Porosity Correlation to The Compressive Strength of Porous Concrete

Hanafi Ashad[1]
[1]Civil Engineering Department, Faculty of Engineering, Moslem University of Indonesia, Makassar, Indonesia
email: hanafi.ashad@umi.ac.id

ABSTRACT

Porous concrete is a type of concrete that has high porosity, allowing water to pass through. This type of concrete can be applied as concrete used for building roads or drainage floors in areas with high levels of rainfall or in regions with high water intensity because porous concrete can drain water from the surface to the subsoil to be absorbed. Permeable concrete is formed from concrete with little acceptable aggregate content or does not use fine aggregate at all. Planning concrete with a compressive strength of 17 MPa, using a pleasing aggregate content composition of 0%, 10%, 20%, 30%, 40%, and 50% by testing the compressive strength for each acceptable aggregate content with a concrete age of 3,7,14,21, and 28 days respectively to obtain data information regarding the compressive strength of each concrete composition and to test the porosity it has. Furthermore, by connecting the compressive strength value obtained with the porosity value, it can be seen that the porosity influences the compressive strength of concrete, namely the higher the porosity value, the lower the compressive strength value obtained, and conversely, the lower the porosity value, the more compressive strength value obtained. In this study, the composition was close to the design compressive strength, namely at an aggregate content of 50%, with a compressive strength value of 16.369 Mpa and a porosity value of 37.179%.

Keywords: Porous concrete; porosity

1. INTRODUCTION

A. Background

Current human civilization demands that businesses for the construction industry can provide a qualified contribution to the surrounding environment, such as efforts to control floods or stagnant water in public facilities must be resolved [1]. One of the problems regarding the above is that in urban areas, there need to be more water catchment areas when it rains, thus allowing puddles on road buildings and sidewalks or overflow of water from drainage [2].

One option to answer this is to use porous concrete for roads with low traffic, sidewalks, or drainage floors. Permeable concrete is expected to drain water from the surface into the soil below to be absorbed [3, 4].

Concrete porosity will be able to describe the size of the strength of concrete by examining how much the contribution and relationship of porosity to significant changes in the compressive strength value of porous concrete [5].

B. Research Purposes

Research objectives are:

1. Obtain the compressive strength of porous concrete
2. To determine the correlation of porosity to the compressive strength of porous concrete.

C. The Scope of Research

This research includes:

1. Tests on the properties of concrete include:
   - Compressive strength test
   - Porosity test
2. This research was carried out without the use of added materials.

2. LITERATURE REVIEW

A. Porous Concrete

Porous concrete consists of Portland cement, coarse aggregate, and a small amount of fine aggregate or even no fine aggregate. This concrete has a slump value almost near zero and has high porosity because it has cavities of around 15-25% of the total volume. Because it tends to have high holes, this concrete has a lower compressive strength than regular concrete [6, 7].

Porous concrete is a type of concrete that has high porosity, allowing water to pass through. This type of concrete can be applied as concrete used for road buildings or drainage floors in areas with high levels of rainfall or in regions with high water intensity because porous concrete can drain water from the surface to the subsoil to be absorbed [8].

A high value of porosity in concrete affects the density of concrete, so the density in concrete could be more optimal, which can cause a small strength of concrete. For that, limited porous concrete is only used in areas with low traffic, sidewalks, and parking areas [9, 10]

The ingredients for porous concrete consist of coarse aggregate (gravel), cement, water, and little to no fine aggregate (sand). Before determining the ratio of the mixture, it is necessary to examine the characteristics of the concrete material to determine the factors that will be made as porous concrete [11].

Furthermore, testing the quality of concrete is carried out by testing the compressive strength of concrete using the formula:

$$f'c = \frac{\mathrm{P}}{\mathrm{A}} = \frac{\mathrm{N}}{\mathrm{m}m^2} = \mathrm{MPa}$$

where =
f'c = compressive strength (MPa)
P = crushed load (N)
A = cross-sectional area (mm ^{2})

B. Porosity

Porosity is the space or voids between materials and is the fraction of the volume of these voids to the total volume. Porosity in concrete is defined as the ratio of pore volume (volume filled with water) to the total volume of concrete [12]. The range of pores in concrete generally occurs due to errors in execution and casting, such as the cement water factor, which affects the adhesion between cement paste and aggregate, the size of the slump value, the selection of the type of combined aggregate gradation arrangement, as well as the duration of compaction. The higher the density level of the concrete, the greater the compressive strength or quality of the concrete; conversely, the greater the porosity of the concrete, the smaller the strength of the concrete [13, 14]. This porosity test uses the immersion method to obtain the pore volume value and produce the porosity value using the formula:

$$e = \frac{\mathrm{Vv}}{\mathrm{Vs}} \text{ x } 100\ \%$$

Where :
e = Porosity (%)
Vv = Pore Volume (m3)
Vs = Concrete Volume (m3)

3. DISCUSSION

A. Fine Aggregate Testing

The fine aggregate used in this study was sourced from the Bili-bili River, Gowa Regency, South Sulawesi Province, with the characteristic examination results as shown in Table 1.

Table 1. Results of fine aggregate characteristics test

No	Characteristics	Results	Unit

1	Fineness modulus	2.68	-
2	Water content	5.05	%
3	Volume weight Solid	1.54	kg/m ^{3}
4	Specific gravity	2.77	-
5	absorption	2.67	%
6	Sludge levels	3.81	%
7	organic content	yellowish clear	

B. Coarse Aggregate Testing

Testing the characteristics of the coarse aggregate material sourced from the Bili-bili River, Gowa Regency, South Sulawesi Province, which has gone through the breaking process, is tabled as follows:

Table 2. Results of the fine aggregate characteristics test

No	Characteristics	Results	Unit
1	Fineness modulus	6.83	-
2	Water content	0.82	%
3	Solid volume weight	1.55	kg/m ^{3}
5	Specific gravity	2.54	-
6	absorption	2.02	%
7	Sludge levels	0.58	%
8	wear and tear	0.24	%

C. Concrete Mixing Method

Concrete mixing is carried out using the planned mixing method using the American Concrete Institute (ACI) Lightweight Concrete method, and based on the results of the calculation analysis, the composition for 1 m ^{3} of concrete is obtained and for the needs of the specimen using a cylinder dia model. 150 mm long and 300 mm high, with a design compressive strength of 17 Mpa. as shown in table 3.

Table 3. Concrete mix composition

Acceptable Aggregate Content (%)	Coarse aggregate (kg)	Fine aggregate (kg)	Cement (kg)	Water (ltr)
0%	1125.5	0.000	241.27	181
10%	1125.5	47.619	241.27	181
20%	1125.5	95.238	241.27	181
30%	1125.5	142.857	241.27	181
40%	1125.5	190.477	241.27	181
50%	1125.5	238.096	241.27	181
100%	1125.5	476.191	241.27	181

D. Compressive Strength Test Result

The compressive strength test was carried out at each acceptable aggregate content and concrete age of 3, 7, 14, 21, and 28 days, respectively, as shown in the following table:

Table 4. 3-Day-old concrete compressive strength test results

Test item code	Fine Aggregate Content %	Age of the test object (days)	Weight of test object (kg)	Crushed load (kN)	Area of the test object (mm^2)	Direct pressure (MPa)	Compressive strength 28 days (MPa)	Average compressive strength (MPa)
S1-0	0%	3	9.213	50	17662.5	2.831	5.874	4.895
S2-0		3	9.178	35	17662.5	1.982	4.112	
S3-0		3	9.221	40	17662.5	2.265	4.699	
S1-10	10%	3	9.817	55	17662.5	3.114	6.461	7.440
S2-10		3	9.344	70	17662.5	3.963	8.224	
S3-10		3	9.391	65	17662.5	3.680	7.636	
S1-20	20%	3	10.566	80	17662.5	4.529	9.398	9.594
S2-20		3	10.322	90	17662.5	5.096	10.573	
S3-20		3	10.547	75	17662.5	4.246	8.811	
S1-30	30%	3	10.408	100	17662.5	5.662	11.748	11.552
S2-30		3	10.460	110	17662.5	6.228	12.923	
S3-30		3	10.540	85	17662.5	4.812	9.986	

S1-40	40%	3	10.560	110	17662.5	6.228	12.923	12.531
S2-40		3	10.443	115	17662.5	6.511	13.510	
S3-40		3	10.730	95	17662.5	5.379	11.161	
S1-50	50%	3	10.535	122	17662.5	6.907	14.333	13.393
S2-50		3	10.552	115	17662.5	6.511	13.510	
S3-50		3	10.560	105	17662.5	5.945	12.335	
S1-100	100%	3	12.340	145	17662.5	8.209	17.035	18.014
S2-100		3	12.117	160	17662.5	9.059	18.797	
S3-100		3	12.098	155	17662.5	8.776	18.209	

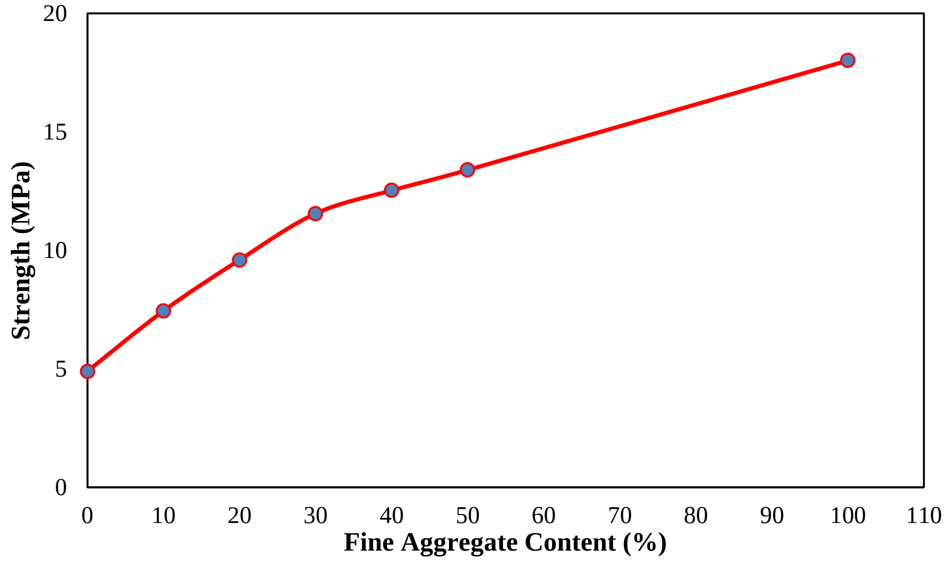

Figure 1. Graph of the relationship between fine aggregate content and compressive strength at 3 days of age

Table 5. Results of 7-day-old concrete compressive strength

Test item code	Fine Aggregate Content %	Age of the test object (days)	Weight of test object (kg)	Crushed load (kN)	Area of the test object (mm^2)	Direct pressure (MPa)	Compressive strength 28 days (MPa)	Average compressive strength (MPa)
S1-0	0%	7	9.310	75	17662.5	4.246	5.422	5.302
S2-0		7	9.700	85	17662.5	4.812	6.145	
S3-0		7	9.520	60	17662.5	3.397	4.338	
S1-10	10%	7	9.780	95	17662.5	5.379	6.868	7.832
S2-10		7	9.845	110	17662.5	6.228	7.953	
S3-10		7	9.773	120	17662.5	6.794	8.675	
S1-20	20%	7	10.630	125	17662.5	7.077	9.037	9.880
S2-20		7	10.332	150	17662.5	8.493	10.844	
S3-20		7	10.504	135	17662.5	7.643	9.760	
S1-30	30%	7	10.556	155	17662.5	8.776	11.206	10.724
S2-30		7	10.880	170	17662.5	9.625	12.290	
S3-30		7	10.890	120	17662.5	6.794	8.675	
S1-40	40%	7	10.440	175	17662.5	9.908	12.652	12.411
S2-40		7	10.600	155	17662.5	8.776	11.206	
S3-40		7	10.834	185	17662.5	10.474	13.375	
S1-50	50%	7	10.560	180	17662.5	10.191	13.013	13.616
S2-50		7	10.370	195	17662.5	11.040	14.098	

S3-50		7	10.735	190	17662.5	10.757	13.736	
S1-100	100%	7	12.330	225	17662.5	12.739	16.267	17.592
S2-100		7	12.870	240	17662.5	13.588	17.351	
S3-100		7	12.650	265	17662.5	15.004	19.158	

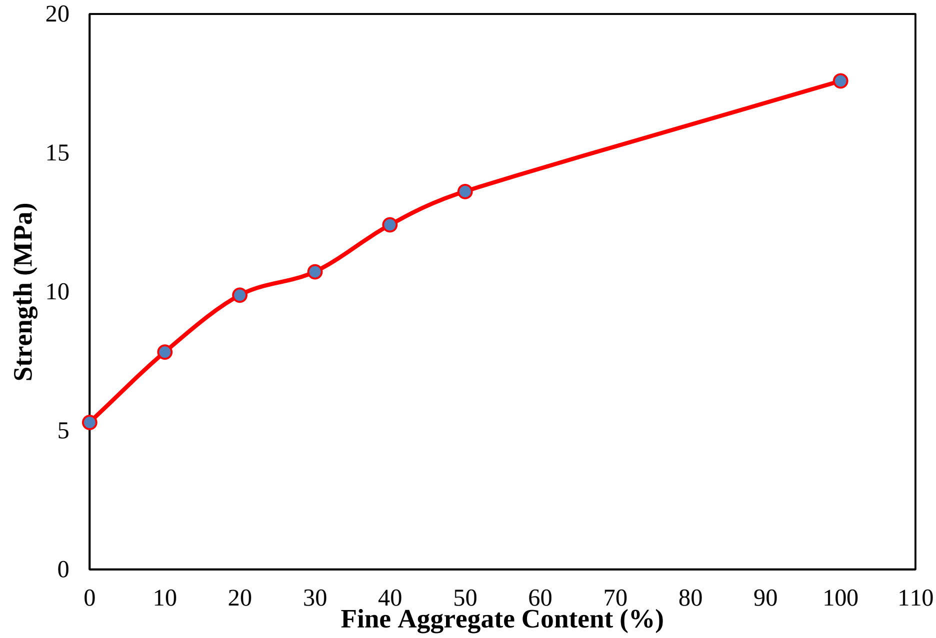

Figure 2. Graph of the relationship between fine aggregate content and concrete compressive strength at 7 days of age

Table 6. Results of 14-day-old concrete compressive strength

Test item code	Fine Aggregate Content %	Age of the test object (days)	Weight of test object (kg)	Crushed load (kN)	Area of the test object (mm^2)	Direct pressure (MPa)	Compressive strength 28 days (MPa)	Average compressive strength (MPa)
S1-0	0%	14	9.780	75	17662.5	4,246	4.146	4.976
S2-0		14	9.544	80	17662.5	4,529	4.423	
S3-0		14	9.370	115	17662.5	6,511	6.358	
S1-10	10%	14	9.450	110	17662.5	6,228	6.081	7.556
S2-10		14	9.887	135	17662.5	7,643	7.463	
S3-10		14	9.267	165	17662.5	9,342	9.122	
S1-20	20%	14	9.980	225	17662.5	12,739	12.439	10.781
S2-20		14	10.210	205	17662.5	11.607	11.333	
S3-20		14	10.175	155	17662.5	8,776	8.569	
S1-30	30%	14	10.554	185	17662.5	10.474	10.228	11.518
S2-30		14	10.173	195	17662.5	11,040	10.781	
S3-30		14	10.882	245	17662.5	13,871	13.545	
S1-40	40%	14	10.585	225	17662.5	12,739	12.439	12.439
S2-40		14	10.120	210	17662.5	11,890	11.610	
S3-40		14	10.858	240	17662.5	13,588	13.268	
S1-50	50%	14	10.670	235	17662.5	13.305	12.992	13.084
S2-50		14	10.685	220	17662.5	12,456	12.163	
S3-50		14	10.887	255	17662.5	14,437	14.098	
S1-100	100%	14	12.553	335	17662.5	18,967	18.520	17.599
S2-100		14	12.578	305	17662.5	17,268	16.862	
S3-100		14	12.230	315	17662.5	17,834	17.415	

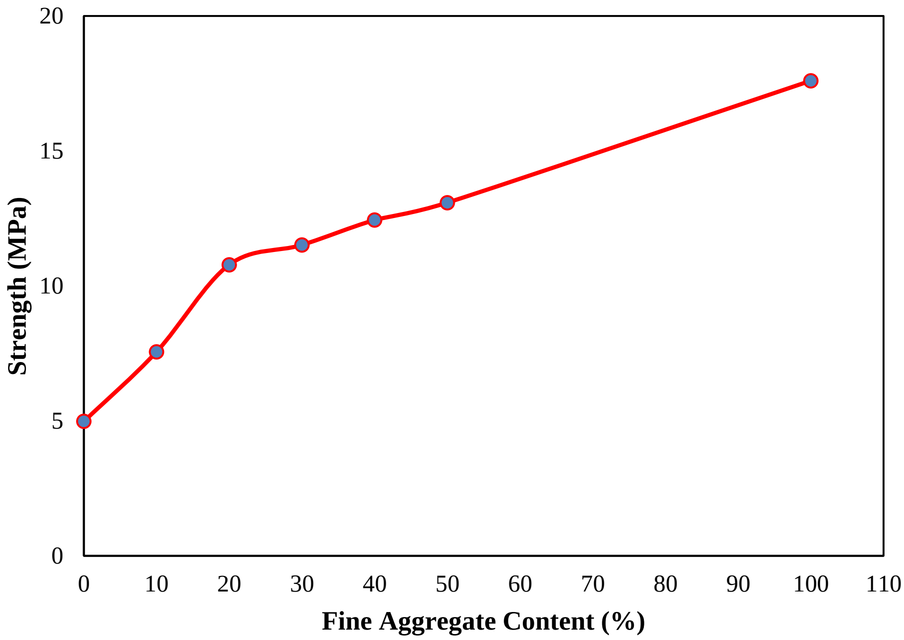

Figure 3. Graph of the relationship between fine aggregate content and concrete compressive strength at 14 days of age

Table 7. 21-day-old concrete compressive strength test results

Test item code	Fine Aggregate Content %	Age of the test object (days)	Weight of test object (kg)	Crushed load (kN)	Area of the test object (mm^2)	Direct pressure (MPa)	Compressive strength 28 days (MPa)	Average compressive strength (MPa)
S1-0	0%	21	9.520	85	17662.5	4.812	4.205	4.287
S2-0		21	9.770	70	17662.5	3.963	3.463	
S3-0		21	9.673	105	17662.5	5.945	5.194	
S1-10	10%	21	9.945	130	17662.5	7.360	6.431	6.760
S2-10		21	10.210	125	17662.5	7.077	6.183	
S3-10		21	10.030	155	17662.5	8.776	7.667	
S1-20	20%	21	10.884	190	17662.5	10.757	9.398	8.821
S2-20		21	10.579	170	17662.5	9.625	8.409	
S3-20		21	10.113	175	17662.5	9.908	8.656	
S1-30	30%	21	10.665	200	17662.5	11.323	9.893	9.646
S2-30		21	10.587	210	17662.5	11.890	10.388	
S3-30		21	10.442	175	17662.5	9.908	8.656	
S1-40	40%	21	10.561	255	17662.5	14.437	12.614	11.047
S2-40		21	10.890	205	17662.5	11.607	10.140	
S3-40		21	10.755	210	17662.5	11.890	10.388	
S1-50	50%	21	10.870	225	17662.5	12.739	11.130	12.037
S2-50		21	10.920	240	17662.5	13.588	11.872	
S3-50		21	10.876	265	17662.5	15.004	13.108	
S1-100	100%	21	12.334	335	17662.5	18.967	16.571	17.643
S2-100		21	12.765	360	17662.5	20.382	17.808	
S3-100		21	12.852	375	17662.5	21.231	18.550	

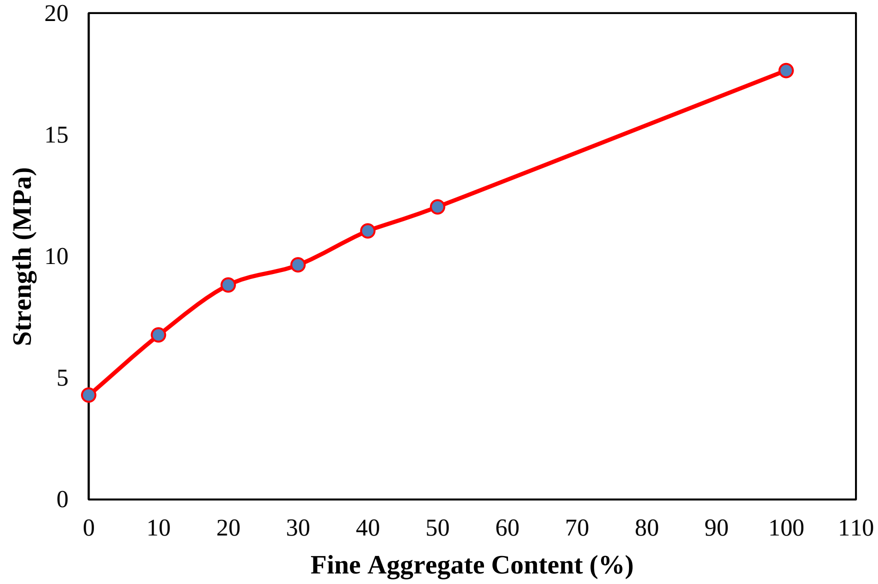

Figure 4. Graph of the relationship between fine aggregate content and concrete compressive strength at 21 days of age

Table 7. 28-day-old concrete compressive strength test results

Test item code	Fine Aggregate Content %	Age of the test object (days)	Weight of test object (kg)	Crushed load (kN)	Area of the test object (mm^2)	Direct pressure (MPa)	Compressive strength 28 days (MPa)	Average compressive strength (MPa)
S1-0	0%	28	9.155	105	17662.5	5.945	4.934	4.856
S2-0		28	9.087	85	17662.5	4.812	3.994	
S3-0		28	9.211	120	17662.5	6.794	5.639	
S1-10	10%	28	9.765	125	17662.5	7.077	5.874	7.205
S2-10		28	9.344	165	17662.5	9.342	7.754	
S3-10		28	9.428	170	17662.5	9.625	7.989	
S1-20	20%	28	10.700	245	17662.5	13.871	11.513	9.712
S2-20		28	10.131	190	17662.5	10.757	8.929	
S3-20		28	10.227	185	17662.5	10.474	8.694	
S1-30	30%	28	10.334	210	17662.5	11.890	9.868	10.182
S2-30		28	10.129	265	17662.5	15.004	12.453	
S3-30		28	10.544	175	17662.5	9.908	8.224	
S1-40	40%	28	10.422	285	17662.5	16.136	13.393	15.038
S2-40		28	10.525	330	17662.5	18.684	15.507	
S3-40		28	10.326	345	17662.5	19.533	16.212	
S1-50	50%	28	10.445	365	17662.5	20.665	17.152	16.369
S2-50		28	10.546	335	17662.5	18.967	15.742	
S3-50		28	10.233	345	17662.5	19.533	16.212	
S1-100	100%	28	12.122	385	17662.5	21.798	18.092	17.622
S2-100		28	12.495	365	17662.5	20.665	17.152	
S3-100		28	12.747	375	17662.5	21.231	17.622	

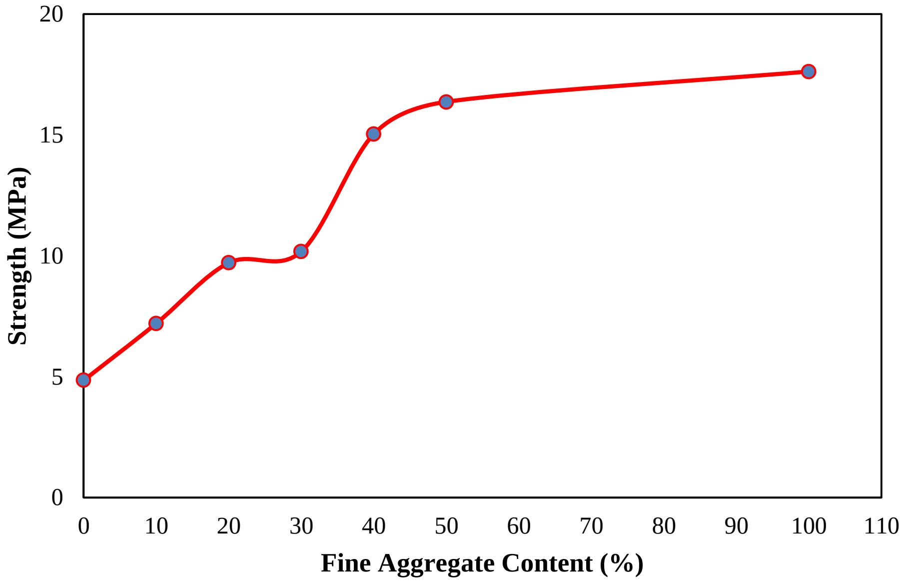

Figure 5. Graph of the relationship between fine aggregate content and concrete compressive strength at 28 days

From the overall test results based on the tables and graphs above, they can be combined into a recapitulation of the average compressive strength as shown in Table 8 below:

Table 8. Recapitulation of concrete compressive strength test results

No	Acceptable Aggregate Content (%)	Age of Concrete (Days)				
		3	7	14	21	28
1	0	4.895	5.302	4.976	4.287	4.856
2	10	7.440	7.832	7.556	6.760	7.205
3	20	9.594	9.880	10.781	8.821	9.712
4	30	11.552	10.724	11.518	9.646	10.182
5	40	12.531	12.411	12.439	11.047	15.038
6	50	13.393	13.616	13.084	12.037	16.369
7	100	18.014	17.592	17.599	17.643	17.622

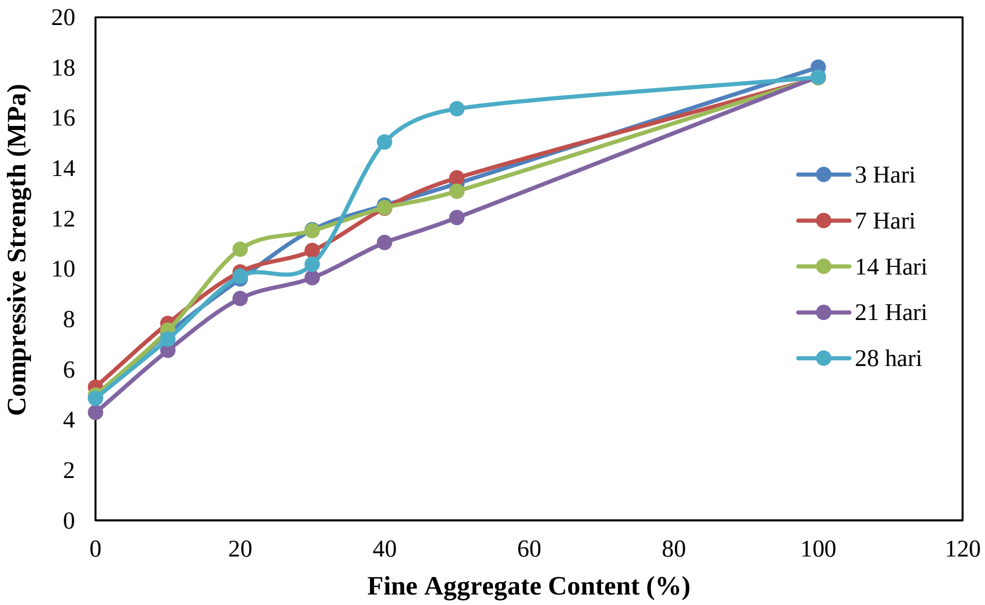

Figure 5. Graph of the relationship between fine aggregate content and concrete compressive strength

The graph above indicates that the use of fine aggregate will significantly affect the compressive strength of concrete and that the lower the acceptable aggregate content contained, the lower the quality of the concrete produced. Vice versa, the higher the use of fine aggregate, the higher the quality of the concrete.

E. Porosity Testing

The results of the porosity test can be seen in Table 9 below:

Table 9. Porosity Test Results

Test item code	Fine Aggregate Simulation %	Age of the test object (days)	Weight of test object before soaking (kg)	Weight of test object after washing (kg)	The volume of test object (m^3)	Volume	Porosity
						Average pore (m^3)	Average (%)
UP 1 – 0	0%	28	5.993	6.159	0.003	0.263	77.811
UP 2 – 0			5.873	6.098			
UP 3 – 0			5.817	6.215			
UP 1 – 10	10%		6.027	6.287		0.235	69.428
UP 2 – 10			6.133	6.389			
UP 3 – 10			6.087	6.275			
UP 1 – 20	20%		6.355	6.605		0.200	59.073
UP 2 – 20			6.311	6.491			
UP 3 – 20			6.302	6.471			
UP 1 – 30	30%		6.508	6.644		0.161	47.633
UP 2 – 30			6.512	6.678			
UP 3 – 30			6.557	6.738			
UP 1 – 40	40%		6.892	6.973		0.135	40.039
UP 2 – 40			6.731	6.954			
UP 3 – 40			6.887	6.989			
UP 1 – 50	50%		7.003	7.103		0.126	37.179
UP 2 – 50			7.009	7.166			
UP 3 – 50			7.068	7.188			
UP 1 – 100	100%		7.773	7.844		0.090	26.627
UP 2 – 100			7.601	7.712			
UP 3 – 100			7.795	7.883			

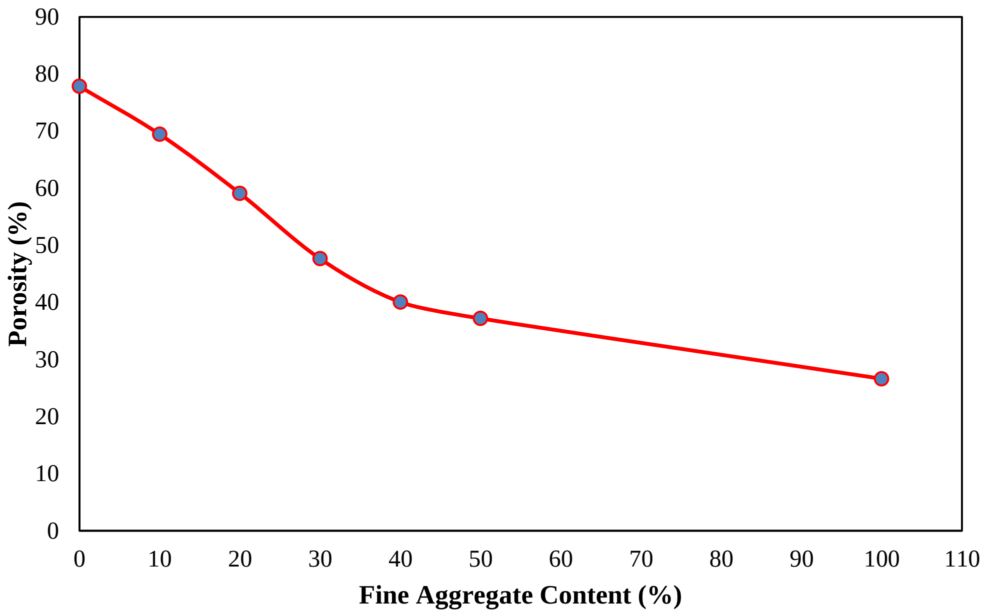

Figure 5. Graph of the Relationship between Fine Aggregate Content and Porosity

The graph above shows that the acceptable aggregate content also affects the magnitude of the porosity value, that the higher the use of fine aggregate, the smaller the porosity value, and vice versa, the smaller the use of fine aggregate, the higher the porosity value will occur. Furthermore, the relationship between compressive strength and porosity can be seen in the following graph:

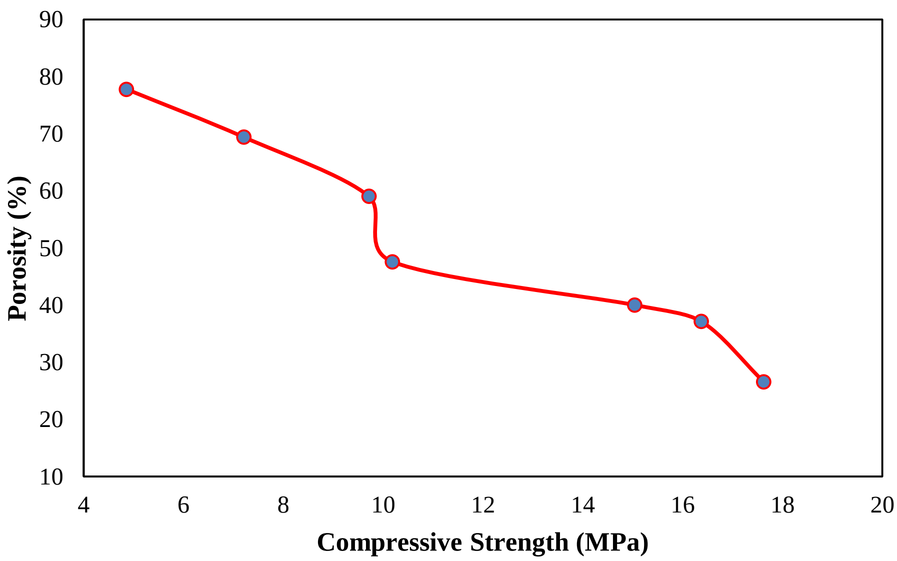

Figure 6. Graph of Compressive Strength and Porosity Relationship

From the graph above, it can be seen that the porosity value greatly influences the compressive strength of concrete, as shown in Figure 6 shows that a high compressive strength value has a low porosity value, and vice versa, a low compressive strength value has a high porosity value.

Furthermore, for the use of porous concrete, based on the results of this study, it is better to use a composition using 50% fine aggregate with a compressive strength of 16.369 MPa and a porosity value of 37.179%. This is because the compressive strength value is close to the design compressive strength, 17 MPa. At the same time, this composition also has a porosity value sufficient to drain water from the concrete surface.

4. Conclusions And Recommendations

A. Conclusion

1. The results of the compressive strength of porous concrete close to the design compressive strength value of 17 MPa were obtained using a composition with an acceptable aggregate content of 50% and 16.369 MPa with a porosity value of 37.179%.
2. That porosity greatly affects the compressive strength of concrete, the higher the porosity value, the lower the compressive strength of the concrete, and vice versa, the lower the porosity value, the higher the resulting compressive strength value.

B. Suggestion

1. It is hoped that future researchers will conduct similar research with concrete compressive strength above 28 days.
2. The results of this study are expected to be a reference and comparison for the benefit of scientific development.

References

[1] ACI 522R-10, for Pervious Concrete, by ACI Committee 522, march 2010.

[2] Agus Kurniawan. 2020. Mechanical Performance of Porous Concrete for Pavement Applications," Journal of Civil Engineering Applications Volume 18, Number 1, February 2020.

[3] Aris Widodo et al., 2017," Analysis of Concrete Compressive Strength with the Addition of Rooving Fibers in Non-Sand Concrete," Journal of Civil Engineering & Planning 19 (2) (2017) pp. 115-120.

[4] Daryanto Ari Prabowo. 2013. Porous Concrete Design for Environmentally Friendly Pavement", e-Journal of Civil Engineering Matrix/ June 2013/96.

[5] Teymouri E., Mousavi S. F., Karami H., Farzin S. and Kheirabad H. 2020. Reducing Urban Runoff Pollution Using Porous Concrete Containing Mineral Adsorbents. J. Environ. Treats. Tech 2020, Volume 8, Issue 1, Pages: 429-436.

[6] Cahya E. N., Arifi E. and Haribowo R. 2020. Recycled Porous Concrete Effectiveness for Filtration Material on Wastewater Treatment. International Journal of GEOMATE, June 2020, Vol.18, Issue 70, pp. 209–214.

[7] Tamai H. 2015. We are enhancing the performance of porous concrete by utilizing the pumice aggregate" Elsevier Procedia Engineering 125 (2015) 732 – 738.

[8] Irzal Agus. 2022. Porous Concrete Design with Variations in Cement Water Factor (FAS) As Environmentally Friendly Concrete. Journal of Unidayan Civil Engineering Innovation Media, Vol. XI, No. 1, May 2022.

[9] Jiwei Cai. 2022. Mix design methods for previously concrete based on the microstructure: Progress, existing problems, and recommendations for future improvement. Elsevier case studies in construction materials 17 (2022)

10] Samsul Nasrul. 2021. The Relationship between Compressive Strength and Flexural Strength in Porous Concrete," Journal of Civil Mechanic Construction Engineering (JRKMS) Volume 04 Number 01 May 2021.

[11] Sary Shandy and Joni Hermanto. 2019. Study of the Correlation of Concrete Porosity to the average compressive strength of concrete using Coarse Angus Stone

Aggregate. Dintek Volume 12 Number 1 March 2019.

[12] Hatanaka S., Mishima N., Maegawa A., and Sakamoto E. 2014. Fundamental Study on Properties of Small Particle Size Porous Concrete. Journal of Advanced Concrete Technology, volume 12 (2014), pp. 12 2014 24-33.

[13] Anggraeni S., Nandiyanto A., Pribadi A. R., and Kadzim Z. 2022. The Effect of Rice Husk Composition on Porous Concrete Performance. Journal of Engineering Science and Technology Vol. 17, No. 2 (2022) 1346 – 1355.

[14] Yulia Wahyuning Tyas. 2020. The Effect of Variation in the Percentage of Superplasticizer on the Mechanical Properties and Porosity of Porous Concrete. Media Civil Engineering, Vol. 18, no. 1, February 2020, p. 33-41.