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Study on Mechanical and Durability Properties of East Borneo Double Layer Porous Concrete Paving Block

Yudi Pranoto [1, 2*], Nor Fazilah Hashim [1], Tumingan [2], Daru Purbaningtyas [2]

[1] *Faculty of Technology and Informatics Razak, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra 54100, Kuala Lumpur, Malaysia.*

[2] *Civil Engineering Department, Samarinda State Polytechnic, Jalan Ciptomangunkusumo 75131, Samarinda, East Kalimantan, Indonesia.*

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Abstract

Massive infrastructure development in East Borneo has reduced the water catchment area. One of the efforts to overcome this is by implementing porous paving with superplasticizer and local materials to improve quality, overcome material scarcity, and save costs. The purpose of this study was to determine the best layer variation of porous paving using Palu and Senoni materials with variations of 1/4, 1/2, and 3/4 of Senoni aggregate. In this study, the test object was made in the form of a beam with a quality of concrete planned at K300 MPa according to the compressive strength, flexural strength, porosity, and permeability values tested at the ages of 7, 14, 21, and 28 days. Based on the results, the variant layer of 1/4 Senoni obtained maximum compressive strength, flexural strength, porosity, and permeability of 17.306 MPa, 3.984 MPa, 18.120%, and 0.216 cm/second at the age of 28 days, respectively. Thus categorized this combination as C quality. Which was included in the C quality group with an application as a pedestrian area. According to the permeability result, double-layer porous paving can accelerate water absorption on the surface to prevent waterlogging when it rains. The increasing variation of layers in double-layer porous paving affects the compressive strength, flexural strength, porosity, and permeability.

Keywords: Paving Porous Double Layer; Senoni Material; Palu Material; Compressive Strength; Porosity.

1. Introduction

Several cities in Indonesia experience flooding problems due to high rainfall and also because the land is closed, which can absorb rainwater inward. One of them is in Samarinda City. Many vacant lands that previously functioned as water catchment areas are now covered by the construction of housing, buildings, shopping centers, and road pavements that mostly use asphalt or concrete. These materials have waterproof properties, which causes puddles on the road surface. To overcome these problems, it is necessary to create road construction using materials to increase water catchment areas, one of which is porous paving.

The characteristic of porous paving with high porosity and permeability causes water to pass through the pavement, reducing runoff and refilling groundwater [1]. The weakness of porous paving is that it has low compressive strength. This is because there are cavities in the mixture [2–4]. Previous studies have been carried out to increase the compressive strength of porous paving, including using fly ash [5-7], using fiber [8, 9], and using porous paving, whose compressive strength is inversely proportional to its permeability [4, 10, 11]. To maximize the function of porosity in porous concrete, Manan et al. maximize the use of sand to increase the compressive strength of porous concrete [12].

* Corresponding author: pranoto@graduate.utm.my

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Porous paving with high permeability has low compressive strength; thus, a superplasticizer was used to improve the quality of porous paving in this study. Superplasticizer is a chemical admixture mostly used to improve implementation performance [5, 13, 14]. One type of superplasticizer is Sikament-NN, which can be used with a dose of 0.3–2.3% of the cement weight, depending on the workability and compressive strength of the planned concrete [10]. Based on the trend test results, the average compressive strength graph has increased by increasing the percentage by 1.3% and 1.8% and has decreased with the addition of 2.3% [9]. The optimum concrete compressive strength is obtained by adding a superplasticizer content of 2% [15]. In addition to using added materials to improve the quality of porous paving, using local materials as construction materials is needed to overcome material scarcity and save costs.

When viewed by the number of layers, porous concrete consists of two types. The first is 1-layer porous concrete [16]. This type of porous concrete is more commonly used because it is easier and faster. Like the research conducted by Liu et al. [17] and Gomez et al. [18]. Second is two-layer porous concrete, as done by Euniza et al. This study uses two types of materials that have different qualities to maximize the function of each layer [19].

Road construction, particularly in Samarinda, still depends on the supply of materials imported from Central Sulawesi. Therefore, the use of local materials as alternative construction materials needs to be developed. From Table 1, the results of testing local aggregates in East Kalimantan show that the use of Senoni aggregates in concrete mixtures produces the highest compressive strength value compared to aggregates from other regions. In terms of texture, Senoni aggregate is good for concrete mixes.

Table 1. East Kalimantan aggregate test results (Abdi et al. (2019) [20])

Properties	Coarse Aggregate					Specification
	Senoni	Log Iram	Batu Besaung	Penajam	Sambera	
Water content	0.32%	1.10%	0.45%	0.85%	1.12%	3 – 5%
Mud content	0.92%	0.98%	0.29%	1.06%	1.53%	1%
Specific gravity	2.64	2.62	2.55	2.66	2.66	2.5 – 2.7
Water absorption	0.44%	1.12%	0.88%	2.05%	2.05%	Max. 3%
Fineness modulus	7.9	7.3	8	8	8	5 – 8
Mix fineness modulus	6.2	5.9	6	5.7	5.5	5 – 6
Eternity	0.7%	1.40%	6.30%	8.50%	10.80%	Max. 12%
Abrasion	22.70%	25.35%	26.48%	25.71%	25.40%	Max. 40%

In addition, the long distance between Samarinda City and Palu City, which has to cross the island, causes shipping costs to be more expensive and the impact on Palu material prices to be more expensive compared to local materials. So, using local materials can save on construction costs and be more economical. Based on this, the researchers tried to combine the use of these materials in the manufacture of double-layer porous paving to find out the best layer variations using Palu and Senoni chipping materials, as well as using superplasticizer-added materials to improve the quality of double-layer porous paving, which will be applied to infrastructure development in Samarinda.

2. Materials and Methods

2.1. Methods

In this research, several stages are needed to get results in accordance with the objectives to be achieved. The implementation steps are explained in the following flowchart (Figure 1).

2.2. Materials

A paving block is a building material made from a mixture of Portland cement, water, and aggregate with or without additives that do not reduce the quality of the concrete [21]. The physical properties based on the quality of concrete brick are shown in Table 2 [22]. There are four types of quality: A, B, C, and D, which categorized into suitable applications.

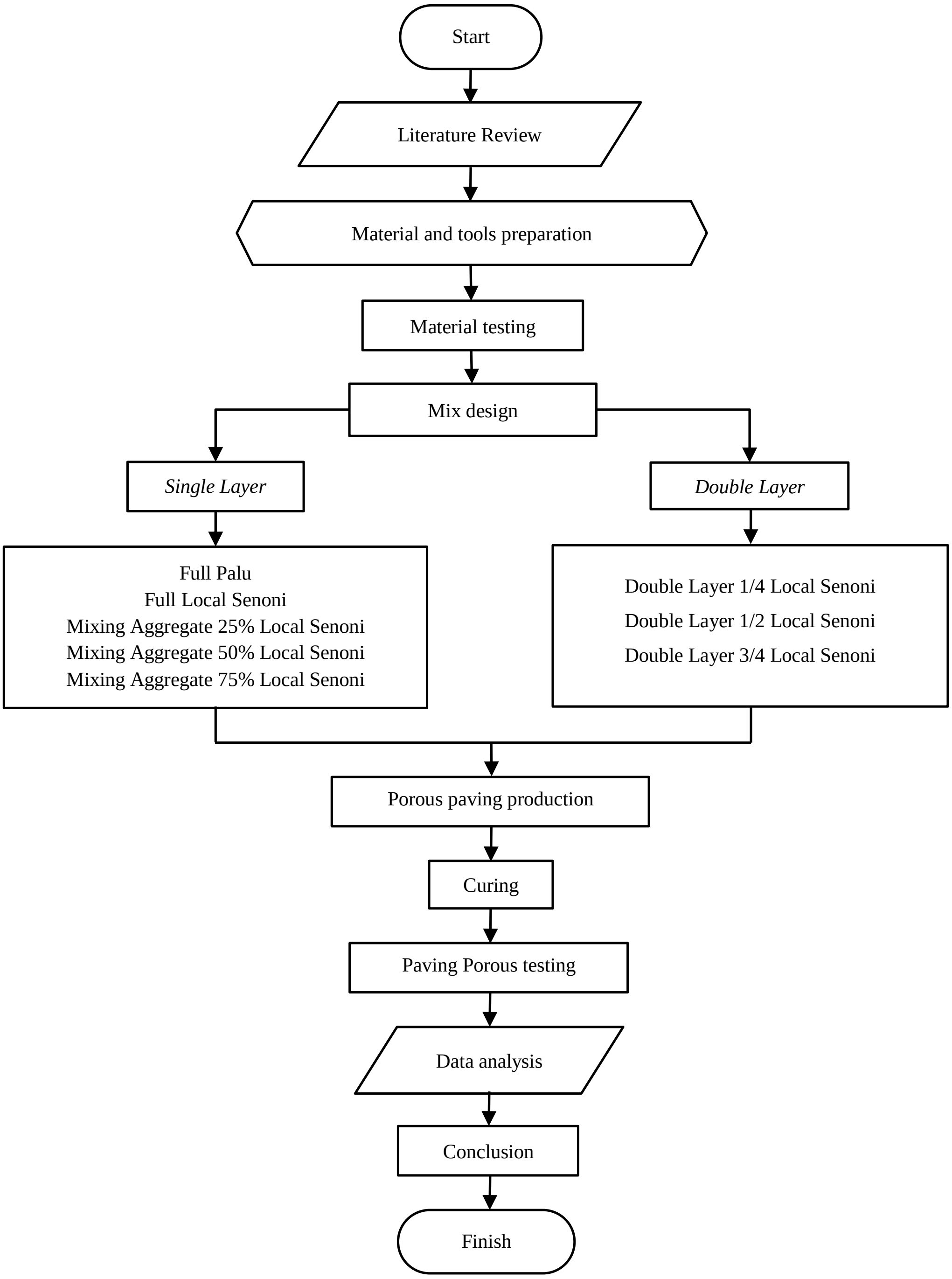


Figure 1. Research flow chart

Table 2. Physical Properties

Quality	Application	Compressive Strength (MPa)		Wear Resistance (mm/minute)		Maximum water absorption (%)
		Average	Min	Average	Min	
A	Road	40	35	0.090	0.103	3
B	Parking	20	17	0.130	0.149	6
C	Pedestrians	15	12.5	0.160	0.184	8
D	Parks	10	8.5	0.219	0.251	10

Porous paving is concrete without sand with a void so water can pass through. Porous paving is made from a mixture of cement, aggregate, water, and other materials without reducing the quality of the porous paving. Material testing is carried out to determine the characteristics, quality, and other parameters needed in the porous paving mix design. Material testing is carried out on all materials used in the porous paving mixture. Results on the testing of Tonasa cement, Palu, and Senoni chipping are shown in Tables 3 and 4.

Table 3. Properties of Tonasa cement

Properties	Standard Test Method	Specification	Results	Information
Normal Consistency	SNI 03-6826-2002 [22]	24–30%	24.3%	Qualify
Setting Time	SNI 03-6827-2002 [23]	45–375 minutes	80 minutes	Qualify
Specific Gravity	SNI 15-2531-2015 [24]	3.00–3.20	3.06	Qualify

Table 4. Properties of Palu and Senoni chipping

Properties	Standard Test Method	Specification	Results		Information
			Palu	Senoni	
Specific Gravity	SNI 03-1969-2008 [25]	2.5 – 2.7	2.66	2.64	Qualify
Water Absorption		Max. 3%	1.85%	1.87%	Qualify
Fineness Modulus	SNI 03-1968-1990 [26]	5 – 8	7.62	7.58	Qualify
Water Content	SNI 03-1971-2011 [27]	Max. 2.5%	0.70%	0.70%	Qualify
Unit Weight	SNI 03-4804-1998 [28]	Min. 1.3 gr/cm³	1.51 gr/cm³	1.52 gr/cm³	Qualify
Mud Content	SNI 03-4141-1996 [29]	1%	0.75%	0.10%	Qualify
Abrasion	SNI 03-2417-2008 [30]	40%	20.44%	22.07%	Qualify

The cement used to manufacture double-layer porous paving is PCC cement (Portland Cement Composite) type I product Tonasa. The aggregate used to manufacture double-layer porous paving is Palu and Senoni chipping from PT. Borneo Prima Material and PT. Bumi Sinar Kencana Company, which passed the 3/8” sieve and was retained on the No. 8 sieve with an aggregate size of 2.36–9.5 mm. The properties of the quality of Palu and Senoni chipping are shown in Table 4.

The superplasticizer used to manufacture double-layer porous paving is Sikament-NN-type Naphthalene Formaldehyde Sulphonate from supplier Sika Balikpapan. The properties of Sikament-NN are listed in Table 5 [31].

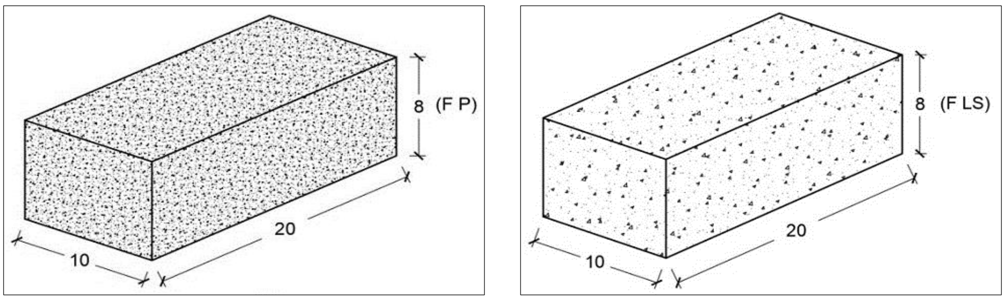
Table 5. Properties of Sikament-NN

Technical Data	
Type	Modified Naphthalene Formaldehyde Sulphonate
Color	Dark Brown
Specific gravity	± 1.17 – 1.19 kg/liter
Age and Storage	At least one year if stored in the original unopened packaging in a dry, cool and shady place
Packaging	Drums 240 kg

Based on the results in Tables 3 to 5, testing on Tonasa cement, Palu and Senoni chipping, and Sikament-NN technical data indicate that the materials conform to the Indonesian National Standard for porous concrete mixtures.

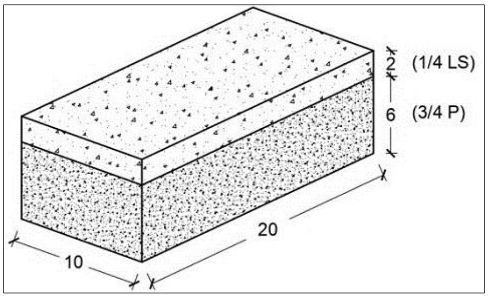
2.3. Test Preparation

The mix design in this study refers to ACI 522R-10 for porous concrete, which uses a superplasticizer with the absence of fine aggregate. In the design of this porous paving mix, a composition of 1 m³ of concrete will be obtained for the porous paving mix with a length of 20 cm, a width of 10 cm, and a thickness of 8 cm. The design of the porous paving composition with various layer combinations is shown in Figure 2, and the total number of tests conducted on the block is shown in Table 6.

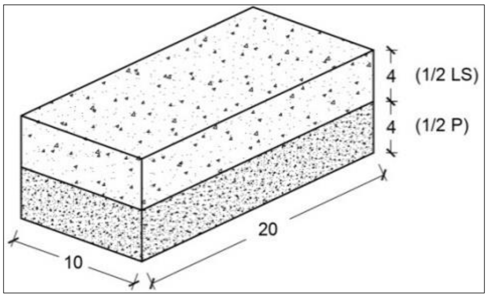


(a) Paving porous full Palu

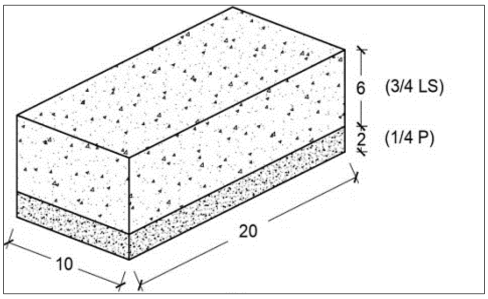
(b) Paving porous full Senoni



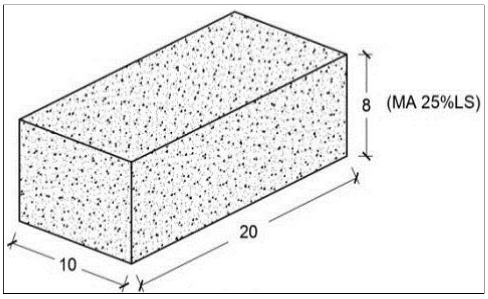
(c) Paving porous double layer 1/4 Senoni



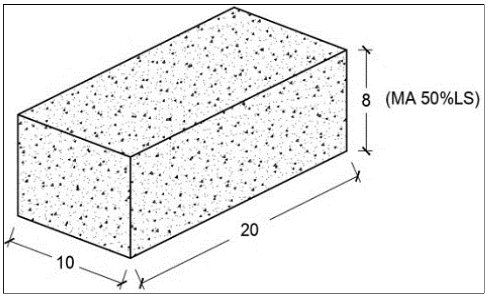
(d) Paving porous double layer 1/2 Senoni



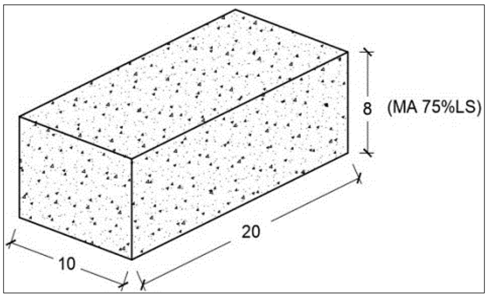
(e) Paving porous double layer 3/4 Senoni



(f) Paving porous mixing aggregate 25% Senoni



(g) Paving porous mixing aggregate 50% Senoni



(h) Paving porous mixing aggregate 75% Senoni

Figure 2. Dimensions and variations of porous paving layers-(a) Paving porous full Palu (b) Paving porous full Senoni (c) Paving porous double layer 1/4 Senoni (d) Paving porous double layer 1/2 Senoni (e) Paving porous double layer 3/4 Senoni (f) Paving porous mixing aggregate 25% Senoni (g) Paving porous mixing aggregate 50% Senoni (h) Paving porous mixing aggregate 75% Senoni.

Table 6. Total of test objects

Variation	Compressive Strength				Flexural Strength				Porosity and Permeability				Results
	Age (Days)												
	7	14	21	28	7	14	21	28	7	14	21	28	
PPFP	3	3	3	3	-	-	-	3	-	-	-	3	18
PPDL-0.25S	3	3	3	3	-	-	-	3	-	-	-	3	18
PPMA-25%S	3	3	3	3	-	-	-	3	-	-	-	3	18
PPDL-0.5S	3	3	3	3	-	-	-	3	-	-	-	3	18
PPMA-50%S	3	3	3	3	-	-	-	3	-	-	-	3	18
PPDL-0.75S	3	3	3	3	-	-	-	3	-	-	-	3	18
PPMA-75%S	3	3	3	3	-	-	-	3	-	-	-	3	18
PPFS	3	3	3	3	-	-	-	3	-	-	-	3	18
Total													**144**

Remarks: PPFP= Paving Porous Full Palu; PPDL-0.25S= Paving Porous Double Layer 1/4 Senoni; PPMA-25%S= Paving Porous Mixing Aggregate 25% Senoni; PPDL-0.5S= Paving Porous Double Layer 1/2 Senoni; PPMA-50%S= Paving Porous Mixing Aggregate 50% Senoni; PPDL-0.75S= Paving Porous Double Layer 3/4 Senoni; PPMA-75%S= Paving Porous Mixing Aggregate 75% Senoni; PPFS= Paving Porous Full Senoni.

Based on Table 6, the total of testing porous paving and making the job mix formula following ACI 522R-10 obtained the results of material requirements for each variation of mixture double layer porous paving, aggregate mixing, and porous cube from Palu and Senoni chipping materials, which are shown in Tables 7 and 8.

Table 7. Paving and cube porous mix design Palu chipping

Variation	Total	Volume	Material Requirements			
			Cement	Sikament-NN	Water	Palu Chipping
KP	12	0.049	16.15	0.332	4.154	71.665
PPFP	24	0.035	11.15	0.236	2.954	50.962
PPDL-0.75P	24	0.026	8.862	0.177	2.215	38.222
PPMA-75%P	24	0.035	8.862	0.177	2.215	38.222
PPDL-0.5P	24	0.017	5.908	0.118	1.477	25.481
PPMA-50%P	24	0.035	5.908	0.118	1.477	25.481
PPDL-0.25P	24	0.009	2.954	0.059	0.738	12.741
PPMA-25%P	24	0.035	2.954	0.059	0.738	12.741
Total			**63.877**	**1.278**	**15.969**	**275.513**

Table 8. Paving and cube porous mix design Senoni chipping

Variation	Total	Volume	Material Requirements			
			Cement	Sikament-NN	Water	Senoni Chipping
KS	12	0.049	16.615	0.332	4.154	71.846
PPFP	24	0.035	11.815	0.236	2.954	51.091
PPDL-0.25S	24	0.009	2.954	0.059	0.738	12.773
PPMA-25%S	24	0.035	2.954	0.059	0.738	12.773
PPDL-0.5S	24	0.017	5.908	0.118	1.477	25.545
PPMA-50%S	24	0.035	5.908	0.118	1.477	25.545
PPDL-0.75S	24	0.026	8.862	0.177	2.215	38.318
PPMA-75%S	24	0.035	8.862	0.177	2.215	38.318
Total			**63.877**	**1.278**	**15.969**	**276.209**

Making porous paving is similar to making concrete without sand. However, it is still necessary to pay attention to accuracy so that the porous concrete produced is in accordance with what is expected. Mixing porous concrete can be divided into two, manually or using a machine (Molen). The difference between making double-layer porous paving and mixing aggregate lies in the method of manufacture; double-layer porous paving is made in layers based on the planned variation of layers, while for porous mixing, the aggregates used are mixed into one homogeneous mixture. The samples were made using a hydraulic paving block press (250 kg/m³) and vibrated for 4 seconds using a vibrator until solid. The end of making porous double-layer paving and mixing aggregates is removed from the hydraulic press to continue curing the test specimens using burlap sacks that have been moistened with water for ± 1 day to avoid unwanted heat of hydration and ensure hydration reactions of cement compounds, including additives, can take place optimally so that the expected quality of concrete can be achieved. Next, the double-layer porous paving and aggregate mixing were dried in the sun to reduce the volume of water contained in the sample after the treatment process. Samples that have been made and treated will be tested, and the data will be taken for later processing test results, which will later conclude the data.

2.4. Test Method

2.4.1. Compressive Strength

This test aims to determine the pressure's strength at the age of 7, 14, 21, and 28 days. The compressive strength of the porous concrete obtained ranges from 2.8−28 MPa [15]. Compressive strength testing uses a compression testing machine. In general, the compressive strength of double-layer porous paving is calculated using Equation 1:

$$f_c' = \frac{P}{A} \tag{1}$$

with $f'c$ is compressive strength (MPa), P is maximum load (N), and A is cross-sectional area (mm^2).

2.4.2. Flexural Strength

This test purposes to determine the flexural strength at the age of 28 days that was conducted using a hydraulic concrete beam testing machine. The flexural strength of the porous concrete obtained is in the range of 1–3.8 MPa [15].

In general, the flexural strength of double-layer porous paving is calculated using Equation 2 [3].

$$R = \frac{3.P.L}{2.b.d^2} \tag{2}$$

with R is modulus of rupture (MPa), P maximum load (N), L is span length (mm), b is average width of a specimen at the fracture (mm), d is average depth of specimen at the fracture (mm).

2.4.3. Porosity

The porosity test is to determine the percentage of voids at the age of 28 days. Porosity testing is based on comparing the weight of water and air in the sample with the weight of the solid sample using digital and water scales. The porosity value of the porous concrete obtained ranges from 15–35% [15]. In general, the porosity of double-layer porous paving is calculated using Equation 3 [4].

$$n = \frac{B-A}{B-C} \times 100\% \tag{3}$$

with n is volume of permeable pore space (voids) (%), A is mass of oven-dried sample in the air (gr), B is mass of surface-dry sample in the air (gr), C is apparent mass of sample in water (gr).

2.4.4. Permeability

Permeability test is to determine the speed of water flows through the sample at the age of 28 days using a permeability measuring machine. The permeability value of the porous concrete obtained is in the range of 0.14–1.22 cm/second [15]. In general, the permeability of double-layer porous paving is calculated using Darcy law with the Equation 4.

$$\frac{dq}{A.dt} = k\frac{dh}{L} \tag{4}$$

with dq is water volume (m^3), dt is flow time (s), A is cross-sectional area (m^2), dh is falling water height (m), L is thickness of the sample (m), and k is permeability coefficient (m/s).

3. Results and Discussion

3.1. Porous Paving Test Results

Data analysis of the test results was carried out to determine the porous paving mixture's variation in the compressive strength, flexural strength, porosity, and permeability values. The data from the recapitulation of porous paving tests at the age of 28 days is shown in Table 9.

Table 9. Recapitulation of porous paving test results at the age of 28 days

Variation	Compressive Strength (MPa)	Flexural Strength (MPa)	Porosity (%)	Permeability (cm/second)
PPFP	18.542	4.531	17.385	0.208
PPDL-0.25S	16.440	3.984	18.120	0.216
PPMA-25%S	18.102	4.453	17.436	0.209
PPDL-0.5S	16.006	3.828	18.551	0.219
PPMA-50%S	17.697	4.297	17.710	0.211
PPDL-0.75S	15.623	3.672	18.978	0.222
PPMA-75%S	17.233	4.063	17.990	0.214
PPFS	15.265	3.594	19.111	0.223

Based on Table 9, in the variation of full Palu porous paving, the highest compressive and flexural strength values are 18.542 MPa and 4.531 MPa, where the lowest porosity and permeability values are 17.383% and 0.208 cm/second. The variation of full Senoni porous paving obtained the lowest compressive and flexural strength values of 15.265 MPa and 3.594 MPa, where the largest porosity and permeability values were 19.111% and 0.223 cm/second. The variation of porous paving using layer and mixing methods results in compressive strength, flexural strength, porosity, and permeability values between the limits of the full Palu and Senoni porous paving. The variation of mixing porous paving with 25% Senoni aggregate obtained the highest compressive and flexural strength values of 18.102 MPa and 4.453 MPa, while the lowest porosity and permeability values were 17.436% and 0.209 cm/second. The variation of double-layer porous paving 3/4 Senoni obtained the lowest compressive and flexural strength values of 15.623 MPa and 3.672 MPa, where the largest porosity and permeability values were 18.978% and 0.222 cm/second.

3.2. Relations Between Compressive Strength, Flexural, Porosity, and Permeability

The relationship between compressive strength, flexural strength, porosity, and permeability of double-layer porous paving and aggregate mixing is used to determine the best layer variation using Palu and Senoni chipping materials and using superplasticizer as an added material to achieve optimum results. The relationship between the values of compressive strength, flexural strength, porosity, and permeability can be shown in Figures 3 to 6.

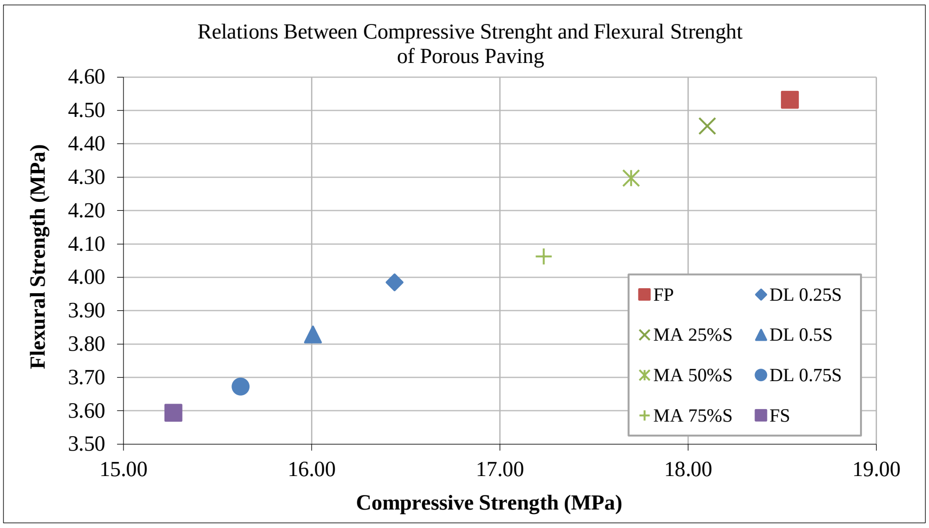


Figure 3. Relations between Compressive Strength and Flexural Strength of Porous Paving

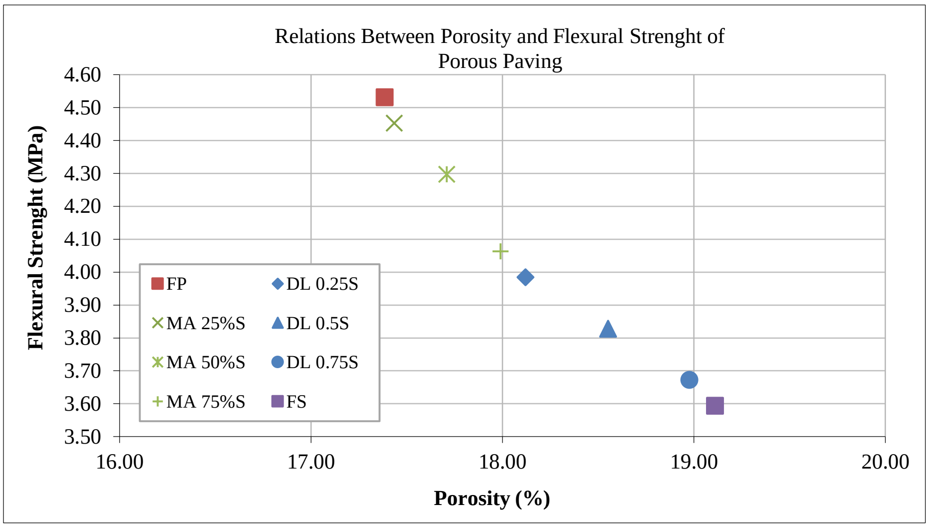


Figure 4. Relations Between Porosity and Flexural Strength of Porous Paving

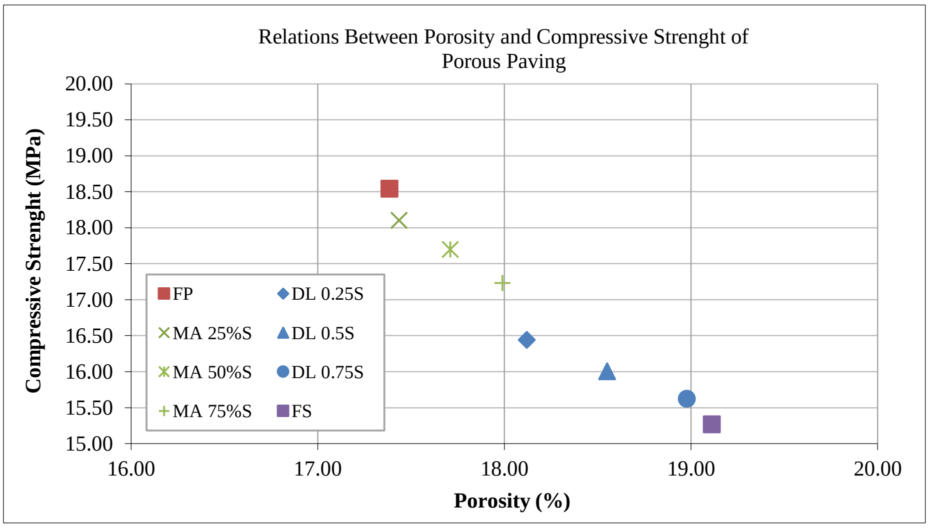


Figure 5. Relations between Porosity and Compressive Strength of Porous Paving

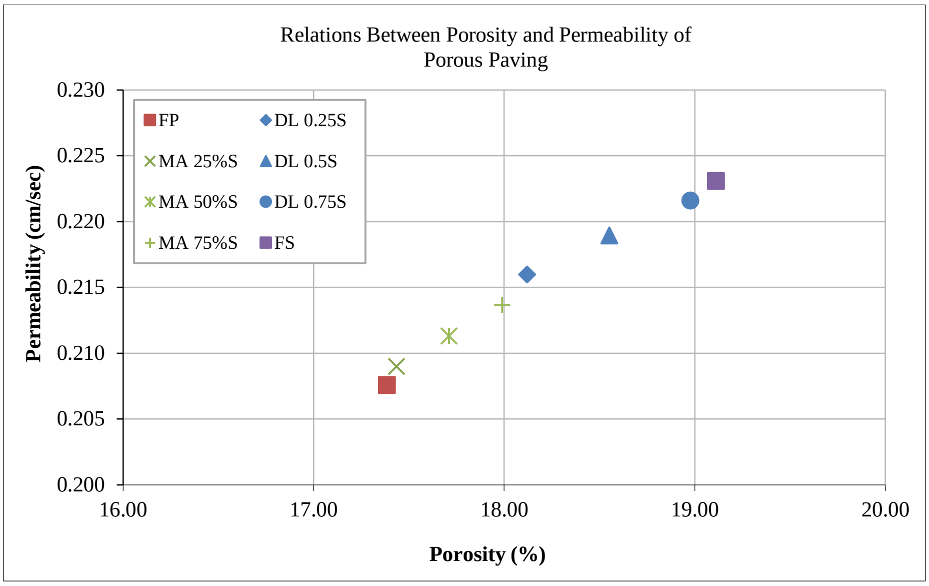


Figure 6. Relations between Porosity and Permeability of Porous Paving

Based on Figures 2 to 5, it can be concluded that the compressive strength of porous paving is directly proportional to the value of flexural strength but inversely proportional to the values of porosity and permeability. The greater the compressive strength and flexural strength of porous paving, the smaller the porosity and permeability of porous paving, and vice versa. This is because in the case of large pores, the friction between the aggregates will be greater and the bonds between the aggregates will be weaker, hence the compressive strength will decrease. As for the variation of porous paving using the mixing method, it has a higher compressive strength value because the aggregates are spread evenly and the aggregate mixture obtained is quite maximal because the aggregates bind to each other, in contrast to using the layer method, where there is a barrier between Senoni chipping layers and chipping Palu, so that when testing the compressive strength of the top layer, it first collapses, which causes the aggregate bond to become weaker and the compressive strength to decrease significantly.

3.3. Porous Paving Quality Group

Based on the calculation of the average compressive strength of all variations of porous paving, then grouping the quality of porous paving for each variation by SNI 03-0961-1996 is categorized into two groups, B and C, as shown in Table 10.

Table 10. Quality group and implementation of porous paving

Variation	Compressive Strength (MPa)	Quality Paving Porous	Application Paving Porous
PPFP	18.542	B	Parking
PPDL-0.25S	16.440	C	Pedestrians
PPMA-25%S	18.102	B	Parking
PPDL-0.5S	16.006	C	Pedestrians
PPMA-50%S	17.697	B	Parking
PPDL-0.75S	15.623	C	Pedestrians
PPMA-75%S	17.233	B	Parking
PPFS	15.265	C	Pedestrians

From the quality grouping data in Table 10, for variations of full Palu porous paving, mixing aggregates porous paving 25%, 50%, and 75% Senoni with compressive strength values of 18.542 MPa, 18.102 MPa, 17.697 MPa, and 17.233 MPa are included in the B quality group with implementation as a place for parking. Variations of double-layer porous paving 1/4, 1/2, and 3/4, as well as full Senoni porous paving with compressive strength values of 16.440 MPa, 16.006 MPa, 15.623 MPa, and 15.265 MPa, are included in the C quality group with implementation as a pedestrian area.

4. Conclusion

Increasing layer variation in double-layer porous paving affects compressive strength, flexural strength, porosity, and permeability. The larger the Senoni chipping layer above the Palu chipping layer, the smaller the compressive strength and flexural strength, which are inversely proportional to the greater porosity and permeability. The test results state that the best variation of double-layer layers is a double-layer porous paving with a 1/4 cm Senoni on the first layer and a 3/4 cm Palu on the second layer. Compared with other variations, the values of compressive strength, flexural strength, porosity, and permeability, respectively, are 16.440 MPa, 3.984 MPa, 18.120%, and 0.216 cm/second. Based on the requirements for the compressive strength of paving blocks in SNI 03-0691-1996 "Paving Blocks", the variation of the double layer porous paving 1/4, 1/2, and 3/4 Senoni with the compressive strength values of 16.440 MPa, 16.006 MPa, and 15.623 MPa is included in the C quality group with application as a pedestrian area.

5. Declarations

5.1. Author Contributions

Conceptualization, Y.P., N.F.H., T.M., and D.P.; methodology, Y.P., N.F.H., T.M., and D.P.; formal analysis, Y.P. and N.F.H.; resources, Y.P., N.F.H., T.M., and D.P.; writing—original draft preparation, Y.P., N.F.H., T.M., and D.P.; writing—review and editing, Y.P., N.F.H., T.M., and D.P. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Rifqi, M. G., Amin, M. S., & Lesmana, Y. I. (2018). Karakteristik Paving Berongga Menggunakan Material Batu Kali Bulat Berbasis Ramah Lingkungan. Potensi: Jurnal Sipil Politeknik, 20(1), 28–32. doi:10.35313/potensi.v20i1.1000.

[2] Xie, N., Akin, M., & Shi, X. (2019). Permeable concrete pavements: A review of environmental benefits and durability. Journal of Cleaner Production, 210, 1605–1621. doi:10.1016/j.jclepro.2018.11.134.

[3] Razzaghmanesh, M., & Beecham, S. (2018). A review of permeable pavement clogging investigations and recommended maintenance regimes. Water (Switzerland), 10(3). doi:10.3390/w10030337.

[4] Kuruppu, U., Rahman, A., & Rahman, M. A. (2019). Permeable pavement as a stormwater best management practice: a review and discussion. Environmental Earth Sciences, 78(10), 1–20. doi:10.1007/s12665-019-8312-2.

[5] Mulyono, T., & Anisah. (2019). Laboratory Experiment: Pervious Concrete for Permeable Pavement, Focus in Compressive Strength and Permeability. IOP Conference Series: Earth and Environmental Science, 366(1), 012019. doi:10.1088/1755-1315/366/1/012019.

[6] Jonbi, J., & Fulazzaky, M. A. (2020). Modeling the water absorption and compressive strength of geopolymer paving block: An empirical approach. Measurement, 158, 107695. doi:10.1016/j.measurement.2020.107695.

[7] Maharana, G., Jena, B., & Panda, S. (2020). A Study On Mechanical And Durability Properties Of Interlocking Fly Ash Based Concrete Paver Block Using Different Types Chopped Fibers. Journal of Xi'an University of Architecture & Technology, 12(5), 6–9.

[8] Junaid, M., Shah, M. Z. A., Yaseen, G., Awan, H. H., Khan, D., & Jawad, M. (2022). Investigating the Effect of Gradation, Temperature and Loading Duration on the Resilient Modulus of Asphalt Concrete. Civil Engineering Journal, 8(2), 278-289. doi:10.28991/CEJ-2022-08-02-07.

[9] Limantara, A. D., Winarto, S., Gardjito, E., Subiyanto, B., Raharjo, D., Santoso, A., Sudarmanto, H. L., & Mudjanarko, S. W. (2018). Optimization of standard mix design of porous paving coconut fiber and shell for the parking area. AIP Conference Proceedings. doi:10.1063/1.5062655.

[10] Zhang, J., Ma, G., Dai, Z., Ming, R., Cui, X., & She, R. (2018). Numerical study on pore clogging mechanism in pervious pavements. Journal of Hydrology, 565, 589–598. doi:10.1016/j.jhydrol.2018.08.072.

[11] Liu, Q., Liu, S., Hu, G., Yang, T., Du, C., & Oeser, M. (2021). Infiltration Capacity and Structural Analysis of Permeable Pavements for Sustainable Urban: A Full-scale Case Study. Journal of Cleaner Production, 288, 125111. doi:10.1016/j.jclepro.2020.125111.

[12] Manan, A., Ahmad, M., Ahmad, F., Basit, A., & Ayaz Khan, M. N. (2018). Experimental Investigation of Compressive Strength and Infiltration Rate of Pervious Concrete by Fully Reduction of Sand. Civil Engineering Journal, 4(4), 724. doi:10.28991/cej-0309127.

[13] Nistratov, A. V., Klimenko, N. N., Pustynnikov, I. V., & Vu, L. K. (2022). Thermal Regeneration and Reuse of Carbon and Glass Fibers from Waste Composites. Emerging Science Journal, 6(5), 967-984. doi:10.28991/ESJ-2022-06-05-04.

[14] Irlan, A. O., Rintawati, D., & Paikun, P. (2020). Literature Study of Porous Concrete with the Addition of Fly Ash, Superplasticizer, and Fibers on Compressive Strength. Kilat, 9(2), 171-180. (In Indonesian).

[15] ACI 522R-10. (2010). Report on Pervious Concrete, American Concrete Institute (ACI), Michigan, United States.

[16] Andres-Valeri, V. C., Juli-Gandara, L., Jato-Espino, D., & Rodriguez-Hernandez, J. (2018). Characterization of the infiltration capacity of porous concrete pavements with low constant head permeability tests. Water (Switzerland), 10(4), 480. doi:10.3390/w10040480.

[17] Liu, Y., Zhuge, Y., Chow, C. W. K., Keegan, A., Li, D., Pham, P. N., Huang, J., & Siddique, R. (2020). Utilization of drinking water treatment sludge in concrete paving blocks: Microstructural analysis, durability and leaching properties. Journal of Environmental Management, 262, 110352. doi:10.1016/j.jenvman.2020.110352.

[18] Gomes, J. P. J., Ponzo, A. P. S., & Oliveira, A. S. de. (2021). Viability of a terrace covered with porous concrete paving blocks for coffee bean drying. Revista Agrogeoambiental, 12(4). doi:10.18406/2316-1817v12n420201523.

[19] Jusli, E., Md. Nor, H., Jaya, R. P., Haron, Z., Yahya, M. N., Azman, M., & Lim, L. K. (2015). Low Noise and Properties of Double Layer Concrete Paving Blocks. ICGSCE 2014, 291–299. doi:10.1007/978-981-287-505-1_34.

[20] Abdi, F. N., Sutanto, H., & Prandaka, E. D. (2019). Effect of Adding Alum to Concrete Mixtures Using Local Coarse Aggregate in East Kalimantan and Fine Aggregate Ex. Mahakam Is Viewed from Compressive Strength. Teknologi Sipil: Jurnal Ilmu Pengetahuan dan Teknologi, 3(1), 50-64. (In Indonesian).

[21] SNI 03-0691-1996. (1996). Bata Beton (Paving block). Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[22] SNI 03-6826-2002. (2002). Normal Consistency Testing Method. Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[23] SNI 03-6827-2002. (2002). Time Setting Test Method. Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[24] SNI 2531:2015. (2015). Hydraulic Cement Density Test Method. Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[25] SNI 1969-2008. (2008). How to test specific gravity and water absorption of coarse aggregate. Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[26] SNI 03-1968-1990 Metode. (1990). Tests on Fine and Coarse Aggregate Sieve Analysis. Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[27] SNI 1971:2011. (2011). How to Test Total Aggregate Water Content by Drying. Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[28] SNI 03-4804-1998. (1998). Test Method for Bulk Weight and Air Voids in Aggregates. Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[29] SNI 03-4141-1996. (1996). Clay Clod Testing Method. Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[30] SNI 03- 2417-2008. (2008). How to Test Aggregate Wear with a Los Angeles Abrasion Machine. Standard Nasional Indonesia (SNI), Jakarta, Indonesia. (In Indonesian).

[31] PT. SIKA. (2017). Product Data Sheet: Sikament ® NN Extra Description, Version 01.01. Bogor, Indonesia. Available online: https://idn.sika.com/dms/getdocument.get/9e1966c9-cc7d-44b3-a81a-31635bfe2309/sikament_nn_extra.pdf (accessed on May 2023).