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Ratio Between Flexural Strength To Compressive Strength Geopolymer Concrete

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Abstract. Building infrastructure always chooses to use strong materials, low costs, easy maintenance and easily available materials. One of these materials is normal concrete which is one of the normal concrete making materials using Portland cement. The process of making Portland cement can cause damage to the environment due to greenhouse emissions, so research is needed to create environmentally friendly concrete, one of which is geopolymer concrete. In geopolymer concrete there is still not too much research done when compared to normal concrete. In this study want to know the relationship between the compressive strength results and the flexural strength results in geopolymer concrete which is represented by a formula in the form of a ratio of the results of the two tests. The ratio obtained from the study will be compared with the ratio of ACI 318 $0.62\sqrt{f'c}$. The compressive strength test used a cylindrical specimen with a size of 15×30 cm and a flexural strength test used a beam-shaped test object with a size of 53×15×15 cm. The results of the research that have been carried out have obtained the ratio of compressive strength and flexural strength in geopolymer concrete $0.477\sqrt{f'c}$ where the ratio value is below the ratio set by ACI 318.

Keywords: Flexural Strength, Compressive Strength, Geopolymer Concrete

1. Introduction

As time goes on, many infrastructure developments in Indonesia have used strong materials, relatively low costs, easy maintenance and easily available materials. One of the materials for the construction of the infrastructure is normal concrete. One of the materials used for normal concrete is Portland cement. Portland cement has become a topic of discussion lately and the surrounding community is also disturbed, because the cement manufacturing process causes greenhouse gas emissions and causes environmental pollution. This proves that it is better to create an environmentally friendly concrete such as geopolymer concrete.

Geopolymer concrete is an environmentally friendly concrete where the use of Portland cement as a base is a binder which is replaced by other materials such as fly ash and rise husk ash which contain silica and aluminum mixed with alkaline liquid to be used as a binder for the manufacture of geopolymer concrete. The use of a combination of fly ash type F produces a high compressive strength and the addition of molarity to geopolymer concrete produces a large compressive strength due to the viscosity of the NaOH liquid making the concrete have a small number of pores. Curing on geopolymer concrete if the longer the curring time is carried out, the higher the yield of flexural strength in geopolymer concrete. The temperature curing temperature is very influential on the results of the compressive strength value and the higher the flexural strength value will produce a good value but if the temperature is too high it will worsen the concrete itself [1]. The value of compressive strength and flexural strength can be related using a correlation formula which aims to estimate a value if one of the values is known.

In normal concrete/cement concrete, the value of the relationship between compressive strength and flexural strength according to ACI 318 get the formula $0.62\sqrt{f'c}$. The value of the ratio of flexural strength to compressive strength in geopolymer concrete, the results obtained are not much different from conventional concrete, namely 10%-15% of the results of flexural strength to compressive strength. Judging from previous geopolymer concrete research, the requirements for the relationship between compressive strength and flexural strength have not been found in geopolymer concrete. Therefore, it is necessary to conduct experimental research on the relationship between flexural strength and compressive strength of geopolymer concrete.

The formulation of the problem to be raised in this study is how the relationship between flexural strength and compressive strength in geopolymer concrete. This study also aims to determine the relationship between flexural strength and compressive strength of concrete where the relationship value in geopolymer concrete does not yet have an official reference such as cement concrete in ACI 318 $0.62\sqrt{f'c}$. In addition, the value of this relationship can be used as a reference for making construction work. The scope of this research is using the results of the flexural strength test with a beam test object of 53×15×15 cm and compressive strength with a cylindrical specimen of 15×30 cm geopolymer concrete.

2. Literature Review

2.1. Geopolymer Concrete

Geopolymer is a polymer of inorganic alumina-silica compounds, which are mostly formed from silicon (Si) and aluminum (Al) compounds. Geopolymer concrete is concrete that does not use cement as a concrete binder. In the manufacture of geopolymer concrete, several alternative materials can be used as binders to replace cement. One of the binders used in the manufacture of geopolymer concrete is fly ash. Fly ash contains silica (Si) and aluminum (Al). The chemical compounds contained in the fly ash will react if given an alkaline solution to form a geopolymer paste. Silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and alkaline liquid as an activator solution are binders used in geopolymer concrete that uses combustion waste such as fly ash [2].

2.1.1. Fly Ash. Fly ash is a material that can be used as a substitute for cement. Fly ash has a function as a binder after being mixed with an alkaline solution. The fly ash was tested by SEM (Scanning Electron Microscope) and XRF (X-Ray Fluorescence) testing to determine the grain size and chemical composition of the fly ash. Fly ash material can be used as a substitute for cement which is not environmentally friendly.

2.1.2. Alkaline Solution/ Activator. Alkaline solution or activator is a solution of 2 main mixtures, namely NaOH (Sodium Hydroxide) in the form of a pallet and mixed with water to get the molarity that will be used for concrete mixtures and Na_2SiO_3 (Sodium Silicate). The concentration or molarity value of NaOH is very influential on the compressive strength of geopolymer concrete. However, NaOH has a low water content so it greatly affects workability of geopolymer concrete [3]. NaOH mixture used to obtain the molarity was determined using the mixture ratio from the research of Rajamane et al. [4]. Sodium silicate plays a role in accelerating the polymerization process in geopolymer concrete.

2.2. Curing Of Specimens

Geopolymer concrete also requires maintenance so that the quality obtained is as planned and the results are optimal. Usually there are concrete curing that use the immersion method and use the curing method with the specified hour and temperature. The use of high temperatures will produce high compressive strength. In addition to high temperatures, curing time also greatly affects the strength of concrete [5].

2.3. *The Results Of Previous Studies*

This study requires the results of previous studies to support the results of research that has been done. In previous studies there have been several conclusions that can be drawn regarding the relationship between compressive strength and flexural strength of geopolymer concrete. The conclusion is in the form of a ratio that has been summarized in Table 1.

Table 1. Reference relationship

Reference	Relationship
ACI 318	$0.62\sqrt{f'c}$
Waqas *et al*., 2021 [6]	$0.25\,(f'c)^{2/3}$
Hamidi, Aslani and Valizadeh, 2020 [7]	$0.00026\,\rho\,(f'c)^{0,24}$
Phoo-ngernkham *et al*., 2016 [8]	$2.78\sqrt{f'c} - 13.95$
Leemann and Hoffmann, 2005 [9]	$0.11\,(f'c)$

3. Experimental Procedure

3.1. *Material Preparation*

Before making concrete, it is necessary to test and prepare the material to be used.

3.1.1 Coarse Aggregate. Coarse aggregate using crushed stone that has been washed until clean. Coarse aggregate using a size that passes through a 1.5" sieve and is retained by sieve No. 4 with good gradation. The results of the water content test is 1.36%, specific gravity is 2.5, absorption is 2.21%, material finer is 0.86%, and abrasion is 16.9%. In the test results of the coarse aggregate material, it will be used as a reference for making mix designs. The coarse aggregate used needs to be prepared for drying until the saturated surface dry.

3.1.2 Fine Aggregate. Fine aggregate using Bangka sand that has been washed until clean with a size that passes sieve no. 4 with good gradation. The results of the water content test is 1.11%, specific gravity is 2.58, absorption is 1.63%, and organic content test is 11. In the test results, the fine aggregate material will be used as a reference for making mix designs. The fine aggregate used needs to be prepared for drying until the saturated surface dry.

3.1.3 Fly Ash Material. The fly ash material used from Electric Steam Power Plant in Suralaya, Banten. Parameter test result of specific gravity fly ash is 2.42. The results of this XRF when compared with ASTM C 618 belong to class F. The results of the SEM test can be seen at Figure 1 that the fly ash grains are irregularly shaped and the grain size is between 12.06 – 0.60 microns and Table 2 it can be seen that the XRF test results, amount of SiO_2, Al_2O_3 and Fe_2O_3 values are 75.15%. Preparation of fly ash needs to be done, namely fly ash is filtered first using sieve No. 30 (0.60 mm) and will be used in the concrete mix.

Table 2. Chemical composition of fly ash

Compound	%	Compound	%
SiO_2	37.385	BaO	0.349
Fe_2O_3	25.223	SrO	0.275
CaO	14.084	Na_2O	0.173
Al_2O_3	12.543	ZrO_2	0.144
K_2O	3.474	ZnO	0.121
TiO_2	2.757	Cl	0.048
P_2O_5	1.638	Rb_2O	0.045
MgO	0.855	Br	0.016
SO_3	0.853	Y_2O_3	0.015

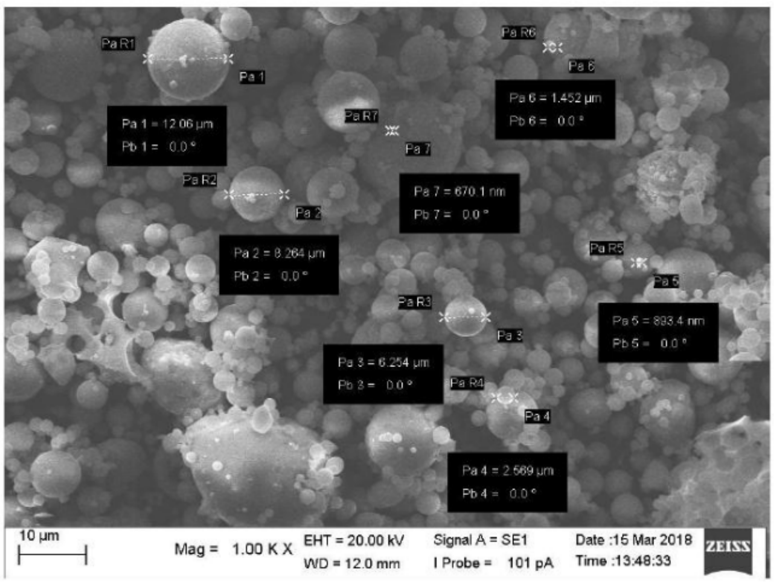

Figure 1. SEM test results on fly ash

3.1.4 Sodium Silicate (Na_2SiO_3). The sodium silicate used contains 52.79% Na_2O and SiO_2. This material can be prepared on the same day as the casting time. Preparation is carried out by weighing according to the needs for the casting. After the material is prepared, it is stored properly so that it does not come into direct contact with air.

3.1.5 Natrium Hydroxida (NaOH). NaOH to be used varies as 8M, 12M, 14M and 16M. The molarity is used as needed to get the desired design quality. The NaOH solution prepared one day before mixing, material is stored and tightly closed until mixing time.

3.2. Mix Design

In this study, the quality of the plan to be planned is between 10-50 MPa. So it is necessary to modify the molarity and amount of paste to obtain the planned quality. The molarity level used is between 8 to 16 molarity. If use a higher molarity level, it can make good quality concrete. The ratio of paste to concrete can also affect the quality of concrete. The concrete paste to be used is between 500 - 700 concrete paste. Each mix design is tested continuously with a series of tests for compressive strength and flexural strength. The mix design will be evaluated and modified continuously until it gets the planned compressive strength.

3.3. Specimen Preparation

Before mixing, it is necessary to prepare a test specimen mold as needed. The test specimens are molded in the form of cylinders and blocks. The number of molds that need to be prepared are 3 cylindrical molds size of 15 × 30 cm and 2 beam molds size of 53 × 15 × 15 cm. The mixing stage can be seen in Table 3. After mixing process complete, fresh concrete immediately put into the mold. The mold is placed in a safe place for 24 hours before opening and curing.

Table 3. Geopolymer concrete mixing process

Stage	Mixing Stage	Time
1	Adding fine aggregate and fly ash to mixer Turn on the mixer	-
2	Mixing the materials	2 minute
3	Adding coarse aggregate	2 minute
4	Adding Na_2SiO_3	2 minute
5	Adding NaOH	2 minute
6	After the mixture is evenly mixed, the slump test is immediately carried out	-

3.4. Curing Methods

Concrete that has been opened from the mold immediately curing. The Curing using steam curing. The steam curing process consists of (1) an initial delay prior to steaming for 24 hours, (2) a period for increasing the temperature from room temperature to 80°C for 1 hour, (3) a period for holding the maximum temperature constant in 80°C for 4 hours and (4) a period for decreasing the temperature from 80°C to room temperature for 1 hour. After steam curing process complete, the specimen will be stored until test in 28 days.

Figure 2. Steam curing

3.5. Specimen Testing

Specimen testing in this study consisted of compressive strength and flexural strength at the age of 28 days. Compressive strength is a test on concrete to find out how much pressure is obtained by concrete and the loading is carried out vertically with a loading speed of 0.26 ± 0.05 MPa/second referring to ASTM C39. Flexural strength is one of the tests on concrete to determine the flexural strength of concrete by providing a load on the concrete beam against two supports from a perpendicular direction to the plane until the test object breaks referring to ASTM C78 with the same test concept as Figure 3.

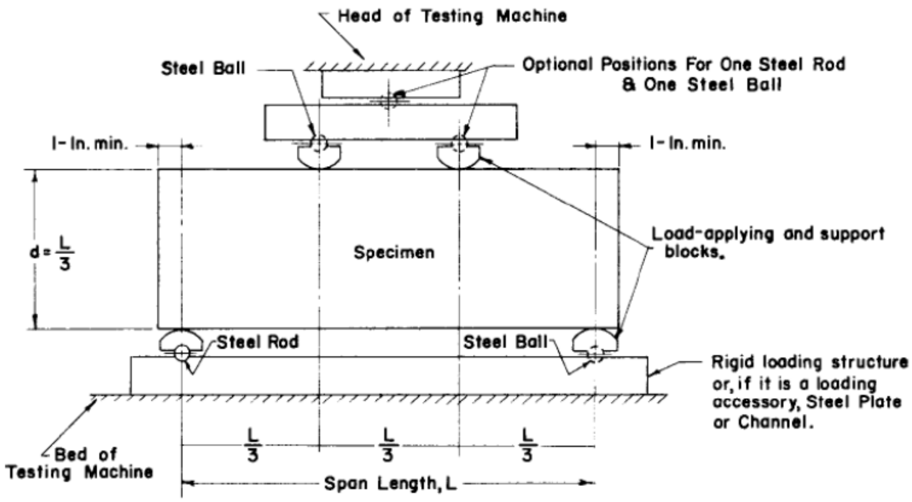

Figure 3. Testing of the beam test object (ASTM C78)

The steps for testing the flexural strength of the beam can be seen in Table 4:

Table 4. Flexural strength testing steps

Steps	Test Steps	Picture
1	Beam are weighed first	
2	The beam is given a help line according to ASTM C78 of L/3	
3	The beam that is ready to be tested can be placed on the prepared support plate	

4	Testing can be started with load the specimen continuously and without shock between 125 and 175 psi/min or 0.86 and 1.21 MPa/min	
5	Beam that have been rupture occurs, the results of the data can be recorded	

4. Result And Discussions

Table 5. Compressive strength and flexural strength

Molarity (M)	Compressive Strength (MPa)	Flexural Strength (MPa)	Molarity (M)	Compressive Strength (MPa)	Flexural Strength (MPa)
8	13.87	1.15	12	35.13	2.45
8	15.80	1.50	16	37.00	2.90
12	25.17	1.70	16	37.30	2.10
16	25.37	1.60	16	38.73	3.60
12	26.07	1.90	14	40.90	3.20
16	26.33	1.95	12	41.15	3.05
16	27.40	1.75	14	42.57	4.10
12	27.40	2.85	16	42.73	3.50
16	30.17	2.05	16	45.90	5.65
8	30.35	1.90	16	45.93	3.35
16	31.58	2.35	16	47.60	4.15
12	32.13	2.55	16	51.70	4.05
16	32.27	2.05	-	-	-

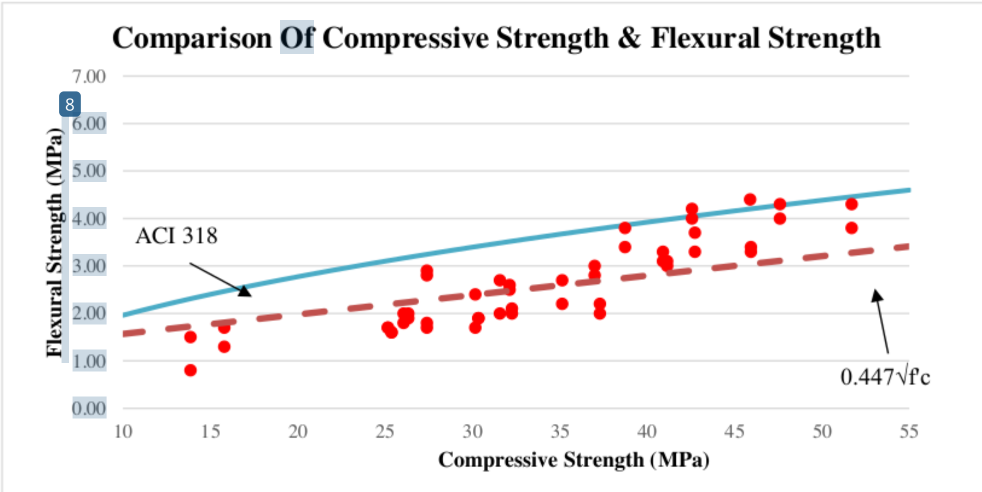

Figure 4. Comparison of compressive strength and flexural strength

The test results obtained for the compressive strength value are between 13.87-51.7 MPa with flexural strength of 1.15 to 5.65 MPa which can be seen in Table 5. The molarity value greatly affects the high and low values of compressive strength and flexural strength, the higher the molarity value used will get the high value the compressive strength and flexural strength. The flexural strength value obtained is still below the flexural strength requirements of ACI 318 which of $0.62\sqrt{f'c}$, but the compressive strength quality of 40 MPa and above already has the same flexural strength value as the ACI 318 requirement. The compressive strength and flexural strength values obtained in this study can be represented by the equation $0.447\sqrt{f'c}$.

5. Conclusions

The following are the conclusions drawn from this research:

- The addition of molarity to NaOH can improve the quality of the concrete.
- The results of the flexural strength test are still below the requirements of ACI 318.
- If the compressive strength value is above 40 MPa, the results of the flexural strength requirements of ACI 318 will be fulfilled.
- The results of the research that have been done that the relationship between compressive strength and flexural strength in geopolymer concrete can be represented by the formula $0.447\sqrt{f'c}$.

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