of 21.02%. This proved that bottom ash aggregates have lower strength compared to coarse aggregate. Besides that, the abrasion value of bottom ash aggregate is 48.52% as compared to coarse aggregate which is 23.84%.

From the compressive test results, the compressive strength decreases as the density of the porous concrete decreases. PC1 specimens have the highest compressive strength whereas the compressive PC4 specimen have the lowest compressive strength. The longer the curing period of porous concrete, it is expected to have greater compressive strength. However, PC3 and PC4 specimens show similar compressive strength of 7-day and 28-day concrete. The difference in aggregate shapes of bottom ash aggregates and coarse aggregates caused the porous concrete to have large voids and lower compaction workability. The mixed aggregate porous concrete with different shape and thick cement paste caused the aggregate to be more difficult to compact.

The porous concrete with higher content of bottom ash aggregate, water permeability rate appeared to be higher with lower compressive strength. This is due to decrease of porous concrete density as the bottom ash aggregate increased. PC4 specimen have the highest water permeability rate whereas the lowest water permeability rate is PC1 specimen which is 30.51 mm/s and 17.34 mm/s respectively. Water permeability rate increases as the compressive strength increases. Based on Table 4 and Figure 9, PC4 specimens have the highest porosity of 21.07% whereas PC1 specimens have the lowest porosity of 12.79%.

The partial cement replacement with 5% fly ash is used for the research. Comparison between control mix and PC1 specimens with 5% fly ash were made and both have similar compressive strength. This shows that 5% fly ash as partial cement replacement is acceptable as the compressive strength of porous concrete maintained. The compressive strength obtained from the porous concrete lies between 7.3N/mm^2 to 12.3N/mm^2.

CONCLUSION

The bottom ash and fly ash as partial replacement of coarse aggregates and cement was studied experimentally. The following are the main conclusions of the study:

(a) The compressive strength of geopolymer porous concrete is decreased by increasing the percentage of the bottom ash replacement. However, the compressive strength of the porous concrete containing with fly ash and bottom ash is lower than that of normal porous concrete and porous concrete containing fly ash.

(b) The compressive strength of normal porous concrete, porous concrete containing with fly ash, and porous concrete containing with fly ash and bottom ash varies from 5.8 MPa to 13.80 MPa, which is acceptable for road pavement construction.

(c) The water permeability rate of the porous concrete samples is within the acceptable range between 2 mm/s and 30 mm/s except for PC4 specimen (60% bottom ash of coarse aggregates replacement) which is 30.51 mm/s.

(d) The increase in the replacement level of bottom ash aggregates in porous concrete increased the total porosity and this also affect the water permeability.

(e) The shape of the aggregates is important to prevent the formation of cavities. Flaky and elongated aggregates can affect the quality of compaction because they prevent good interlocking between aggregates. When the aggregates are properly compacted, there are no voids.

The use of porous concrete containing bottom ash and fly ash is considered acceptable in the construction industry because it can reduce by years the disposal of fly ash and bottom ash, which requires high costs and large areas of land. Overall, it can be concluded that it is possible to use bottom ash as aggregates in porous concrete, as partial or total replacement for natural aggregates, in the composition of porous concrete.

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