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Laboratory Experiment: Pervious Concrete for Permeable Pavement, Focus in Compressive Strength and Permeability

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Abstract. The aim of this research was to determine the compressive strength of pervious concrete and permeability based on trials in the laboratory. The method accomplish is an experiment in the laboratory in accordance with appropriate standards and concerned to research. Local material was used in mixtures. Portland Cement Composite with water-cement (W/C) ratio 0.27 to 0.34, aggregates with variations in types and sizes and using ingredients added to fly ash and superplasticizer. Mixture of trial using 4.25 for aggregate-cement ratios (A/C) with proportion of 6% fine aggregate (sand), 15% flay-ash and superplasticizer with low dosages. The test results show a slight difference in compressive strength with variations in W/C including the use of aggregate types. The permeability using of natural aggregate is more porous compared to crushed stone. The effect of aggregate size from small-to-large will result in decreased density (unit weight) and increased void in the mixture. A good agreement was reached in the case of mixtures with 0.30 wcr and aggregate size that passed 12.5 mm sieve and retaining at 9.5 mm to provided compressive strength.
Keywords: pervious concrete, compression strength, infiltration rate

1. Introduction

Climate change can and is producing a wide array of impacts that affect infrastructure on a broad scale. An infrastructure asset's vulnerability to climate change is highly context sensitive, with its location and the adaptive capacity of local businesses, governments, and communities all being influential [1]. Its impacts on transportation systems, and literature is now emerging on how climate change specifically affects pavement systems and what adaptation strategies might be pursued [2]. A traditional pavement on paved surfaces can help reduce runoff by infiltrating rain water. These alternative materials which include pervious asphalt, pervious concrete, interlocking pavers, and plastic grid pavers, allow rain and snowmelt to seep through the surface down to underlying layers of soil and gravel. Permeable pavements can help filter out pollutants that contribute to water pollution [3], and also reduce deleterious content. As a kind of materials applied in road base course and wearing coarse pavement, porous concrete is required to have satisfactory strength, permeability, dynamic stability, scouring resistance and volume stability [4,5]. Permeable pavement or no-fines concrete, this type of concrete is different from conventional concrete squarely due to complete absence of or presence of a fairly small amount of, fine aggregate in its mixtures [6,7]. Pervious concrete over is on the rise due to its environmental advantages, such as reducing tire pavement interaction noise, moderating storm-water runoff, and limiting the pollutants entering groundwater an aggregate storage bed will reduce storm water runoff volume, rate, and pollutants [2,8–12]. Pervious concrete is one of solution to overcome flooding. The impact of flooding can be reduced by providing sustainable material for permeable pavement using pervious concrete. Thousands of people have been affected by flooding in Indonesia over the last few years. When a major new flood event occurs, many people wonder about the link between the extreme event observed and the global phenomenon of climate change, especially as damage caused by floods has increased significantly in recent decades [13]. Losses due to flooding in humans and property are inevitable. However, as our environment changes, so does the need to become increasingly aware of the problems that surround it a specially increasing soil permeability [14].

The main important function is its ability to transport large volumes of water through its pores to the underlying strata, while serving as a pavement for vehicular and pedestrian traffic or local road [15–18]. Due to its highly porous nature, the mechanical properties of PC are different than those of conventional Portland cement concrete (PCC). The amount of cementitious material used per volume of pervious concrete varies, however a good starting point is about 355 kg/m3.Water drainage rates (permeability or percolation) range from 100 to 900 L/min/ m2 of surface. As the void content increases, the water drainage rate through the concrete also increases. If more strength is needed, a small amount of fine aggregate could be added to the mix, but this will reduce the void content and its permeability. Typical compressive strength ranges between 3.5 to 28 MPa, although 17 MPa is common. Slump is usually less than 3". Superplasticizer are used as chemical admixtures to water reduction for affect the water/cementitious ratio, influence workability and setting times. Superplasticizer which permits a high reduction in the water content of a given mix without affecting the consistence, or which increases the slump/flow considerably without affecting the water content; or produces both effects simultaneously [19]. Also, improved compressive and flexural strength, and improved consistence, and enhance mechanical properties and durability by adding ingredients added to minerals in the form of fly ash. Fly ash has been used in concrete at levels ranging from 15% to 25% by mass of the cementitious material component [20,21]. Typically, pervious concrete has a water to cementitious materials ratio (wcr) of 0.35 to 0.45 with a void content of 15 to 25%. The mixture is composed of cementitious materials, coarse aggregate and water with little (5% to 7%) to no fine aggregates [6-7, 22-23].

A void space that comprises porosity is interconnected and rapidly permeable to water movement and is fundamentally different than entrained air captured in the cement paste. Producing pervious concrete with a specific design void content, typically around 20%, allows quality control by determining the design unit weight for a corresponding. The primary considerations when determining a mixture design are [17,23]; strength required for a particular pavement section design; Durability; and Porosity to produce the desired permeability and maximize the required maintenance intervals. Porosity of increases the unit weight decreases linearly. Unit weight relationship, compressive strength decreases with increased porosity. Permeability increases with increased porosity. Permeability tends to be very low (<10 in./hr) below 15% porosity and increases rapidly above 25%.

2. Materials and Methods

The experiment was focused on compression strength and permeability and the utilization of locally available materials (Jakarta, Indonesia), given in following list,

2.1. Material

Portland Cement Composite (PCC), as per Indonesian National Standard/SNI [24] was used for this experiment with proportion 350, 400 and 450 kg/m3. The physical properties of are presented in Table 1. Coarse aggregate used in porous concrete should be clean, hard and from durable [6, 25 – 28]. Two types of locally available coarse aggregate were included in the study, crushed stone and rounded river gravel or natural aggregate [23]. Their physical properties are given in Table 2 and Table 3. Sieve analysis procedure under ASTM C136:2012 for sand and coarse aggregates to gradation analysis. The gradations of the aggregates. Three different grades for coarse aggregate, i.e. the aggregate passing through the 19 mm sieve and retained on the 12.5 mm sieve; passing through 12.5 mm sieve and retained on the 9.5 mm sieve, and the aggregate passing through the 9.5 mm sieve and retained on the 4.75 mm sieve. The combined aggregates with 6% sand (fine) and 94% coarse aggregate, were tried to set in this

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test in this experiment research. The result shown in Figure 1 for natural aggregate and Figure 2 for crushed stone. On these figure, upper and lower gradation limit for combined aggregate gradations [30], for pervious concrete the upper gradation limit the mixture is too rocky for manual placement techniques and the surface too open for a smooth texture. The lower gradation limit represents an area below which low to zero permeability becomes probable. Chemical admixtures using Sika® ViscoCrete®1003–superplasticizer technology in this research is 0.2% of the cement and dissolved in part of the mixing water. Dosage of admixtures according to EN 206-1, admixture quantities for low dosages < 0.2% of the cement are only allowed if they are dissolved in part of the mixing water [19]. Mineral admixture using 15% fly-ash by cement mass added to mixture [20-21]. Result of Fly-ash Scanning Electron Microscopy (SEM) see Table 4 with total $SiO_2+Al_2O_3+Fe_2O_3$ = 50.57% included in class C with minimum requirement of 70% [29]. An average specific gravity test for fly ash is 2.30. Potable water available in laboratory with the normal pH, conforming to SNI (Indonesia National Standard) requirements, was used for mixing concrete and curing the specimens. [30].

Table 1. Portland cement properties

Description	Standard Test	Result
Specific gravity	SNI 2531:2015 (ASTM C188-17)	3,053
Consistency Test	SNI 03-6826-2002 (ASTM C187-11)	29.5%
Initial Setting time	ASTM 191-18	73 minutes
Final Setting time	SNI 03-6827-2002 (ASTM 191-18)	455 minutes
Bulk density (kg/m^3)	-	1420 kg/m^3

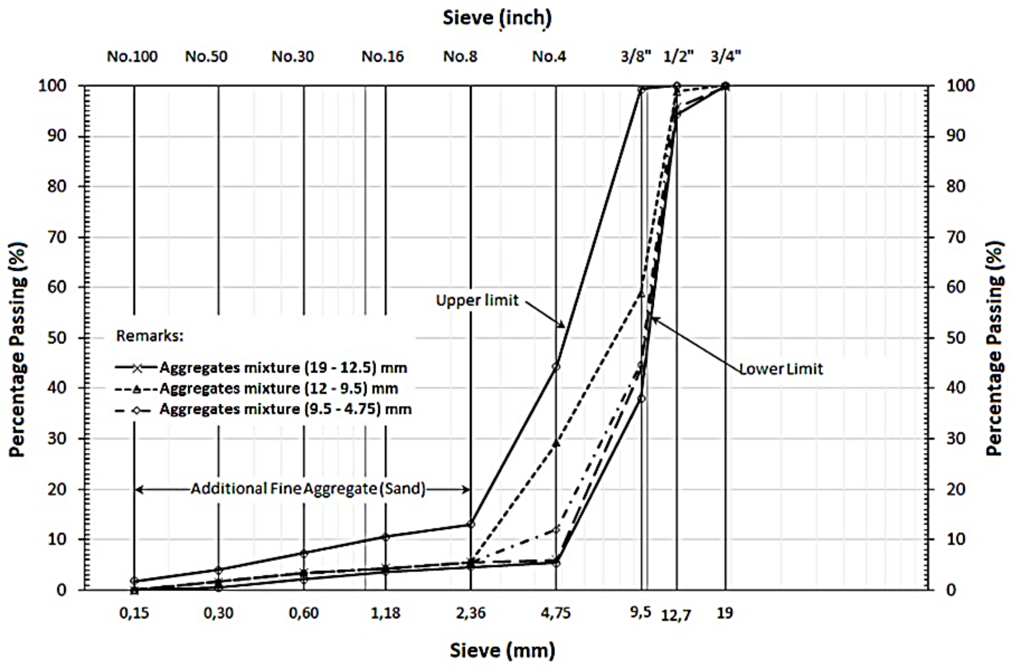

Figure 1. Combined aggregates for crushed stone with various size

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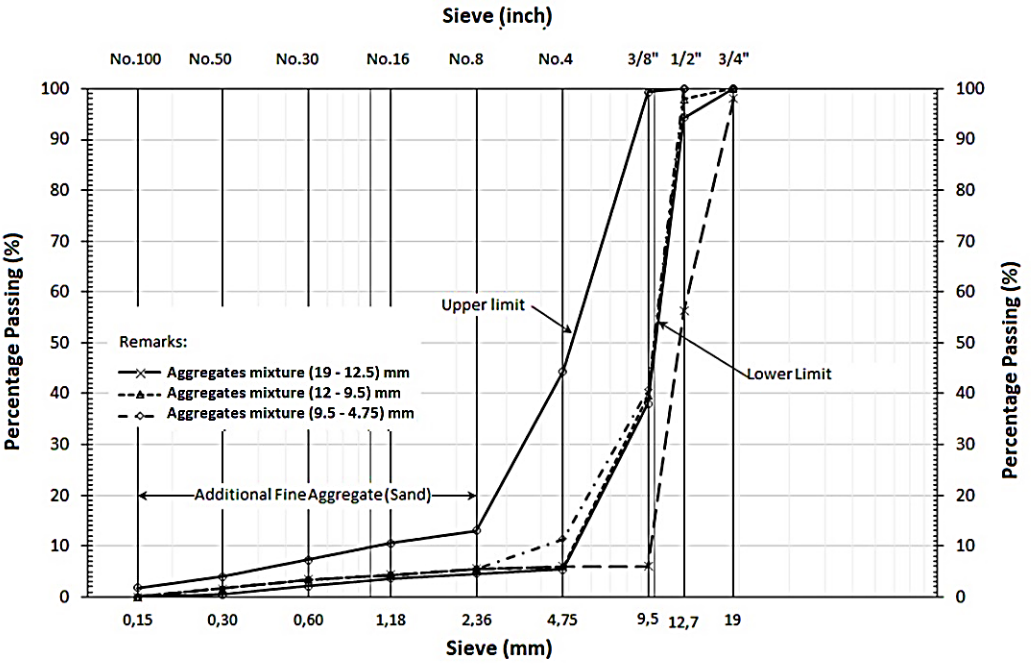


Figure 2. Combined aggregates for natural aggregate with various size

Table 2. Coarse aggregate properties

Description	Standard Test	Average Result					
		Natural Aggregates (mm)			Crushed Aggregates (mm)		
		(19–12.5)	(12.5–9.5)	(9.5–4.75)	(19–12.5)	(12.5–9.5)	(9.5–4.75)
Specific gravity	SNI 1970:2016 (ASTM C127-15)	2.518	2.535	2.573	2.461	2.503	2.576
Bulk density (kg/m^3)	SNI 03-4804-1998 (ASTM C29/29M-17a)	1580	1597	1608	1610	1595	1627
Absorbtion (%)	SNI 1970:2016 (ASTM C127-15)	1.158	1.032	0.956	1.020	0.960	0.770

Table 3. Fine aggregate properties

Description	Standard Test	Result
Water content	SNI 8319:2016 (ASTM C70-13)	1.075 %
Specific gravity	SNI 1970:2016 (ASTM C128-15)	2.822 gr/cm^3
Absorbtion	SNI 1970:2016 (ASTM C128-15)	4.589 %
Clay Lumps and Friable Particles	ASTM C142 / C142M - 17	3.77 %
Organic Impurities	SNI 2816:2014 (ASTM C40/C40M-11)	Organic Plate No. 3

Table 4. Result of Fly-ash Scanning Electron Microscopy (SEM).

Atom	Mass (%)	Relative Mass %	Oxide Result
O	45.03	16	Silicon dioxide (SiO_2)
C	29.86	12	= 27.81
Al	14.83	27	Aluminum oxide
Si	5.05	28	(Al_2O_3) = 10.73
Ca	3.61	40	Iron oxide (Fe_2O_3)
Fe	1.62	56	= 12.03
	100	100	Total = 50.57%

2.2. Mixture Proportion

Local materials (Figure 3) is important thing in making a concrete mix design and the use of economical materials as possible, an appropriate concrete of adequate strength, porosity and permeability. Material properties of pervious concrete depend on both materials and placement technique. The coarse aggregate content [23] was varied to achieve the proper thickness of paste surrounding the aggregate by trial and error, based on mix proportion of no-fines concrete[15]. A total of ten sets of mixes were designed in a standard manner. A water to cementitious materials ratio (wcr) of 0.27, 0.3, and 0.34. It was considered in the mix proportion with A/C ratio is 4.25, 6% sand, 15% fly-ash by cement and 0.2% superplasticizer for all ten sets of mixes are used [31]. Proportion material shown in Table 5.

Figure 3. Local material

Table 5. Previous concrete mixture for natural and crushed with max. aggregate 19 mm, 12.5 mm, 9.5 mm and 4.25 A/C (1 m^3 pervious concrete)

Material	Water Cement Ratio (wcr)		
	0.27	**0.3**	**0.34**
Portland Cement Composite (kg)	350	400	450
Water (liter)	94.5	120	153
Coarse Aggregate (kg)	1398.25	1598	1797.75
Fine Aggregate (kg)	89.25	102	114.75
Fly-Ash (kg)	52.5	60	67.5
Superplasticizer (liter)	0.7	0.8	0.9
Total	1985.2	2280.8	2583.9

2.3. Mixing, Casting and Compaction

The mixing and casting procedure complied with SNI 7974:2013 [32] with mixing equipment in Figure 4 (a). The compaction method is one of the most influential factors in the specimen preparation for previous concrete. Two compaction methods have been assessed [33], in this research, one was using compaction (Figure 4.b and 4.c) by drop hammer and the other was using of a tamping rod [34,35]. Although the hammer compaction packed the aggregate particles together more tightly, the density of porous concrete samples increased with the loss of permeability. As the impaction strength of a falling hammer was so strong to crush the weak aggregate and create weak layers, the vibration method equal to be more suitable for majority of aggregates. However, for the sake of achieving the maximum cohesion between aggregate particles, a combined compaction method was attempted, that was, not only applied the standard rodding compaction method, but also incorporated a drop hummer compactor. This compaction effort allowed most of the coarse aggregate not to deform under compaction whilst increase the contact surface and alignment of aggregate particles, which was believed a substantial aspect to increase the strength of porous concrete [33].

(a) (b) (c)

Figure 4. (a) Mixing Equipment, (b) Drop hammer, and (c) Tamping Rod and slum test

2.4. Density, Void, Compression and permeability

A sample of fresh pervious concrete is placed and consolidated using a standard proctor hammer (Figure 5). The density and void content of the pervious concrete are calculated based on the measured mass of the consolidated concrete specimen, the volume of the measure, and the total mass of materials batched. The theoretical density is a laboratory determination, and is assumed to remain constant for all batches made using identical component ingredients and proportions [35]. It is calculated from the following equation:

$$T = \frac{M_s}{V_s} \quad (1)$$

where, T theoretical density of the concrete computed on an airfree basis, kg/m3, M_s total mass of all materials batched, kg, and V_s sum of the absolute volumes of the component ingredients in the batch, m3. Calculate of V_s is mass of the concrete in saturated surface density (M_{ssd}) by subtracting the mass of the concrete in water, M_w. Density (Unit Weight), D by dividing the net mass of concrete by the volume of the measure, V_m. Mass of the concrete by subtracting the mass of the measure, M_m, from the mass of the measure filled with concrete, M_c. The calculate as follows

$$D = \frac{M_c - M_m}{V_m} \quad (2)$$

Figure 5. Sample test of Density fresh concrete

Void content is a percentage of voids as Equation 3, and the result shown in Table 6.

$$U = \left(\frac{T-D}{T}\right)100\% \quad (3)$$

Table 6. Density and void content

Aggeragetes (Passed-Retained)	M_s	M_{ssd}	M_w	V_s	T	M_c	$M_c - M_m$ [a)]	D	U
Natural aggregates									
	3355	3495	2188	1307	2.567	27260	18560	1.915	25417
(19 – 12.5) mm	3368	3449	2127	1322	2.548	27620	18920	1.952	23395
	3214	3320	2100	1220	2.634	28890	20190	2.083	20945
(12.5 - 9.5) mm	3120	3236	2015	1221	2.555	28450	19750	2.037	20273
	3250	3347	2104	1243	2.615	28780	20080	2.071	20781
(9.5 - 4.75) mm	3095	3275	2078	1197	2.586	28900	20200	2.084	19413
Crashed stone									
	3135	3264	2015	1249	2.510	27260	18560	1.915	23725
(19 – 12.5) mm	3154	3340	2105	1235	2.554	27620	18920	1.952	23580
	3114	3420	2210	1210	2.574	28890	20190	2.083	19075
(12.5 - 9.5) mm	3120	3206	2010	1196	2.609	28450	19750	2.037	21905
	3150	3347	2214	1133	2.780	28780	20080	2.071	25499
(9.5 - 4.75) mm	3182	3251	2078	1173	2.713	28900	20200	2.084	23188

[a)] Weight of Mold (M_m) = 8700 gram and volume = 9694.402 cm^3.

The cast cylinders were demolded after 24 h, labeled and weighted for various testing (Figure 6). Then the samples were cured by water [32]. For each batch, two samples were prepared for permeability testing and others were for compression, three tested at 7 days and 28 days, respectively. The results showing up below were all average values. The compressive strengths testing of concrete specimens were carried out in the laboratory [27,36]. Prior to loading process, caps were placed on the ends of samples. Type of capping used depended on surface condition of the concrete samples. Sulphur capping was used for samples with rough surface like porous concrete in shown Figure 7. Compressive Strength (f_c') describes the typical concrete ability to receive compressive force per unit area. The compressive strength test was conducted in accordance with ASTM C-39 and calculated using equation [27]:

$$f_c' = \frac{P}{A} \quad (4)$$

where, f_c' = compressive strength (MPa), P = maximum compressive force (N), and A = cross-sectional area of the specimen (m^2). Result of test shown in Table 7, example typical crushed specimen test shown in Figure 8.

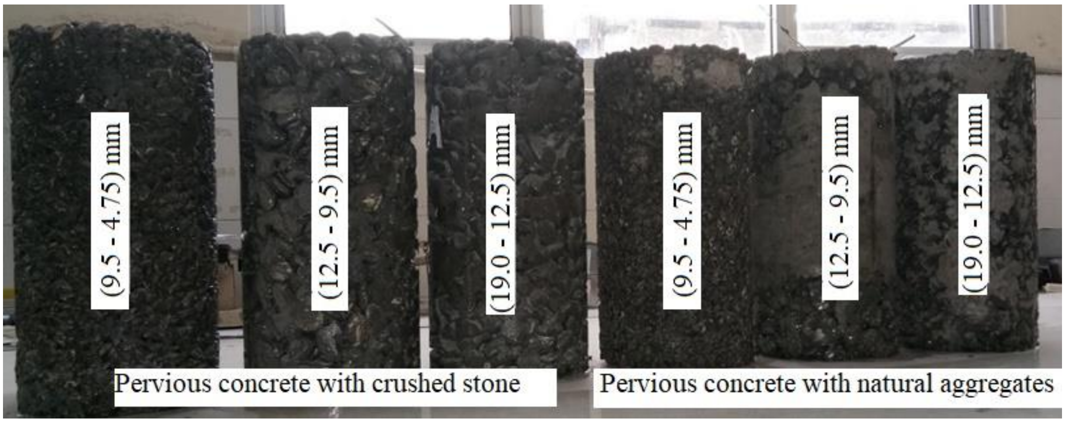


Figure 6. Sample test with various type and size aggregates

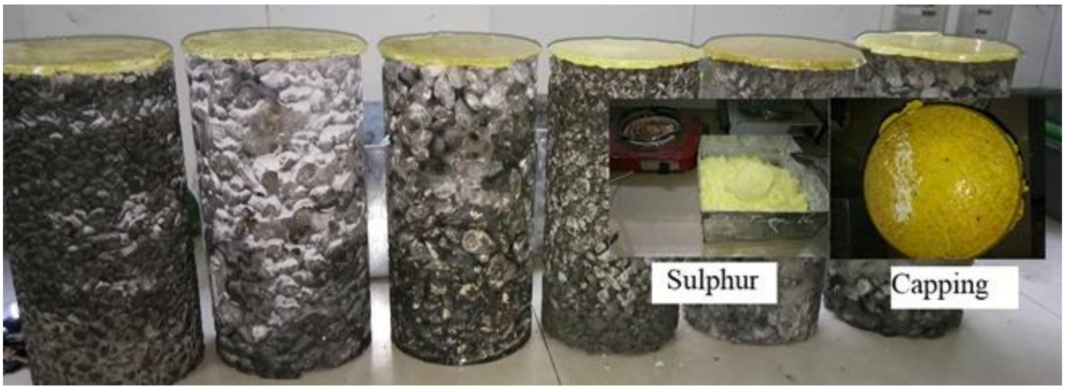


Figure 7. Sulphur capping used in samples with rough surface

Figure 8. Compression strength test (a) sample with (9.5 - 4.75) mm natural aggregate, (b) typical collapse after compression for (9.5 - 4.75) mm natural aggregate, (c) sample with (19.0 - 12. 5) mm (d) typical collapse.

Permeable or infiltrations test for water to penetrate through porous concrete was expressed in millimeters per second (mm/s). Since porous concrete generally owns a much higher permeability compared to the normal dense concrete, the permeability test method for the latter one was not suitable for testing porous concrete [37]. In our research, to determine of infiltration, the cylindrical pervious concrete wrapped in plastic on the circumference was used in this test. With inline duck type, the pipe was tight to inhibit water leakage along the sides of the sample and the top of sample placing a plastic cylinder pipe (Figure 9). The infiltration rate is calculated using the following equation (5).

Figure 9. Permeable test in experiment

$$I = \frac{KM}{D^2 t} \quad (5)$$

where I is the surface infiltration rate (mm/min), K== 76,394,433.33 (mm^3·s/(kg·min)), M is the mass of infiltrated water (kg), D is the ring's inside diameter (mm), and t is time required for water used in the test to infiltrate the surface (s). Result shown in Table 8.

Table 7. Result of compression strength test

W/C Ratio	3-Days [A)]						28-Days [B)]					
	A	B	C	D	E	F	A	B	C	D	E	F
0.27	9.1	11.9	13.0	7.1	9.3	10.5	15.8	20.4	23.2	14.7	19.0	20.7
	8.5	13.0	13.6	7.9	12.2	12.7	17.5	17.0	22.1	16.7	15.3	21.2
	8.8	11.6	14.4	7.4	8.5	12.7	17.0	18.1	20.9	16.7	17.3	19.5
Average	8.8	12.2	13.7	7.5	10.0	12.0	16.8	18.5	22.1	16.0	17.2	20.5
0.30	10.2	11.6	13.9	9.6	10.8	12.2	15.3	17.5	22.4	14.4	16.1	21.5
	9.9	13.6	14.7	9.1	13.3	13.9	17.0	20.4	21.8	16.1	19.5	19.2
	9.3	12.2	11.6	8.2	10.8	9.1	16.7	18.4	20.4	15.8	16.4	17.3
Average	9.8	12.4	13.4	9.0	11.6	11.7	16.3	18.8	21.5	15.5	17.4	19.3
0.34	9.6	11.9	10.5	8.8	9.9	7.4	16.7	17.0	18.7	15.8	15.0	17.3
	9.9	11.3	13.3	8.5	10.5	12.4	17.5	20.1	20.1	16.1	17.5	19.2
	9.3	11.6	11.9	8.5	9.1	10.5	17.3	19.0	20.9	16.4	18.1	20.1
Average	9.6	11.6	11.9	8.6	9.8	10.1	17.2	18.7	19.9	16.1	16.9	18.9

[a)] f_c' with natural aggregates, A = passed 19 mm and retained 12.5 mm; B = passed 12.5 mm and retained 9.5 mm; C = passed 9.5 mm and retained 4.75 mm

[b)] f_c' with crushed stone, D = passed 19 mm and retained 12.5 mm; E = passed 12.5 mm and retained 9.5 mm; F = passed 9.5 mm and retained 4.75 mm

Table 8: Result of permeability test average with various W/C ratio

	Natural aggregate with W/C 0.27			Crushed stone with W/C 0.27		
t (second)	60.64	71.75	100.0	60.79	83.11	119.0
I (mm/min)[a)]	23.76	19.82	14.25	23.45	17.10	11.98
	Natural aggregate with W/C 0.27			Crushed stone with W/C 0.27		
t (second)	62.72	71.25	93.64	77.72	76.78	100.8
I (mm/min)	22.69	20.26	15.18	18.30	18.57	14.13
	Natural aggregate with W/C 0.27			Crushed stone with W/C 0.27		
t (second)	67.89	70.20	135.6	76.54	81.02	109.4
I (mm/min)	20.94	20.39	11.62	18.59	17.62	13.02

[a)] Using of Eq. 5, K== 76,394,433.33 (mm^3·s/(kg·min)), M = 5 kg, D= 150 mm, and t is time required for water used in the test to infiltrate the surface (s).

3. Results and Discussion

During the mixing, the nature of fresh mixture workability was controlled visually [7]. A greater aggregate mixture with potential for segregation, this is prevented by manually mixed after placing. The W/C ratio with 0.34 in the mixture gives more plasticity compared to 0.27. Low-dosage Superplasticizer of 0.2% mixed in water does not shown a large change in the plasticity of fresh concrete.

3.1 Effect of Aggregate Type and Size on Compressive Strength and Permeability

Based on Table 6, the unit weight (density) and void in mixture of the pervious concrete using natural aggregates and crushed stone, indicating that the coarse aggregates with passed 19 mm and retained 12.5 mm will be increased void in mixture and decreased a density shown in Figure 10. The smaller aggregates size with passed 9.5 mm and retained 4.75 mm will be increased unit weight of pervious concrete and decreased void in mixture, but not slight in pervious concrete with crushed stone. Increased void in the mixture will increase concrete permeability as indicated by the high rate of infiltration.

Compressive strength at the age of 3-days, the average test results showed that with the increase of the cement water ratio in the previous concrete mixture using natural aggregates and crushed stone showed a slightly difference with a compressive strength increase of about 10%. Increasing the size of the aggregate will reduce the compressive strength of the concrete. Optimal concrete compressive strength is achieved by using a 12.5 mm aggregate that passes and is retained at 9.5 mm, as shown in Figure 11 (a). The same thing is shown for the compressive strength for 28-days (see Figure 11 (b)).

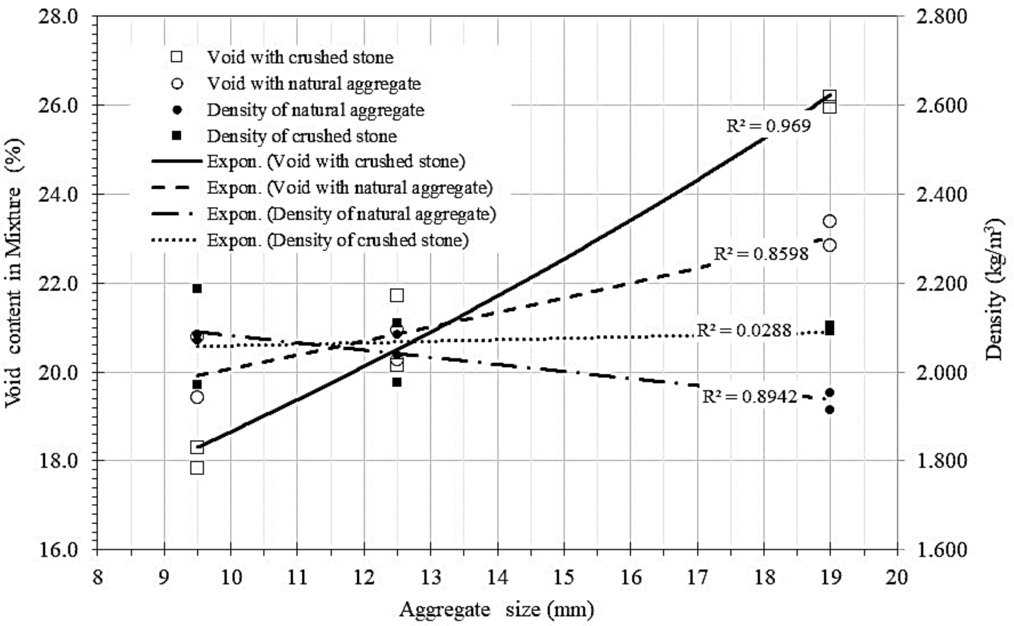
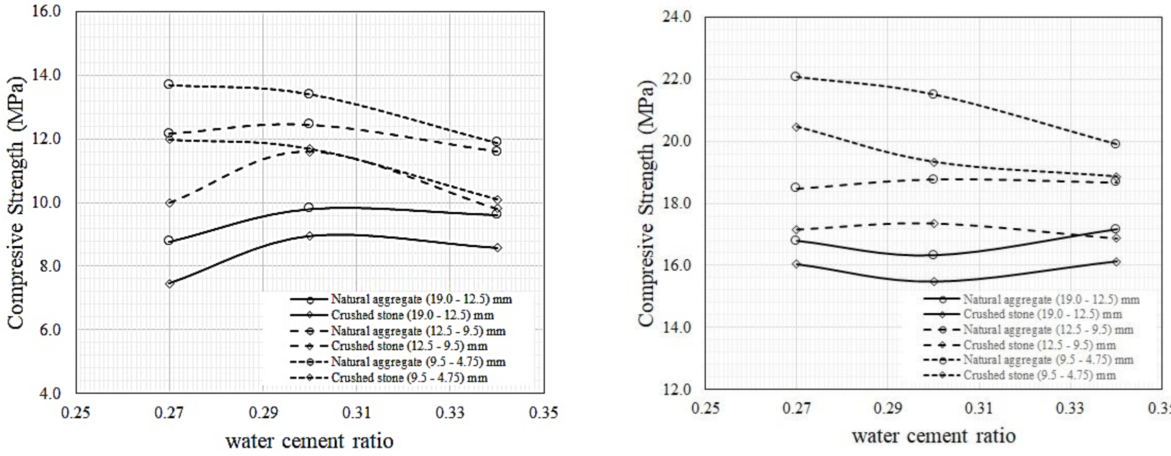


Figure 10: Void content and density in pervious concrete mixture with various type and size aggregates

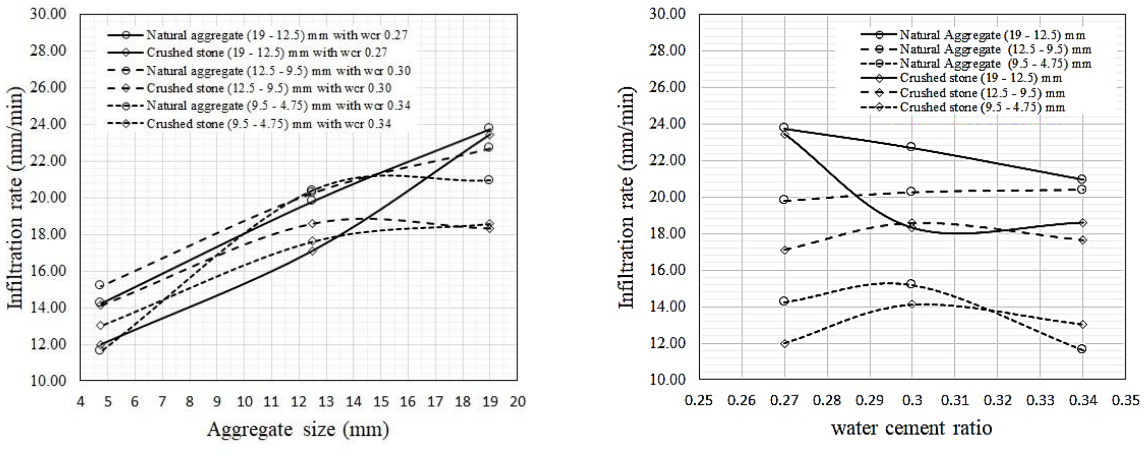


(a) (b)

Figure 11: (a) Compressive strength at 3-days with various aggregate type and size, (b) Compressive strength at 28-days with various aggregate type and size

3.2 Effect of Aggregates Size and W/C Ratio on Permeability

Based on the results of the permeability test (Table 8), small aggregates will provide void in mixed for pervious concrete mixtures, so that the rate of infiltration in pervious concrete using size aggregates passed 9.5 mm and retained 4.75 mm sieves will be produces a lower permeability than concrete using aggregates passed 19 mm sieve and retained 12.5 mm. The larger the aggregate size will be increased the void in the mixture and increase the rate of infiltration (permeability), as shown in Figure 122 (a). The use of different water cement ratio, as shown in Figure 132 (b), that's the fits permeability approximately with wcr 0.3 for all aggregate sizes and type.



(a) (b)

Figure 12: (a) with various aggregates, (b) Infiltration rate with various water cement ratio

The results of the tests showed that a highest water-cement ratio would produce a low compressive strength in accordance with the data from and this result was not clearly shown in this study for the difference in wcr range 0.27 to 0.34 because it uses added admixture with a low dosage of 0,2% of the weight of cement. The difference can be seen clearly when using admixture as a superplasticizer (SP) which is close to the maximum number. The use of SP will increase the workability to highest consistency with the equal compressive strength. The use of natural aggregates compared to fractions in this study has not shown the rate of infiltration which results in a large difference for wcr variation. The use of different compaction methods will produce void in mixed is different according to the results of the research carried out. Implementation in the field generally uses roller compaction, in this test uses a combination of drop hammer and tamping rod. For flexure strength in this research was not carried out. To estimate flexure strength can use empirical equations based on the value of the compressive test, using as $f_r = 0.62\sqrt{f_c'}$, as found in the standard [38, 39]. The highest of compressive strength, accordingly the flexural strength is highest.

4. Conclusion

The results of the experiment laboratory on the effect of aggregate size and type on compressive strength with different W/C ratio in pervious concrete mixes cannot be clearly demonstrated, because of differences in the use of water cement ratio in the mixture 0.27 to 0.34 is small. Therefore, it is necessary to make a greater difference in the water cement ratio or if using the water cement ratio in the same range the use of chemical additives with levels that are close to the maximum according to the manufacturer's recommendations will be able to produce highest compressive strength and flexural strength. The use of different types of aggregates and sizes in pervious concrete mixtures with variations in W/C ratio 0.27 to 0.34, giving a different permeability level of approximately 20%. Optimization of the proportion of the aggregate size proposed in this study was to use aggregates that passed 12.5 mm sieve and retaining at 9.5 mm. The results of using these aggregates with W/C ratio 0.3 provide compressive strength from 8 – 14 MPa for 3-days and 15 – 22 MPa at 28 days. The resulting density is between 2.0 to 2.15 kg/m^3 with void in the mixture at intervals of 20% – 22%, and resulting permeability range 17 to 21 mm / min.

5. References

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