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Porous Concrete As Road Infrastructure Using Coarse Aggregate Uniform Gradation

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Abstract*. Porous concrete is commonly used in road linings with minimal traffic, parking areas, pedestrian paths, and parks. The strength of porous concrete depends on the size of the aggregate and the correct composition of water and cement. The objective of the study was to analyse the effect of cement water factor in uniformly graded porous concrete on compressive strength and permeability in uniformly graded porous concrete on permeability values. The relationship between the compressive strength of concrete tends to decrease as the value of cement water factor increases. The water-cement factor strongly influences the permeability value. The greater the value of cement water factor, the smaller the permeability of uniformly graded porous concrete, this is due to the deposition of cement water at the base of the slab. The use of super plasticizer (SP) in porous concrete accelerates the pavement process, but does not improve permeability. cement water factor 0.35 with a 28-day treatment period obtained a Slump test value of 178 mm, cement water factor 0.5 of 192 mm, cement water factor 0.6 with a 28-day treatment period obtained a Slump test value of 196 mm. while porous concrete with a cement water factor of 0.35 has an average compressive strength of 6.13 Mpa, while a cement water factor of 0.50 has an average compressive strength of 5.47 Mpa, and a cement water factor of 0.60 has an average compressive strength of 5.00 Mpa.*

Keywords: *Porous concrete; Slump test; Compressive strength; Permeability*

1. INTRODUCTION

Porous concrete, also known as hollow concrete, is a type of concrete that consists of coarse aggregate, cement, water, and chemical additives. Due to its high porosity, non-sand concrete is lightweight and weak. Many different names are known for non-sand concrete, such as pervious concrete, concrete without fine aggregate, and porous concrete (Harber, 2005). Porous concrete is concrete that has a high degree of porosity and is used as a concrete slab. This allows rainwater and water from other sources to pass through, reducing surface runoff and increasing the water table NRMCA (Pool, 2007). Parking lots, walkways, sidewalks, gardens, tennis courts, slope stabilisation, greenhouse floors, swimming pool terraces, zoo areas, drainage, road shoulders, highway pavement surface layers, noise dampening, and roads with low traffic volumes usually use porous concrete. However, pavements that receive heavy traffic and heavy wheel loads usually do not use this type of concrete (Obla et al., 2007). The purpose of the study was to analyse the effect of cement water factor (fas) on uniformly graded porous concrete on compressive strength and permeability values.

To produce porous concrete, fine aggregate is removed from the mix. An agglomeration of coarse aggregate particles of uniform size is produced, with each particle coated by a layer of cement paste. According to the mix design ACI 522R-10 (Bautista Pereda, 2018), 1 cubic metre of porous concrete consists of: cement (270 to 415 kilograms), aggregate (1190 to 1480

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kilograms), cement water factor (0.27 to 0.34), and the use of chemical admixtures (Abadjieva & Sephiri, 2000), The higher the ratio of aggregate to cement, the lower the compressive strength of the concrete. The compressive strength of sandless concrete ranges from 1.1 to 8.3 MPa, depending on the ratio of aggregate to cement.

Composite and pozzolanic Portland cement, both of which are concrete steps in the application of sustainable material technology, can increase cement production by reducing energy consumption and reducing the use of non-renewable natural resources (Antiohos et al., 2005). Based on European standards EN 197-1:2011, Portland composite cements are classified as CEM II (Sanjuán & Argiz, 2012).

2. LITERATURE REVIEW

Porous concrete is often applied as a surface in pedestrian areas such as parks, sidewalks, and night car parks. (Xu et al., 2007), Porous concrete has been used as a green bottom to protect river embankments in Japan (Motwhatu Tama, 2001) Porous concrete is also used for handing 3w (Park & Tia, 2004). According to (Bentz et al., 2008), Porous concrete features key features such as microstructure, material bonding, and permeability (Rustan, 2019). The use of porous concrete in Europe to manage urban hydrology includes reducing traffic noise, improving anti-skid resistance of roads, and increasing permeability levels. (Knapen et al., 2003), (Van Gemert et al., 2005). The results of testing the compressive strength of seawater mixed porous concrete at the age of 28 days of treatment can be concluded that the decrease in compressive strength and split tensile strength values as the value of the cement water factor used increases. The average compressive strength between normal porous concrete and seawater mixed porous concrete has no significant difference. Normal porous concrete with a cement water factor of 0.30 and 0.35 is 6.568 Mpa and 4.435 Mpa. Seawater mixed porous concrete with a cement water factor of 0.30 and 0.35 is 6.700 Mpa and 3.774 mpa. (Adnan & Alim, 2024).

The average compressive strength of the porous concrete decreased by between 16.43 and 54.70% for every 15% increase in RCA This is due to the presence of adhered mortar on the RCA, which absorbs the designated mixing water and reduces the amount of cement paste, reducing the bond strength between the cement paste and the coarse aggregate. The cube compressive strengths of 21.42 MPa and 17.37 MPa for 15 and 30% RCA replacement were higher than the typical value (17 MPa) used in non-structural construction applications (Muda et al., 2023).

The permeability of porous concrete increases with increasing RCA content by between 17.12 and 35.66% due to the increased void ratio. The value ranges from 1.84 to 2.86 cm/s, which is high enough to be used as a drainage system. This shows that as the percentage of RCA increases in the mixes, the permeability of the concrete increases (Pareek & Hong, 2020). As for many porous media, the strength of porous concrete is significantly affected by the porosity of its internal structure, the development of a mathematical model to characterize the relationship between compressive strength and porosity for porous concrete by analyzing empirical results and theoretical derivations. the proposed model could provide a better prediction of porous concrete compressive strength based on the material porosity (Lian et al., 2011). Porous concrete paving block (PCPB) is a block with continuous voids which are intentionally incorporated into concrete. The permeability and strength of PCPB with different sizes of coarse aggregate . Three different sizes of coarse aggregate were used namely passing 10 mm retained 5 mm (as control), passing 8 mm retained 5 mm (CA 5 – 8) and passing 10 mm retained 8 mm (CA 8 – 10). the size of coarse aggregate affects the strength and porosity of the specimens. The result also shown that PCPB with CA 8 – 10 caused in low strength, but high in porosity and permeability compared to the other blocks. Beside that PCPB using CA 8 – 10 is able to remove surface runoff efficiently (Abd Halim et al., 2018).

Porous concrete, which is generally considered as an environment-friendly pavement, plays an important role in sponge city. Then the different cube and cuboid specimens were nominated to measure the compressive strength and flexural strength of porous concrete respectively. Two different sizes of cylindrical specimens were selected to test the compressive strength and splitting strength. The results show that porosity, aggregate size, aggregate type, cement grade could affect the strength of porous concrete. Moreover, the compressive strength, flexural strength, splitting strength of the porous concrete with two different sizes, and the compressive strength and splitting strength with different shapes are significantly different (Zhang et al., 2021). The optimum mixture proportions were used in the preparation of high performance porous concretes containing three sizes of coarse aggregates with appropriate amount of high water-reducing and thickening (cohesive) agents. Tests carried out on this concrete were: slump, slump-flow, void ratio, and coefficient of permeability, compressive and flexural strengths, and strength development rate. Its strength development rate was also examined at curing age of 1, 3, 7, 14 and 28 days at 20 C and 60% relative humidity (R.H.). Consequently, high performance porous concrete exhibited good workability and cohesiveness with no segregation or bleeding, and developed high strength compared to conventional porous concrete, good workability and cohesiveness without any special compaction or vibration

(Bhutta et al., 2012). The compressive strength increases as the amount of fine aggregates increases. The highest percentage change in compressive strength was found in the mixture without fine aggregate which was 46.15% of the mixture with 15% fine aggregate. Permeability decreases as the amount of fine aggregate increases. The highest percentage of permeability changes was found in the mixture without fine aggregate, which is 62.6% of the mixture with 15% fine aggregate. Porosity decreases as the number of fine aggregates increases. The highest porosity percentage change was found in the mixture with 20% fine aggregate which was 87.24% to the mixture with 25% fine aggregate (Sanjaya et al., 2021). Based on the microstructure analysis, the addition of 10% metakaolin in PCC pervious concrete improved the density of polished surface cement paste matrix. The consumption of CH phase due to metakaolin addition is also confirmed by the results from XRD analysis. The inclusion of MK particles with silicate minerals act as nucleation agent which significantly consume the formation of CH and therefore enhance the formation of CSH gel that increase the compressive strength of pervious concrete (Supit & Pandei, 2019).

Pervious concrete is widely used in various fields because of its high permeability. Strength and permeability are two important design parameters for pervious concrete, but limited research has been conducted so far on their mutual relationship. In addition, a modified permeability testing method for pervious concrete is developed, as the existing permeability testing devices for pervious concrete have not considered the specimen–container interface leakage induced by the large number of open pores on the surface of specimen, thus affecting the testing precision of permeability (Cui et al., 2017). An increase in the aggregate particle size and porosity increased the pore size and fractal dimension, and the relationship between the compressive strength and porosity conformed to the Ryshkewitch model. Although vegetation growth reduced the compressive strength and permeability coefficient of PRC, the rainwater infiltration and vegetation compatibility of PRC was confirmed (Wang & Sun, 2023).

3. METHODS

3.1 This research was conducted at the Structures and Concrete Laboratory

This research was conducted at the Structures and Concrete Laboratory of the Civil Engineering Study Programme of Muhammadiyah University of Parepare, with an experimental method, where experiments were carried out directly to evaluate the relationship between the variables under study.

Figure 3.1 This research was conducted at the Structures and Concrete Laboratory

3.2 Materials used

1. The aggregate used was coarse aggregate retained by a 19.5 mm sieve, (SNI, 2016), (ASTM C33, 2008).
2. Cement used Portland cement is the type of cement used, (SNI 15-7064-2004, 1999), (ASTM C430, 2017).
3. The water used came from the borehole of Muhammadiyah University of Parepare (ASTM, 1981).

3.3 Aggregate Characteristic Examination

The examination of the characteristics of the aggregates included; Aggregate specific gravity examination, to determine the specific gravity of the aggregates and the water absorption rate. The variables tested include the specific gravity of the aggregate in dry state, Saturated Surface Dry, and Apparent Specific gravity. The following is a description of the specific gravity tested; Absorption refers to the percentage by weight of water that can be absorbed by the pores compared to the weight of the dry aggregate; Estimation of coarse aggregate content, generally, in construction projects, an empirical relationship between the concrete making process and its working properties is often used to determine the volume of coarse aggregate. For certain applications that require more viscous concrete (with low viscosity), such as pavement construction, the volume of coarse aggregate may be added by about 10% (ASTM C33, 2008)**;** (ASTM C33; 1500 - E117 - Concrete Technology and Codes - 05, 2017).

Figure 3.2 Each variation of water cement ratio (w/c)

3.4 Preparation of test specimens

Each variation of water cement ratio (w/c) was tested for compressive strength using at least three cylindrical samples with a diameter of 150 mm and a height of 300 mm. To test the permeability of the concrete, three sample slabs of 500 mm length, 500 mm width and 150 mm height were used for each variation of the water cement ratio (w/c) (ASTM E1856-13(2021), 2021)..

3.5 Curing of test specimens

The compressive strength (f'c) of structural concrete corresponds to at least 17 MPa. There is no upper limit to the maximum value of f'c unless the provisions of a particular standard limit the value (B S Nasional, 2019); (ASTM C31, 2024).

3.6 Porous Concrete Mix Composition

For designing porous concrete mixes, laboratory tests are conducted using the trial-and-error method, where various ingredients are tried to create a mix with the desired workability. After several trials, the most suitable mix plan was selected comparing cement, aggregate and water. For example, the mix ratio is taken as follows: 1 part cement, 6 parts aggregate, and 0.6 parts water (Ang & Lihndal, 2012); (Tuan et al., 2023).

3.7 Specific gravity and percentage of pore volume measurement

Before starting the compressive strength test, a test cylinder was used to measure the specific gravity and pore volume of the hollow concrete. The test cylinder had a height of 300 mm and a diameter of 150 mm. After being removed from the water, the test cylinder was dried to a dry surface (ASTM D 3576, 2018).

3.8 Compressive strength test

The compressive strength test was conducted after the concrete reached 28 days of age based on ASTM. The compressive strength of concrete refers to its ability to withstand compressive force per unit area. To test the compressive strength of concrete, cylindrical samples with a diameter of 150 mm and a height of 300 mm were used. The compressive strength of concrete was measured after 28 days and expressed in Mpa. During the 28 days, the concrete was stored and treated at a constant temperature and humidity. According to SNI, for structural concrete, the compressive strength f'c shall not be less than 17 MPa. The maximum value of *f'c* is not limited except where limited by the provisions of a particular standard (SNI 03-2847, 2013); (ASTM C 39/C 39M –01, 2022).

3.9 Permeability test

Porosity in porous concrete is measured by the ratio of the volume of air voids to the total volume of the specimen. The porosity value of porous concrete largely depends on the size of the air voids formed. As the air voids increase, the porosity value of porous concrete also increases, facilitating rapid water flow. There is a negative correlation between the strength of porous concrete and its porosity value due to a decrease in the bond between the aggregate and the cement (ASTM D2434-68, 2000).

4. RESULTS

4.1 Characteristics of coarse aggregates

Testing of coarse aggregate is tested to determine the characteristics of coarse aggregate based on SNI and ASTM on the provisions of coarse aggregate. Aggregate test results sludge content aggregate by 0,35%; wearing aggregate by 20,3%; water content aggregate by 1,01%; weight of loose condition volume aggregate by 1,65; weight of solid state volume aggregate by 1,78; absorption aggregate by 2,47%; apparent specific gravity aggregate by 2,65; specific gravity dry basis aggregate by 2,49%; surface dry specific gravity aggregate 2,55: modulus of fineness aggregate 7,03. based on SNI and ASTM on the provisions of coarse aggregate meet the requirements

Table 4.1. Determination of solid volume per 1m³ of concrete (m³)

No	Determination of solid volume per 1m³ of concrete	*w/c* 0,35	*w/c* 0,5	*w/c* 0,6
1	Volume of water	0,12	331,29	295,08
2	The solid volume of cement	0,11	165,644	177,049
3	Volume absolute	0,54	1536,829	1536,829
4	Amount of solid volume	0,77	2033,76	2008,96

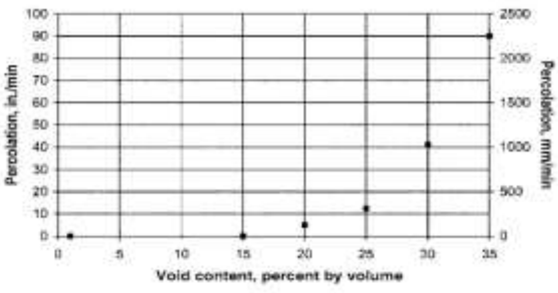


Figure 4.1 Estimate of permeability

4.2 Slump test

The examination of the slump test aims to evaluate whether there is any change in the moisture content of the concrete mix. In addition, the slump value also reflects the consistency and workability of the concrete according to certain requirements.

Table 4.2 Results of the Slump test value

Curing (day)	Mixture time ($\pm 10\ minute$)		
	w/c 0,35	w/c 0,50	w/c 0,60
28	178	192	196

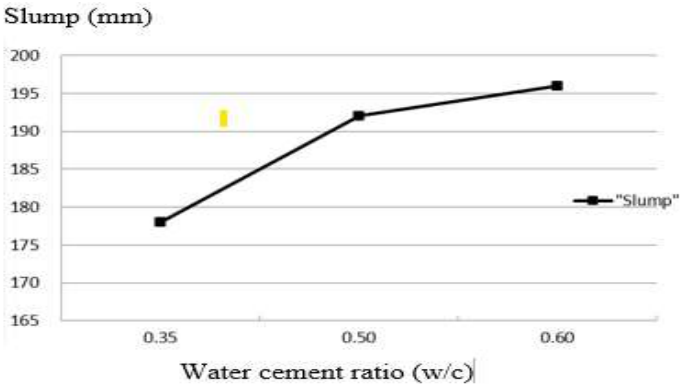


Figure 4.2 Relationship between water cement ratio and slump

4.3 Compressive strength

At the finishing and curing stage, the specimens were then subjected to strong pressure testing. After reaching 28 days of age, strong pressure testing was carried out for each mix: porous concrete with w/c 0.35; w/c 0.5; and w/c 0.6. Before conducting the compressive strength test on the porous concrete, the specimens were weighed for each variation for each variation to be used as test samples and to ensure the condition of the samples in SSD (Saturated Surfaces Dry).

Table 4.3 Recapitulation of compressive strength results of Porous concrete versus w/c

No	Curing (day)	Compressive strength (Mpa)		
		w/c 0,35	w/c 0,50	w/c 0,60
1	28	5.662	5,093	4,244
2		7.643	5,659	5,093
3		5.096	4,527	4,810
The average		6.134	5,093	4,716

Table 4.3, shows that porous concrete with a w/c of 0.35 has an average compressive strength of 6.13 Mpa, while a w/c of 0.50 has an average compressive strength of 5.47 Mpa, and a w/c of 0.60 has an average compressive strength of 5.00 Mpa. The results show that the application of water cement ratio greatly affects the compressive strength of porous concrete.

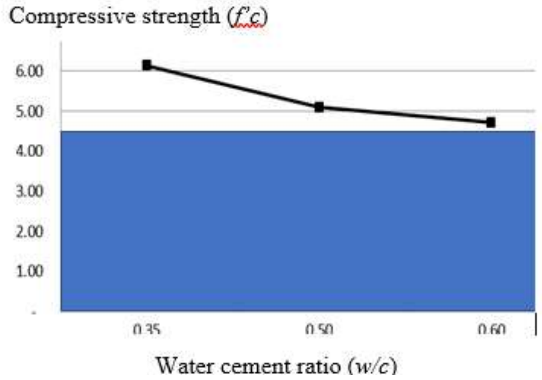


Figure 4.3 Relationship between compressive strength and water cement ratio

Show is figure 4.3, it can be seen that the compressive strength of concrete decreases as the water cement ratio value increases. This is because the greater the value of w/c, the greater the potential for water cement to settle at the bottom of the mould so that the binding of aggregates by water cement is less effective.

4.4 Porous Concrete Permeability

Permeability testing was carried out after the specimens reached 28 days of age, with six samples consisting of three variations of the water cement ratio of porous concrete using uniformly graded aggregates. The following are the results of the permeability testing of porous concrete:

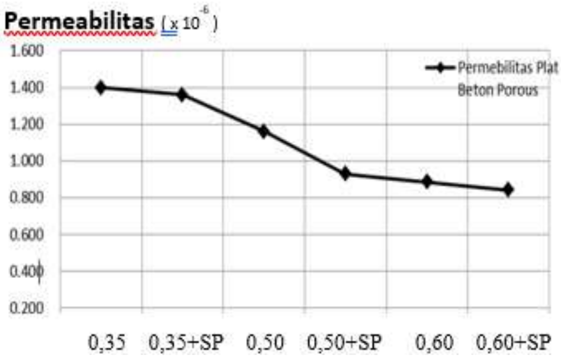
Table 4.4 Permeability of concrete

with cross-sectional area of 0.25m2; sample thickness of 0.15m; water drop height of 0.3m; water level of 0.19m; hose diameter of 0.0127m2.

No	Permeability Concrete	Water cement ratio (*w/c*)					
		0,35	0,35+SP	0,50	0,50+SP	0,60	0,60+SP
1	Time of flow (dt)	35	36	41	53	55	59
2	Water flow (m^3)	2.42E-05	2.42E-05	2.42E-05	2.42E-05	2.42E-05	2.42E-05
3	Coefficient of permeability	0.0000014	0.00000136	0.00000116	0.00000093	0.00000088	0.00000084

Figure 4.4 water-cement ratio and permeability

Based on table 5 and figure 6.b, the water cement factor is very influential on the permeability value, this can be seen in figure 5 which shows that uniformly graded porous concrete with a very large water cement ratio value can cause water-cement to settle at the bottom of the mould so that the base of the slab becomes impermeable so that permeability becomes less effective. The use of liquid superplasticiser (SP) in the manufacture of uniformly graded porous concrete, causes acceleration of post-casting concrete pavement, but tends to increase workability, so that for the same fas value the permeability of porous concrete without superplasticiser is better than porous concrete using superplasticiser (SP).



Water cement ratio (w/c)

Figure 4.5 Diagram of the relationship between water-cement ratio and permeability

5. DISCUSSION

The characteristic compressive strength of concrete (f'c) is significantly affected by the water cement ratio (w/c). The relationship between the compressive strength of concrete tends to decrease as the w/c value increases. This is because the greater the w/c value, the greater the potential for water - cement to settle at the bottom of the mould so that the binding of aggregates by water - cement is less effective. Restate the study’s main purpose.

The water-cement ratio (w/c) strongly influences the permeability value. The greater the fas value, the smaller the permeability of uniformly graded porous concrete, which is due to the deposition of water-cement at the base of the slab. The use of superplasticiser (SP) in porous concrete accelerates the pavement process, but does not improve permeability.

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