Compressive strength of pervious concrete paving blocks for pavement with the addition of fly ash

E Septiandini¹, I Widiasanti¹*, C A Pamungkas¹, A S S Putri¹, T Mulyono² and N Z P Abdul³

¹ Program Studi Teknik Sipil, Fakultas Teknik, Universitas Negeri Jakarta, Jalan Rawamangun Muka, Jakarta 13220, Indonesia.
² Program Studi Transportasi, Fakultas Teknik, Universitas Negeri Jakarta, Jalan Rawamangun Muka, Jakarta 13220, Indonesia.
³ Program Studi Pendidikan Teknik Bangunan, Fakultas Teknik, Universitas Negeri Jakarta, Jalan Rawamangun Muka, Jakarta 13220, Indonesia.

*irika@unj.ac.id

Abstract. Pervious concrete paving blocks (PCPB) is a material that widely used for the surface layer of road either for traffic or non-traffic needs. The main characteristic is the pores within the concrete which can allow water to pass through so it can prevent inundation when rain comes. Good absorption rate is not in line with its compressive strength. In order to enhance its compressive strength, some fly ash was added to the weight of the cement in the mixture. Fly ash (FA) is a coal combustion residue that has similarity with cement content and properties. Admixture for pervious concrete typed SikaMix-10 NT were added to increase the workability of the mixture. This research uses quantitative methods based on the results of experiments conducted in the laboratory. The planning of mixture refers to the ACI 522R-10 standard. Several tests were carried out to determine the quality such as compressive strength test, infiltration test, porosity test and wear resistance by analysing the results guided by SNI 03-0691-1996. The results generally showed that the addition of some fly ash was made to have compressive strength, absorption, porosity and wear resistance that has fulfilled C classification for application in pedestrian paths or sidewalks.

1. Introduction

Rigid pavement material, known as concrete plates were being used in various types of construction, which one is applied as a road surface covering material [1]. Starting from the road designated for vehicle traffic lanes to the pedestrian path/sidewalk using concrete paver. High durability is one of the main factors in choosing concrete materials [2]. The use of concrete is most common in urban areas that have a high level of mobility [3]. The use of concrete for road surface covering has the disadvantage of low water absorption rate [4]. This can be seen from the occurrence of puddles on the road surface layer that can interfere surface water management, causing flooding during heavy rains on the road especially if the drainage system is not functioning properly. Based on these considerations the best solution or alternative is to use pervious concrete [5].

Pervious concrete is defined as a concrete material with a mixture of hydraulic cement that has a gap/poros so that it has a high level of permeability that allows water to penetrate through it [6]. There are various pervious materials used for road surfaces, one of which is concrete blocks [7]. Concrete
blocks has a mixture consisting of cement, coarse aggregate, water and with or without sand as fine aggregate [8]. The porosity of a typical pervious concrete varies in general is between 15% – 25% and the water permeability coefficient is about 2–6 mm/s [9]. This type of concrete brick has vesicles/pores of a certain size that allow absorption of surface water to be transmitted into the ground so that surface water puddles can be minimized and useful as land for absorption especially if used in urban areas that begin to have minimal green land [7]. The good absorption rate of PCPB is in line with the level of porosity, but porosity can also cause the decrease in the quality of concrete blocks in terms of compressive strength [10]. Referring to previous studies, pervious concrete blocks with a ratio of cement to coarse aggregate of 0.30 and an aggregate size of 9.5 mm have compressive strength values of around 10 MPa with an infiltration rate of 0.4 cm/s [11,12].

Various studies have been carried out to improve the compressive strength of pervious concrete blocks including replacing some or adding certain materials [13]. One of the materials that can be used to increase thecompressive strength of concrete blocks is fly ash [14]. Flying ash is the residue resulting from coal combustion obtained from the Steam Power Plant (PLTU) [15]. The production of the coal combustion waste in Indonesia is estimated to reach 9.72 million tons in 2020 [16]. The burning coal produces fly ash around 25% - 30% and bottom ash about 2-3% that is depending on the quality of coal [17]. The coal combustion waste is classified as B3 waste and if it’s not use appropriately, fly ash can cause air, soil and water pollution due to its ability to generate dust and heavy metal composition [16]. The use of fly ash for concrete mix is to partially replace the use of Portland cement because fly ash has similar properties with cement and reacts with calcium hydroxide at a certain temperature. This research was conducted by utilizing fly ash as an effort to improve the properties of pervious concrete paving blocks which has low compressive strength.

2. Research methods

2.1. Methods

In this study there are several measurement variables for PCPB which will be used to determine the characteristics and quality of concrete blocks samples corresponding with the concrete mix plan.

This research was conducted at PT. Semen Indonesia Beton and Industrial Test Laboratory and Technical Goods, DKI Jakarta Industrial Service. Determination of the quality of PCPB is done by quantitative analysis methods through experiments by conducting several tests on samples of test specimens.

The composition planned of PCPB consist cement, fly ash, coarse aggregate and water. There is no addition of sand as fine aggregate in order to increase the permeability of PCPB. The compressive strength was planned to achieved 15 MPa with the aim that it can be applied to for pedestrian paths or sidewalk. The porosity planed percentage is 20%. Calculation of PCPB mixture refers to ACI 522R-10 with a cement water ratio (w/c) determined at 0.27. Admixture for pervious concrete typed SikaMix-10 were added by 0.7% to the weight of cement [18].

2.2. Variables and samples

To support and obtain accurate research results, several independent variables are used, namely the addition of some fly ash into a concrete brick mixture to replace cement with a percentage variation of 18% and 21% and a concrete brick with 0% fly ash content as a control specimen. The specimen for PCPB in this study is in the form of blocks with dimensions of length, width and height respectively are 16 cm × 8 cm × 8 cm.

Compressive strength testing is carried out in accordance with SNI 03-0691-1996 at 7, 14, 28 days curing ages with the aim of seeing whether there is an increase or decrease of its strength during increasing concrete age. The number of sample specimens for each variation for each age of concrete testing was 3 samples so that the total sample of compressive strength test was 27 pieces.

The aim of infiltration rate testing of PCPB is to know how long and the amount of water absorbed by the test object using ASTM 1701 / C 1701M - 09 standard on "Standard Test Method for Infiltration
Rate of In Place"[19]. Infiltration rate testing is carried out at the age of 28 days concrete bricks with 12 samples for each variation.

Examination of wear resistance ability of PCPB refers to SNI 03-0028-1987 standard on Testing Plain Cement Tiles [8]. Wear testing is done to determine the durability of concrete blocks against friction and impact using Los Angeles machine test equipment and a number of steel balls as auxiliary components. The sample dimension for wear testing is in square with a side length of 50 mm × 50 mm and a thickness of 20 mm. Tests carried out at the age of 28 days with the number of each sample of 5 pieces for each variation.

Porosity testing is carried out to determine the percentage of the gap/cavity in the concrete blocks. The testing standard refers to ASTM C642-06 "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete"[20]. The test was carried out at 28 days with the number of each sample of 2 pieces for each variation.

3. Results and discussion

Before planning the PCPB mixture, the preliminary testing of PCPB compiler materials were done with applicable standards. The testing of coarse aggregate size 4.75 mm – 9.5 mm shows that it has a specific saturated surface dry (SSD) density of 2.56 gr/cm$^3$, capacity of water absorption is 3.72%, solid content weight of 1365.49 gr/cm$^3$, water content of 5.10%, sludge value of 0.93%, and fineness modulus value of 5.5.

Referring to SNI 03-1969-1990 the required specific gravity value is 2.5 gr/cm$^3$ – 2.7 gr/cm$^3$, then the SSD density of the coarse aggregate used meets the requirements. The value of water absorption capacity required by SNI 03-2461-2002 is below 2%, while the test results obtained are more than the specified value so it can allow the decrease in durability if it used. The results of aggregate sludge test have fulfilled the SK SNI S-04-1989-F requirements, which is a maximum of 1%. Whereas the value of fineness modulus meets the requirements of SNI 03-1968-1990, which is between 5.0 – 8.0.

The calculation of the PCPB design mixture obtained composition per 1 m$^3$ for each variation of the addition of fly ash as follows.

| No. | Materials  | Weight per sample (kg) FA 0% | Weight per sample (kg) FA 18% | Weight per sample (kg) FA 21% |
|-----|------------|-------------------------------|-------------------------------|-------------------------------|
| 1.  | Aggregate  | 54.85                         | 54.85                         | 54.85                         |
| 2.  | Cement     | 15.45                         | 15.45                         | 15.45                         |
| 3.  | Fly ash    | 0.00                          | 2.78                          | 3.24                          |
| 4.  | Water      | 4.17                          | 4.17                          | 4.17                          |
| 5.  | Admixture  | 0.13                          | 0.127                         | 0.13                          |

The design of the material composition above is then used for making PCPB mixes and then fresh concrete will be mould using formwork with a size according to plan then the next step is the curing process of the test specimens. Some tests to determine the quality of PCPB are carried out after the curing process and according to the age of the specified concrete blocks.

Hereinafter the test results of physical appearances, compressive strength, infiltration rate, wear test and porosity test as follows below.
Table 2. Results of physical appearance test.

| Variations | Weight (kg) | Sample dimensions (mm) |
|------------|-------------|------------------------|
|            |             | Length | Width | Thickness |
| FA 0%      | 2,07        | 161,52 | 84,46 | 81,55      |
|            | 2,02        | 160,18 | 85,15 | 84,55      |
|            | 2,00        | 162,21 | 82,71 | 84,12      |
| FA 18%     | 2,16        | 161,74 | 83,72 | 83,14      |
|            | 2,18        | 162,16 | 83,97 | 82,75      |
|            | 2,01        | 161,46 | 81,97 | 82,93      |
| FA 21%     | 1,99        | 162,65 | 82,90 | 81,75      |
|            | 2,10        | 160,09 | 85,26 | 80,29      |
|            | 2,16        | 161,35 | 86,20 | 83,37      |

The test results of the physical appearance of PCPB which include measurements of unit weight and dimensions meet the standards required by SNI 03-0691-1996 where the minimum thickness for concrete blocks is 60 mm with a tolerance of + 8%.

Table 3. Compression test results.

| Variations | Age (days) | Average of compression strength (MPa) |
|------------|------------|--------------------------------------|
| FA 0%      | 7          | 5,96                                 |
|            | 14         | 6,86                                 |
|            | 28         | 9,51                                 |
| FA 18%     | 7          | 7,88                                 |
|            | 14         | 7,78                                 |
|            | 28         | 13,05                                |
| FA 21%     | 7          | 7,34                                 |
|            | 14         | 5,38                                 |
|            | 28         | 14,98                                |

Based on the average compressive strength values above it can be concluded that the compressive strength values of PCPB with the addition of FA 18% and FA 21% is higher than without the addition of fly ash. This indicates prove that the addition of fly ash can enhance the compressive strength. However, there was a decrease when the concrete block at the age of 14 days, wherein the addition of FA 18% by 1,27% and the FA 21% by 27%. This can be caused by uneven compaction and density of fly ash which is dense enough to speed up setting time. At the age of 28 days, the compressive strength of concrete blocks increased 41% at FA 18% and 65% at FA 21%.

Table 4. Infiltration test results

| Variations | Pre-wetting (s) | Time of absorption (s) | Weight of water (lbs) | Diameter (in) | Constant (in.²/lbs.hour) | Infiltration rates (in/hour) |
|------------|-----------------|------------------------|-----------------------|---------------|--------------------------|------------------------------|
| FA 0%      | 12,55           | 36,49                  | 40                    | 12            | 126,87                   | 0,96                         |
| FA 18%     | 13,44           | 39,32                  |                       |               |                          | 0,89                         |
| FA 21%     | 23,17           | 12,88                  |                       |               |                          | 0,71                         |

Based on the results of infiltration rate testing, the fastest rate value is at FA 0% while the addition of FA 18% and 21% results are lower. This shows that the more percentage addition of fly ash can slower the rate of infiltration due to the characteristic of fly ash as a filler which can increase internal cohesion.
and reduce the porosity of the transition area within concrete blocks so that the infiltration speed decreases.

The wear resistance test results at FA 0% is 0.29 mm/min, at FA 18% and 21% is 0.26 mm/min on average. Based on wear resistance values, it can be concluded that with the addition of fly ash, porous concrete blocks have a good trend (regression value) because it tends to be denser than without fly ash.

In porosity testing, the average porosity values for FA 0%, 18% and 21% respectively are 20.45%, 16.06%, 15.09%. This value still meets the porosity value required by ACI 522R-10, which is between 15% - 35%. The higher levels of the addition of fly ash decreases its porosity due to the nature of the fly ash as a filler which makes the concrete more solid.

4. Conclusion

Based on the test results of compressive strength, infiltration rate, wear resistance and porosity that have been done, it can be concluded that PCPB with the addition of fly ash 18% and 21% can be classified as C quality paving blocks that can be applied for pedestrian paths or sidewalk [8] with minimum compressive strength value of at 13.05 MPa and wear resistance of 0.26 mm/min. The compressive strength of this research is higher than former study of PCPB [21] where the compressive strength range is 6.54 to 8.86 MPa.

Acknowledgments

The authors would like to thank the Faculty of Engineering, Jakarta State University for providing grant funds so that this research can be carried out properly. The author is extremely grateful to colleagues who have collaborated in completing this article.

References

[1] Liu Y, Li T and Yu L 2019 Urban heat island mitigation and hydrology performance of innovative permeable pavement: A pilot-scale study J. Clean. Prod.
[2] Petrova T, Chistyakov E and Makarov Y 2018 Methods of road surface durability improvement Transp. Res. Procedia 36 586–90
[3] Cui T, Long Y and Wang Y 2019 Choosing the LID for urban storm management in the south of taiyuan basin by comparing the storm water reduction efficiency Water 11
[4] Putri E E, Yuliet R, Hoo S C, Mannan A, Silas L, Hashim W, Ibrahim W, Kabit M R and Tasnim S 2020 stormpav green pavement the environmentally friendly pavement 4th ICEEDM 05008 3–8
[5] Guo W and Liao H 2015 Optimum coverage ratio of permeable pavement for rainwater infiltration of car park Procds. of the 16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering pp 2–5
[6] Comitee A 2010 ACI 522R-10 Report on Pervious Concrete
[7] Kováč * M and Šiščáková A 2018 Pervious concrete as an environmental solution for pavements: focus on key properties Environments
[8] Indonesia S N and Nasional B S 1996 Bata beton
[9] Peng H, Yin J and Song W 2018 Mechanical and hydraulic behaviors of eco-friendly pervious concrete incorporating fly ash and blast furnace slag Appl. Sci. 8
[10] Li L G, Feng J J, Zhu J, Chu S H and Kwan A K H 2019 Pervious concrete: effects of porosity on permeability and strength Mag. Concr. Res. 1–35
[11] Opiso E M, Supremo R P and Perodes J R 2019 Heliyon Effects of coal fly ash and fine sawdust on the performance of pervious concrete Heliyon 5
[12] Joung Y and Grasley Z C 2008 Evaluation and optimization of durable pervious concrete for use in urban areas vol 7
[13] Admure A M, Gandhi A V, Adsul S S, Agarkar A A, Bhor G S and Kolte G P 2017 Experimental evaluation of characteristics of pervious concrete pavement with fly ash Internartional J. Innov. Res. Sci. Eng. Technol. 6
[14] Mallisa H and Turuallo G 2017 The maximum percentage of fly ash to replace part of original Portland cement (OPC) in producing high strength concrete AIP Conference Proceedings vol 1903

[15] Namarak C, Bumrungsri C and Tangchirapat W 2018 Development of concrete paving blocks prepared from waste materials without portland cement Mater. Sci. 24

[16] Prihutami P, Sediawan W B and Astuti W 2020 Effect of temperature on rare earth elements recovery from coal fly ash using citric acid Int. Conf. Chem. Eng. UNPAR

[17] Nurwidayati R, Ekaputri J and Suprobo P 2019 Bond behaviour between reinforcing bars and geopolymer concrete by using pull-out test ICSBE 4008

[18] Sika 2018 Product Data Sheet SikaMix-10 NT

[19] International A 2009 ASTM C 1701/C 1701M-09 Standard Test Method for Infiltration Rate of In Place Pervious Concrete

[20] International A 2008 ASTM C 642-06 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

[21] Muthaiyan U M and Thirumalai S 2017 Studies on the properties of pervious fly ash – cement concrete as a pavement material Cogent Eng. 13