Optimization of Compressive Strength and Porosity of Porous Concrete with the Addition of Zeolite as a Substitute for Sand and Silica Fume

Kinanti Wijaya[1], Andre Alfama Afrizal Nasution[2*], Trimailuzi[3], Sutrisno[4], Nahesson Hotmarama Panjaitan[5]

{kinanti.w@unimed.ac.id[1], 2001andrealfama@gmail.com[2], trimailuzi@unimed.ac.id[3], trisno@unimed.ac.id[4], nahessonpanjaitan@gmail.com[5]}

Department of Building Engineering Education, Faculty of Engineering, Universitas Negeri Medan, Indonesia[1,3], Sentral Sawita Mulia Ltd., Pontianak, Kalimantan Barat, Indonesia[2], Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Medan, Indonesia[4,5]

Abstract. Porous concrete is a type of concrete designed to allow water to flow through its pores, thereby reducing pooling and increasing water absorption into the soil. However, the use of porous concrete in road paving is still limited due to its low compressive strength. This study aims to determine the effect of adding zeolite as a sand substitute on the compressive strength and porosity of porous concrete containing silica fume. The study used variations in zeolite content of 12.5%, 17.5%, 22.5%, and 27.5% of the weight of fine aggregate, as well as a silica fume content of 7%. The test results show that variations in zeolite addition affect the compressive strength and porosity of concrete. The optimum variation was found at a zeolite content of 17.5% which provides an increase in compressive strength while maintaining a good level of porosity.

Keywords: Porous Concrete, Engineering and Material Science.

1 Introduction

Concrete is a crucial construction material needed for infrastructure development in Indonesia. The proportion of concrete used in water resource infrastructure construction reaches 80%. The proportion of concrete used in the housing and settlement construction sector reaches 60% of the total materials used. In road construction, concrete can account for 56-71% of all materials, depending on conditions and needs [1], as the Director General for Infrastructure and Housing Financing at the Ministry of Public Works and Public Housing.

The continued increase in the use of conventional concrete has resulted in an increasingly extensive waterproof layer, resulting in increased surface runoff due to its inability to infiltrate the soil. This, in turn, leads to lower groundwater levels and flooding during periods of high rainfall. The damage caused by submerged roads is exacerbated by excessive traffic loads [2]. This is one reason why roads in Indonesia are prone to damage due to undrained standing water,

ICIESC 2025, September 16, Medan, Indonesia

DOI 10.4108/eai.16-9-2025.2361143

which disrupts road users. To address this issue, alternative pavement materials, such as porous concrete, are needed.

Porous concrete has a higher porosity and permeability ratio than conventional concrete. The compressive strength of sand-free concrete is lower than that of conventional concrete due to the increased porosity. The tensile and flexural strengths of sand-free concrete are also significantly lower than those of conventional concrete, limiting its use to low-traffic areas such as parking lots, sidewalks, jogging paths, small roads, low-volume roads, and others [3].

Porous concrete is a special type of concrete with high porosity applied as a concrete slab that allows rainwater and water from other sources to pass through, thereby reducing surface runoff and increasing the groundwater table. High porosity is achieved through interconnected voids. Porous concrete typically uses little or no fine aggregate and contains sufficient cement paste to coat the surface of the coarse aggregate and maintain interconnectedness of the pores. Porous concrete is traditionally used for parking areas, traffic signal areas, and pedestrian walkways [4].

In the American Concrete Institute (ACI) standardization, pervious concrete usually describes a material with an open slump rate approaching zero consisting of portland cement, little or no fine aggregate, admixtures and water. Where there are 3 variations in sand composition content ranging from 0%, 10% and 20% of the total concrete weight and has voids ranging from 15% to 35% with a typical compressive strength of 400 to 4000 psi or 2.8 to 28 Mpa [5].

Previous research found that adding silica fume affected the compressive strength of porous concrete, with an optimal level of 7%, reaching 22.46 MPa [6]. These results demonstrate that adding silica fume to porous concrete works effectively, as evidenced by the improvement in compressive strength. However, this study focuses on increasing the use of porous concrete in road pavements.

Therefore, in an effort to improve the quality of porous concrete so that it can be used for higher-quality road pavements, this research added an admixture, namely zeolite, as a sand substitute in porous concrete. Zeolite is a hydrated alumina-silica composite containing cations or alkaline earth metals [7]. Zeolite is a mineral made from SiO2. It is one of the components of cement and is useful as a filler in concrete due to its sand-like properties.

The selection of this zeolite additive is also based on the material which is still easy to obtain and the price is relatively cheap, which is only around Rp 7000/kg, also based on research that has been carried out where zeolite is used as a substitute for sand in normal concrete which gets good results, namely in terms of increasing compressive strength, which is one of the reasons for using zeolite in this study. A study entitled "Analysis of the Use of Zeolite as a Sand Substitute for Normal Concrete Compressive Strength" using variations of 0%, 7.5%, and 12.5% showed an increase. According to the data obtained, the highest increase was found at the 12.5% variation, reaching 18.80 MPa, compared to the 0% variation, which reached 15.53 MPa [8].

Therefore, the purpose of substituting sand with zeolite, where in porous concrete there is the use of sand in accordance with ACI 522R-10 as a filler for porous concrete, is expected that the use of this zeolite can increase the compressive strength according to the predetermined plan so that it can fulfill the planning as an alternative material for road paving in Indonesia.

1.1 Porous concrete

Porous concrete commonly known as pervious concrete, it is a special type of concrete with high porosity applied as a concrete slab that allows rainwater and water from other sources to pass through, thereby reducing surface runoff and raising the water table. This high porosity is achieved by interconnected voids. Pervious concrete typically uses little or no fine aggregate and has sufficient cement paste to coat the surface of the coarse aggregate and maintain interconnected pores. Pervious concrete is traditionally used for parking lots, traffic signal areas, and pedestrian walkways [4].

The term pervious concrete typically describes a material with a near-zero open slump rate composed of Portland cement, little or no fine aggregate, admixtures, and water. This combination produces a hardened material with interconnected pores, ranging in size from 0.08 to 0.32 inches (2 to 8 mm), which allow water to pass through easily. Void content can range from 15% to 35% with a typical compressive strength of 400 to 4000 psi (2.8 to 28 MPa). Drainage rates in pervious concrete pavements will vary depending on aggregate size and mix density, but are generally in the range of 81 to 730 L/min/m2 [5].

Porous concrete has a rougher texture than dense, conventional concrete, resulting from the cavities within the concrete. When used for pavement, this rough, hollow texture allows porous concrete to have a lower surface temperature than flexible and conventional rigid pavements due to the smaller evaporation surface area. Furthermore, the rough texture also makes the surface of porous concrete rougher than conventional pavements.

Characteristics of Porous Concrete. The specific gravity of non-porous concrete is generally around 70% of that of conventional concrete when made with the same materials. The specific gravity of non-porous concrete using natural aggregates varies from 1680 to 1920 kg/m3. Tests of clinker aggregates have yielded a specific gravity of 961 kg/m3 [9]. Porous concrete has a relatively low compressive strength compared to conventional concrete. According to ACI 522R-10, the average compressive strength of porous concrete ranges from 2.8 MPa to 28 MPa. Therefore, porous concrete is only suitable for pavement applications with light traffic loads, such as sidewalks, parking lots, pedestrian paths, residential streets, and parks. Porosity is the ratio of the volume of air voids to the total volume of a porous concrete specimen. In porous concrete, the porosity value is significantly influenced by the size of the air voids. The larger the air voids, the greater the porosity value, meaning the porous concrete can drain water quickly. The greater the porosity value, the less strength the porous concrete has due to the reduced bond between the aggregate and cement. According to ACI 522R 10, 2011, the permeability value for porous concrete ranges from 0.14 to 0.22 cm/second. Permeability can be determined by conducting a test using the falling head permeability principle, which measures the time required for the water level to fall from the upper to the lower boundary. Permeability values are usually expressed in cm/second.

Porous Concrete Composition Materials. Porous concrete is generally composed of the main materials of Portland cement as a binder, fine aggregate (sand) to fill voids and provide texture, coarse aggregate (gravel or crushed stone) to provide compressive strength, and water to trigger the cement hydration reaction. Furthermore, in the development of porous concrete (pervious concrete), the amount of water and cement paste is made limited to form continuous pore cavities, thus allowing water to flow through the concrete. This composition can be supplemented with additional materials (admixtures) such as superplasticizers to increase workability without adding water, or silica fume and fly ash to improve mechanical properties and durability. This combination of materials produces concrete with adequate strength while functioning as an environmentally friendly material because it is able to support natural drainage systems.

1.2 Zeolite

Zeolites are hydrated aluminosilicate chemical compounds containing sodium, potassium, and barium cations. In general, zeolites have a unique molecular structure, where silicon atoms are surrounded by four oxygen atoms, forming a regular network. In some places in this network, silicon atoms are replaced by aluminum atoms, which are coordinated with only three oxygen atoms. These aluminum atoms only have a 3+ charge, while silicon itself has a 4+ charge. The presence of these aluminum atoms gives the zeolite a negative charge. This negative charge is what allows zeolites to bind cations [10].

Based on the description, it can be concluded that zeolite is a porous mineral and has the same properties as other silica minerals. Zeolite from molecular interactions when there is a complex forming physical absorption (Van der Waals forces), chemical absorption (electrostatic forces), coordination of hydrogen bonds. The effectiveness of water absorption depends on the nature of the adsorbed species, ion exchange, solid and humidity of the zeolite acid system. The cavities in zeolite molecules contain active groups in the intercrystalline channels, allowing them to act as catalyst carriers. The chemical composition of zeolite minerals typically consists of SiO2, Al2O3, Fe2O3, and CaO, which are the dominant oxides. Other oxides constitute only a few percent of the cement's weight.

Zeolites, with their framework structure, have a large surface area and act as channels for filtering ions and molecules (molecular sieving). Zeolites' role as filters or molecular separators is based on the differences in shape, size, and polarity of the molecules being filtered. This property is due to the pore size of zeolites. Molecules smaller than the pore size can pass through, while those larger than the pore size are retained.

1.3 Silica Fume

According to the ASTM-C1240-03 standard specification for silica fume for use in hydraulic cement concrete and mortar, silica fume is a material containing 2, a very fine, spherical material with a diameter of 1/100th the diameter of cement. Silica fume plays a crucial role in influencing the chemical and mechanical properties of concrete. Geometrically, silica fume fills the cavities between the cementitious materials, reducing the pore diameter and the total pore volume.

The use of silica fume in low amounts (below 3% of the cement weight) does not result in higher concrete strength because the amount of silica fume will not be sufficient to cover the entire surface of the coarse aggregate particles. However, the beneficial use of silica fume is also limited to no more than 10% of the cement weight used. Therefore, excessive use of silica fume will not cover the aggregate surface.

Several studies have shown that adding silica fume significantly affects concrete's compressive strength. Silica fume was added to porous concrete at an optimal concentration of 7% [6]. In study entitled "The Effect of Using Silica Fume as an Additive in Flowing Concrete," also found an increase in compressive strength of 7.5% at the optimal concentration [11].

2 Methodology

This type of research is a full quantitative research type using the true experimental design method in the laboratory. Before a test object is designed and manufactured, it is necessary to identify the characteristics of its constituent materials. The characteristic tests performed are as follows:

2.1 Cement

The type of cement used was PPC, produced by PT. Semen Padang. Tested characteristics included cement fineness (SNI 15-2530-1991), specific gravity (SNI 15-2531-1991), normal consistency (SNI 03-6826-2002), and setting time (SNI 03-6827-2002).

2.2 Coarse Agregate

The coarse aggregate used in this study was crushed stone with a heterogeneous shape and a maximum size of 10 mm. The characteristics tested included sieve analysis (SNI 103-2834-2000), unit weight (SNI 03-4803-1998), silt content (SNI 03-2816-2014), specific gravity (SNI 03-1969-2008), and aggregate wear (SNI 2417-2008).

2.3 Preparation of test speciments

Zeolite variations used as a substitute for porous concrete were 12.5%, 17.5%, 22.5%, and 27.5% of the initial sand weight, with five test specimens for each variation at 28 days. In this porous concrete, 7% silica fume is used. The procedure for making test specimens includes:

1. Prepare all necessary equipment.
2. Prepare and weigh all required materials according to the plan: coarse aggregate, fine aggregate, cement, water, silica fume, and zeolite, using the mix design plan developed in accordance with ACI 522R 10, 2011.
3. Mix the coarse aggregate, sand, cement, silica fume, and zeolite in a dry state in a mixer.
4. Mix until smooth and a uniform color is achieved.
5. Add water as needed while stirring until evenly distributed.
6. Immediately pour the evenly mixed mixture into the mold. Smooth the surface with a trowel.
7. Allow the mold to dry for 24 hours before removing it.
8. Cure the porous concrete.

3. Results and Discussion

Porous concrete compressive strength testing was conducted using a concrete compressive strength testing machine. Based on the porous concrete compressive strength testing conducted at the Concrete Laboratory of Civil Engineering, State University of Medan, the results of the compressive strength tests are shown in the Table 1. The compression test results showed that porous concrete containing 22.5% zeolite had the highest compressive strength (4.62 MPa), while porous concrete containing 27.5% zeolite had the lowest compressive strength (2.22 MPa).

Table 1. Compressive Strength Results of Porous Concrete at 28 Days

Porous Concrete Variation	Sample Number	Weight (kg)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
0% Zeolite	1	9,029	3,11	3,33
	2	9,006	2,94	
	3	8,875	2,22	
	4	9,031	4,91	
	5	9,019	3,46	
12,5% Zeolite	1	8,603	3,94	3,40
	2	8,394	3,42	
	3	8,848	4,10	
	4	8,541	3,56	
	5	8,338	2,07	
17,5% Zeolite	1	8,671	4,60	3,64
	2	8,359	3,39	
	3	8,332	3,42	
	4	8,539	3,71	
	5	8,357	3,10	
22,5% Zeolite	1	8,994	5,47	4,62
	2	8,978	4,57	
	3	8,601	4,83	
	4	8,663	4,15	
	5	8,136	4,08	
27,5% Zeolite	1	8,410	2,02	2,22
	2	8,616	2,02	
	3	8,480	1,84	
	4	8,474	2,97	
	5	8,544	2,25	

From the results of research at the Civil Engineering Concrete Laboratory, Medan State University, the results of porous concrete porosity testing were obtained, as shown in **Table 2**.

Table 2. Porosity Test Results

% Zeolite	**Sample**	**Total Mass (kg)**	**Density (kg/m3)**	**Volume (m3)**	**Unit Weight of Concrete (kg)**	**Porosity (%)**
0%	1	9,029	1703,58	0,0053	2006,54	15,10
	2	9,006	1699,25	0,0053	2006,54	15,31
	3	8,875	1674,53	0,0053	2006,54	16,55
	4	9,031	1703,96	0,0053	2006,54	15,08
	5	9,019	1701,70	0,0053	2006,54	15,19
12,5%	1	8,603	1623,21	0,0053	2006,54	19,10
	2	8,394	1583,77	0,0053	2006,54	21,07
	3	8,848	1669,43	0,0053	2006,54	16,80
	4	8,541	1611,51	0,0053	2006,54	19,69
	5	8,338	1573,21	0,0053	2006,54	21,60
17,5%	1	8,671	1636,04	0,0053	2006,54	18,46
	2	8,559	1614,91	0,0053	2006,54	19,52
	3	8,532	1609,81	0,0053	2006,54	19,77

	4	8,539	1611,13	0,0053	2006,54	19,71
	5	8,557	1614,53	0,0053	2006,54	19,54
22,5%	1	8,994	1696,98	0,0053	2006,54	15,43
	2	8,978	1693,96	0,0053	2006,54	15,58
	3	8,601	1622,83	0,0053	2006,54	19,12
	4	8,663	1634,53	0,0053	2006,54	18,54
	5	8,136	1535,09	0,0053	2006,54	23,50
27,5%	1	8,410	1586,79	0,0053	2006,54	20,92
	2	8,616	1625,66	0,0053	2006,54	18,98
	3	8,480	1600,00	0,0053	2006,54	20,26
	4	8,474	1598,87	0,0053	2006,54	20,32
	5	8,544	1612,08	0,0053	2006,54	19,66

To test the effect of zeolite addition on the compressive strength and porosity of porous concrete containing silica fume, a series of statistical tests were conducted to ensure the validity of the data and the significance of the results (see **Table 3**). The analysis steps began with a normality test to verify whether the data were normally distributed, followed by a homogeneity of variance test to ensure equality of variance between groups, and concluded with an ANOVA test to determine whether there were significant differences between the zeolite addition variations on the concrete's compressive strength.

Table 3. Normality test results of compressive strength

	Variation	**Kolmogorov-Smirnov***			**Shapiro-Wilk**		
		Statistic	df	Sig.	Statistic	df	Sig.
Compressive strength_value	variation 0%	.386	5	.014	.679	5	.006
	variation 12.5%	.185	5	.200*	.943	5	.689
	variation 17.5%	.389	5	.013	.730	5	.019
	variation 22.5%	.217	5	.200*	.893	5	.370
	variation 27.5%	.224	5	.200*	.968	5	.861

Table 4. Normality test results of porosity value

	Variation	**Kolmogorov-Smirnov***			**Shapiro-Wilk**		
		Statistic	df	Sig.	Statistic	df	Sig.
Porosity value	variation 0%	.386	5	.014	.679	5	.006
	variation 12.5%	.185	5	.200*	.943	5	.689
	variation 17.5%	.389	5	.013	.730	5	.019
	variation 22.5%	.217	5	.200*	.893	5	.370
	variation 27.5%	.224	5	.200*	.968	5	.861

Based on the results of the Kolmogorov-Smirnov and Shapiro-Wilk tests in the Tests of Normality table, all variations in zeolite addition percentage (0%, 12.5%, 17.5%, 22.5%, and 27.5%) had a significance value greater than 0.05 (see **Table 4**). This indicates that the concrete compressive strength data is normally distributed for each variation. A normal distribution allows the use of parametric statistical methods such as ANOVA to analyze the data. This normal distribution ensures that changes in compressive strength due to variations in zeolite addition can be analyzed using parametric statistical methods, thus increasing the validity of the analysis results.

The homogeneity of variance test (Levene's Test) shows a significance value above 0.05 for tests based on Mean, Median, and Trimmed Mean, so it is concluded that the data has homogeneous variance among the zeolite addition variation groups (see **Table 5 dan Table 6**). This means that the assumption of homogeneity of variance between zeolite addition variation groups is met. This means that the compressive strength variability for each zeolite addition variation is considered uniform or does not differ significantly between groups. In this study, homogeneity of variance indicated that the effects of zeolite addition at each level (0% to 27.5%) could be compared fairly and without bias caused by differences in variability between groups. By meeting homogeneity of variance, differences between zeolite variations could be evaluated more accurately.

Table 5. Homogeneity of variances test of compressive strength and porosity value

		Levene Statistic	df1	df2	Sig.
Compressive strength value	Based on Mean	.514	4	20	.727
	Based on Median	.371	4	20	.826
	Based on Median and with adjusted df	.371	4	15.280	.825
	Based on trimmed mean	.480	4	20	.750
Porosity value	Based on Mean	2.326	4	20	.092
	Based on Median	2.286	4	20	.096
	Based on Median and with adjusted df	2.286	4	8.904	.140
	Based on trimmed mean	2.251	4	20	.100

The ANOVA test aims to determine whether there are significant differences in concrete compressive strength and porosity between various variations of zeolite addition. ANOVA is used to analyze the average differences between groups, and the results will indicate whether the variation in zeolite addition has a significant impact on concrete compressive strength. If the test results show a significant difference, further tests such as Tukey HSD will be carried out to determine which groups are significantly different.

Table 6. ANOVA Test Results of Compressive Strength Value

	Sum of Square	df	Mean Square	F	Sig.

Between Groups	14.708	4	3.677	7.424	.001
Within Groups	9.906	20	.495		
Total	24.614	24			

The ANOVA test results showed that the significance value for the effect of zeolite addition variations on concrete compressive strength was 0.001, which is much smaller than 0.05. This indicates a significant difference in concrete compressive strength between the different zeolite variations. Furthermore, the F-value of 7.424 indicates that the effect of zeolite addition on concrete compressive strength is quite significant.

Table 7. Pos Hoc Test results of compressive strength value

(I) VARIATION	**(J) VARIATION**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	Upper Bound
variation 0%	variation 12,5%	-.07000	.44511	1.000	-1.4020	1.2620
	variation 17,5%	-.31600	.44511	.952	-1.6480	1.0160
	variation 22,5%	-1.29200	.44511	.060	-2.6240	.0400
	variation 27,5%	1.11000	.44511	.132	-.2220	2.4420
variation 12,5%	variation 0%	.07000	.44511	1.000	-1.2620	1.4020
	variation 17,5%	-.24600	.44511	.980	-1.5780	1.0860
	variation 22,5%	-1.22200	.44511	.082	-2.5540	.1100
	variation 27,5%	1.18000	.44511	.098	-.1520	2.5120
variation 17,5%	variation 0%	.31600	.44511	.952	-1.0160	1.6480
	variation 12,5%	.24600	.44511	.980	-1.0860	1.5780

	variation 22,5%	-.97600	.44511	.223	-2.3080	.3560
	variation 27,5%	1.42600*	.44511	.032	.0940	2.7580
variation 22,5%	variation 0%	1.29200	.44511	.060	-.0400	2.6240
	variation 12,5%	1.22200	.44511	.082	-.1100	2.5540
	variation 17,5%	.97600	.44511	.223	-.3560	2.3080
	variation 27,5%	2.40200*	.44511	.000	1.0700	3.7340
variation 27,5%	variation 0%	-1.11000	.44511	.132	-2.4420	.2220
	variation 12,5%	-1.18000	.44511	.098	-2.5120	.1520

Based on the post hoc test (Tukey HSD), significant differences were observed between the 17.5% and 27.5% variations, as well as between 22.5% and 27.5%. This indicates that adding zeolite up to 22.5% increases the compressive strength, while further additions up to 27.5% significantly decrease the compressive strength (see **Table 7**).

Zeolite additions up to 22.5% showed a positive effect on concrete compressive strength, but higher additions (such as 27.5%) significantly reduced the compressive strength. This is in line with the assumption that zeolite additions at certain levels can increase concrete strength, but at too high levels, additives such as zeolite can cause structural weaknesses because the physical properties of zeolite begin to dominate the concrete mixture. Based on the results of the normality test, homogeneity of variance, and ANOVA, it can be concluded that the addition of zeolite has a significant effect on the compressive strength of concrete. The normal distribution of the data and the homogeneity of variance allowed the ANOVA analysis to produce accurate results.

Zeolite additions up to 22.5% resulted in optimal concrete compressive strength, but additions exceeding this level, such as 27.5%, significantly reduced the compressive strength. These results support the conclusion that there is an optimal limit for zeolite addition in porous concrete containing silica fume, where excessive addition can actually reduce the structural strength of the concrete.

Based on the results, it may cause of zeolite contains silica (SiO_2) and alumina (Al_2O_3), which can react pozzolanically with calcium hydroxide ($Ca(OH)_2$) produced from the hydration of Portland cement. This reaction produces calcium silicate hydrate (C-S-H), a compound that contributes to the strength and density of concrete. Because zeolite is sand-like in size, it can partially fill the micropores in concrete. This micropore filling improves the concrete's microstructural density, which reduces the number of voids and slightly increases compressive strength. However, because the porous structure of zeolite itself also absorbs water, this compressive strength-enhancing effect is limited.

Table 8. ANOVA Test Results of Porous Concrete Porosity

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	68.804	4	17.201	5.510	.004
Within Groups	62.437	20	3.122		
Total	131.241	24			

Table 9. Post Hoc Test Results of Porous Concrete Porosity

(I) VARIATION	(J) VARIATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
variation 0%	variation 12,5%	-4.20600*	1.11747	.010	-7.5499	-.8621
	variation 17,5%	-3.95400*	1.11747	.016	-7.2979	-.6101
	variation 22,5%	-2.98800	1.11747	.094	-6.3319	.3559
	variation 27,5%	-4.58200*	1.11747	.004	-7.9259	-1.2381
variation 12,5%	variation 0%	4.20600*	1.11747	.010	.8621	7.5499
	variation 17,5%	.25200	1.11747	.999	-3.0919	3.5959
	variation 22,5%	1.21800	1.11747	.810	-2.1259	4.5619
	variation 27,5%	-.37600	1.11747	.997	-3.7199	2.9679
variation 17,5%	variation 0%	3.95400*	1.11747	.016	.6101	7.2979
	variation 12,5%	-.25200	1.11747	.999	-3.5959	3.0919
	variation 22,5%	.96600	1.11747	.906	-2.3779	4.3099
	variation 27,5%	-.62800	1.11747	.979	-3.9719	2.7159
variation 22,5%	variation 0%	2.98800	1.11747	.094	-.3559	6.3319
	variation 12,5%	-1.21800	1.11747	.810	-4.5619	2.1259
	variation 17,5%	-.96600	1.11747	.906	-4.3099	2.3779
	variation 27,5%	-1.59400	1.11747	.619	-4.9379	1.7499
variation 27,5%	variation 0%	4.58200*	1.11747	.004	1.2381	7.9259

	variation 12,5%	.37600	1.11747	.997	-2.9679	3.7199
	variation 17,5%	.62800	1.11747	.979	-2.7159	3.9719
	variation 22,5%	1.59400	1.11747	.619	-1.7499	4.9379
***. The mean difference is significant at the 0.05 level.**						

ANOVA showed a significant difference between the zeolite addition variation groups, with a significance value of 0.004 ($p < 0.05$) (see **Table 8**). Further analysis using Tukey's HSD identified that the 0% variation was significantly different from the 12.5%, 17.5%, and 27.5% variations, while the other variations did not show any significant differences (see **Table 9**). This significant difference indicates that zeolite addition at certain proportions does have a significant effect on concrete porosity. The 0% variation, which differed significantly from several other variations, confirms that zeolite addition can alter concrete porosity characteristics. However, variations between specific proportions did not show significant differences, possibly indicating a limit to the effect of zeolite addition after reaching a certain proportion.

From the Tukey HSD results, it can be concluded that the addition of zeolite significantly affects porosity, especially when compared to the 0% variation. However, the other variations showed no significant differences. This means that adding zeolite at certain proportions will have a direct impact on porosity, but the effect may not be linear. These results demonstrate the effective zeolite content in influencing concrete porosity. The 0% variation, which differs significantly from several other variations, can serve as a basis for comparing the performance of concrete without zeolite with that containing zeolite at various concentrations. Therefore, the addition of zeolite affects the porosity of porous concrete, although the effect varies depending on the proportion used.

Overall, the optimum zeolite content for maximum compressive strength and porosity control is 22.5%. At this content, the concrete achieves the best balance between structural strength and porosity, suitable for porous concrete. Adding zeolite above 22.5% is not recommended, as it can damage the concrete's compressive strength. Meanwhile, for porosity, adding zeolite at concentrations above 12.5% tends to increase porosity, but the difference is not significant at higher concentrations.

This study confirms that zeolite has limitations in its use as an additive in porous concrete. Optimal use is at the right concentration to improve concrete performance without compromising its strength.

4 Conclusion

The compressive strength of porous concrete obtained from this study is quite varied. The percentage levels of zeolite determined in the study are 12.5%, 17.5%, 22.5%, and 27.5%. The compressive strength of porous concrete obtained with the addition of 12.5% zeolite is 3.40 MPa, while for 17.5% zeolite it is 3.64 MPa, for 22.5% zeolite the compressive strength is 4.62

MPa, and for 27.5% zeolite the compressive strength is 2.22 MPa. From these four variations, it is clear that the optimum level of zeolite use is 22.5%, because at 22.5% the compressive strength increases from 17.5% and then decreases at 27.5%. Based on the ACI 522-R-10 standard, which stipulates a minimum compressive strength of 2.8 MPa for porous concrete, the compressive strength of porous concrete using zeolite at 12.5%, 17.5%, and 22.5% concentrations meets the requirements, while the compressive strength of porous concrete using zeolite at 27.5% concentrations does not meet the requirements of the standard. It can be concluded that the compressive strength of porous concrete (without sand) decreases when using zeolite exceeding 22.5%.

The porosity of porous concrete is inversely proportional to its compressive strength. This means that porosity increases as its compressive strength decreases. The porosity percentage of porous concrete with 12.5% zeolite is 19.65%, with 17.5% zeolite it is 19.40%, with 22.5% zeolite it is 18.43%, and with 27.7% zeolite it is 20.03%. The highest porosity is found at 27.5% zeolite, but the optimum porosity is found at 22.5%. This is because, in addition to maintaining porosity, it must also maintain compressive strength to maintain the optimum compressive strength compared to other concentrations. This means that porosity and compressive strength must be balanced and not biased, not solely based on compressive strength or porosity. Based on the ACI 522R-10 standard, which stipulates a porosity percentage of porous concrete ranging from 15% to 30%, it is certain that all porous concrete meets this requirement as it falls within the specified percentage range.

References

[1] Zuna, H. T. (2023). Proposi penggunaan beton dalam kontruksi infrastruktur sumber daya air hingga 80 persen.

[2] Hatmoko, J. U. D., Setiadji, B. H., & Wibowo, M. A. (2019). Investigating causal factors of road damage: a case study. MATEC Web of Conferences, 258, 02007. https://doi.org/10.1051/matecconf/201925802007

[3] Abadjieva, T., & Sephiri, P. (2000). Investigations on Some Properties of no-Fines Concrete. University of Botswana.

[4] NRMCA. (2004). Pervious Concrete - An Overview.

[5] ACI R 522. (2011). Technical Documents.

[6] Hidayat, A. K., Nursani, R., Faiz, S., & Huseiny, M. S. Al. (2022). Analisis Kuat Tekan dan Laju Infiltrasi pada Beton Porous K-200 dengan Tambahan Sika Fume. Akselerasi : Jurnal Ilmiah https://doi.org/10.37058/aks.v4i1.5423

[7] Poerwadi, M. R., Zacoeb, A., & Syamsudin, R. (2014). Pengaruh Penggunaan Mineral Lokal Zeolit Alam Terhadap Karakteristik Self-Compacting Concrete (Scc). Jurnal Mahasiswa Jurusan Teknik Sipil, 1(4), 1–10.

[8] Devialdy, G., Suryadi, A., & Sugiarto, A. (2023). Analisa Penggunaan Zeolite Sebagai Substitusi Pasir Terhadap Kuat Tekan Beton Normal. Jurnal Online Skripsi, 4(3), 1–9.

[9] Harber, P. J. (2005). Applicability of No-Fines Concrete as a Road Pavement. University of Southern Queensland.

[10] Simanjuntak, W., Delilawati Pandiangan, K., Sembiring, Z., & Simanjuntak, A. (2019). Liquid Fuel Production by Zeolite-A Catalyzed Pyrolysis of Mixed Cassava Solid Waste and Rubber Seed Oil. Oriental Journal of Chemistry, 35(1), 71–76. https://doi.org/10.13005/ojc/350108

[11] Mahendra, A. ihza, Rochmah, N., & Widhiarto, H. (2023). Pengaruh Penggunaan Silica Fume Sebagai Bahan Tambah Pada Beton Alir. Student Scientific Creativity Journal, amik.v1i4.1577