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Study of Modulus of Rupture on Geopolymer Concrete Temperature Difference Methods of Steam Curing

Muhammad Ujianto[1,2,*], *Masni A.* Majid[2], *Zakaria Sulthon* Aulia[1], *Yenny* Nurchasanah[1], *Budi* Setiawan[1] and *Abdul* Rochman[1]

[1]Department of Civil Engineering, Faculty of Engineering, Universitas Muhammadiyah Surakarta, Indonesia
[2]Faculty of Civil and Environmental Engineering Universiti Tun Hussein Onn Malaysia

Abstract. Geopolymer concrete is concrete without cement. Cement replacement due to cement production has resulted in a global warming effect. Fly ash as a substitute for cement is a waste of coal production containing pozzolan properties. Concrete must have reliable mechanical properties of the modulus of rupture. This research aims to study the influence of the modulus of rupture on the steam curing of geopolymer concrete-based fly ash as a substitute for cement and alkaline activator of 12 Mol NaOH: Na_2SiO_3 (3:1). The applied steam curing temperatures are 60°C, 70°C, and 80°C. After steam curing, the sample is stored at ambient curing and submerged in water. The sample beam is 15 x 15 cm x 60 cm to find the value of the modulus of rupture. The test results obtained a modulus of rupture concrete geopolymer steam curing temperature of 80 and ambient curing of 3.87 MPa. Steam curing of 70°C and ambient curing of 3,71 MPa. Steam curing of 60°C and the ambient curing is 2.71MPa. It can be concluded that the higher the steam curing temperature the value of the modulus of rupture is higher.

1 Introduction

The development of the world of construction is being carried out very steadily, so as not to leave Indonesia in the race to follow the development. The structure of a building is not far from the use of concrete. This selection is due to the advantages offered by concrete structures, which are easy to shape or mold, have high-pressure strength, are easy to work with, are weather resistant, and have high temperatures. In addition to having the advantages of concrete has shortcomings, one of them is not strong against the flexure or modulus of rupture. The modulus of rupture is the value of the maximum flexural strength acting on a simple beam of concrete before it collapses due to loading [1]. The tensile strength of concrete is measured by its flexural strength, often known as its modulus of rupture (MOR). It is a crucial feature in the design of structural concrete because it affects the flexural cracking, shear strength, deflection characteristics, and brittleness ratio of concrete. The conventional definition of tensile strength is as a function of compressive strength [2].

Along with the speed of construction, concrete materials are increasingly being used, especially concrete materials that are very easy to obtain. The search for materials through excessive exploitation will reduce the availability of materials in nature. The search for material with excessive exploitation will reduce the availability of material in nature. The annual use of concrete reaches approximately 8.8 million tons and will continue to increase from year to year due to the need for means and supplies [3]. Consumption of the volume of concrete used globally for construction projects exceeds 12 billion tons per year. To support that figure, cement production in 2001 reached 1.65 billion metric tons [4].

Cement is one of the environmentally unfriendly building materials. The consequences of cement production continuously have a considerable negative impact on environmental damage. The cement industry is becoming one of the contributors to the emission of CO_2 gases in the air, To produce 1 ton of cement, it produces approximately 1 ton of CO_2 gas as a by-product [5]. These gas emissions are one of the causes of global warming and climate change at the moment. There is a need for alternative materials to replace cement by utilizing waste from industrial production in accordance with global warming increases the importance of such waste utilization.

The Paiton Steam Electricity Mining Industry (PLTU) has unleashed one of Indonesia's largest electricity producers by using coal combustion as engine power. The result of the main product of this industry leaves some waste one of which is fly ash in 2015 PT PLTU Paiton produced 7.5 tons of fly ash per hour [6]. According to the report of the specific work visit of the IV DPR commission to the eastern Java province, the result of fly ash residues amounted to 114,660 tons during the period from June 2019 to 2020. The experts are trying to innovate to replace the use of cement with fly ash, which is beneficial in reducing CO_2 emissions from cement production and environmental pollution caused by the accumulation or deposition of coal-burning waste[7]. Fly

* Corresponding author: ujianto@ums.ac.id

ash has great potential as a substitute for cement given that the power generation of PLTU will continue for the next few years. The advantages of fly ash as a cement replacement material have shortcomings in the hardening time of the binder. To support the disadvantage, it is necessary to mix additional materials so that the concrete can react perfectly so that it meet workmanship standards and the length of hardening time.

The mixture that allows chemical compounds to form between fly ash and other materials is an alkaline solution. The solutions used are Na_2SiO_3 and NaOH as alkali activators.

Alkaline activators are chemicals used to react to the silica (Si) and alumina (Al) content. The activators use sodium silicate (Na_2SiO_3) which accelerates the polymerization reaction, while the alkaline solution uses sodium hydroxide (NaOH) which helps the inter-particle bonding process [8][9]. The application of cement replacement technology using fly ash is called geopolymer concrete. Geopolymers are the replacement of Portland cement as a binding material of concrete mixture with other materials such as fly ash, rise husk ash, and other materials that are rich in silica and aluminum [10].

This research will study the effect modulus of rupture on geopolymer concrete using fly ash as a cement substitute and activator 12 mol, with steam curing.

2 Research Methods.

The research was carried out using laboratory testing methods. This study seeks the value of the modulus of rupture with the best results and quality of steam curing temperatures 60ºC, 70ºC, 80ºC, for 14 days then ambient and water curing. Mixture design geopolymer concrete using SNI 7656-2012.

The implementation of the research is divided into five stages including preparation of tool equipment and materials, material quality inspection, mix design and making samples, testing compressive strength and modulus of rupture of specimens, as well as discussion and conclusions. The materials used are fine aggregates passing sieve No.4, and coarse aggregate sieve No.1 fly ash with type F from PT. CAHYO SETYO WIJAYA Pakisjajar, Malang, East Java, Indonesia, source of coal residue combustion PLTU Paiton, alkaline activators such as NaOH and Na_2SiO_3 taken from chemical stores.
All of these materials have undergone quality testing so that they meet the requirements for concrete mixing work. Proportions of concrete mixtures and simulation of treatment types can be seen in **Table 1**.

The preparation of the proportions of the geopolymer concrete mixture takes into account the maximum coarse aggregate size of 2.54 cm, water cement factor (fas) of 0.35, with the use of alkali activator 12 molar NaOH and Na2SiO3 in a ratio of 3:1. The preparation of the test specimens consists of a cylindrical test specimens with a diameter of 15 cm and a height of 30 cm for testing the thermal strength. Meanwhile, for testing the modulus of rupture of concrete, a beam specimen measuring 15 cm x 15 cm x 60 cm is used. After the casting reaches one day of age, the mold is released. To obtain good modulus of rupture results, treatment is carried out (Table 1), the results of steam treatment at temperatures of 60ºC, 70ºC, and 80ºC, will be compared with ambient curing and normal concrete curing. Normal concrete mix design is the same as geopolymer concrete, the only difference is that it does not use an alkali activator and uses fly ash instead of cement.

Table 1. Mix design results in a Geopolymer concrete mixture

Composition Material per m^3							
Curing	Fly-ash (kg)	Water (l)	NaOH (kg)	Na_2 SiO_3 (kg)	Aggregate fine (kg)		Aggregate coarse (kg)
Steam (14 days)	after *steam* (14 days)						
60ºC	water	553	138.4	66.43	22.58	1111.3	559.8
	room						
70ºC	water						
	room						
80ºC	water						
	room						
room (28 days)				0.915			

2.1 The Geopolymer Concrete Characteristics Testing

2.1.1 Slump test

Slump test is a test used to measure the level of workability of the concrete mixture, which affects the level of workability of the concrete. The tool used to measure the slump value is an Abram cone with SNI 1972-2008 work standards.

2.1.2 Compressive strength

Compressive strength is the ability of concrete to accept the compressive force of area unity. In this study, a concrete compressive strength was carried out in 28 days. In (SNI 1974, 2011), cast-in-place concrete strength has the same characteristic as the structural concrete due to the same curing conditions where the specimen had the same curing with the concrete slab. Analogy testing concrete compressive strength and the area of the surface that receives the force can be seen in **Figure 1**.

The formula that used to measure concrete compressive strength value based on the research in the laboratory can be seen in this equation (1):

$$f'c = \frac{P}{A} \tag{1}$$

Note: f'c = Compressive Strength (MPa)
P = Load Strength (N)
A = Area of Surface Specimen (mm^2)

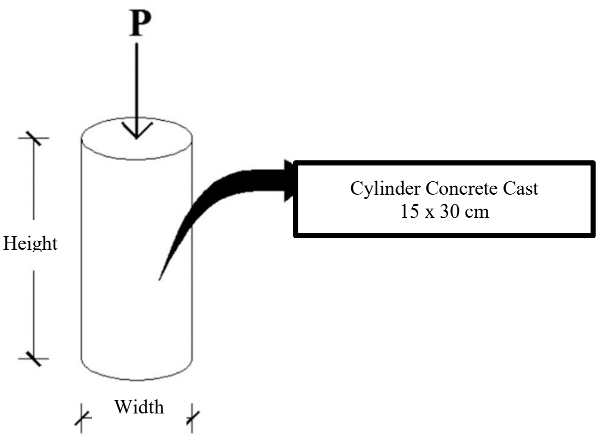

Figure 1. Concrete Compressive Strength Test

2.1.3 Modulus of Rupture

Modulus of rupture commonly called flexural strength is the ability of a concrete block placed in two positions to withstand forces in a direction perpendicular to the axis of the test object, which is applied to it, until the test object breaks, expressed in Mega Pascal (MPa) force per unit area (SNI 4431-2011), this test uses the applicable SNI requirements as in Figure 2 – Figure 4.

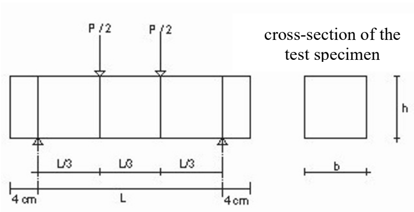

Figure 2. Illustration of Beam Testing

Fail in 1/3 of the middle span

$$\sigma 1 = (P \,.\, L)/(b \,.\, h^2) \tag{2}$$

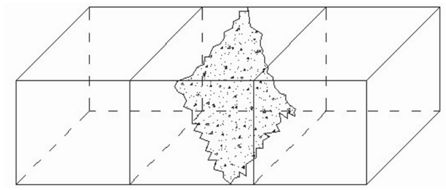

Figure 3. Fail in 1/3 of the middle span

Fail outside 1/3 of center span and line breaks at <5% of span

$$\sigma 1 = (P \,.\, a)/(b \,.\, h^2) \tag{2}$$

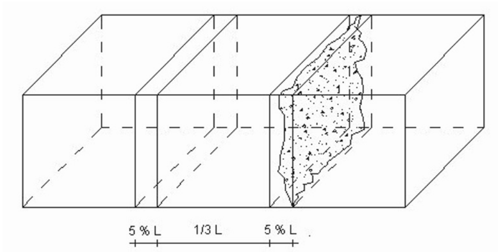

Figure 4. Fail outside 1/3 of the center span

3 Results And Discussion

The test aims to determine the quality of the material used and the performance of the beam specimens produced.

3.1 Slump Test

Slump tests are conducted to determine the performance of fresh concrete, its workability, and the viscosity of the mixture in the concrete. This test was carried out by measuring the drop from the top of the fresh concrete to the bottom of the stick placed on Abram's cone, by standards to SNI 1972-2008—results from the slump test on geopolymer concrete 7.5 cm and normal concrete 9 cm.

Figure 5. Geopolymer Concrete Slump Test Results

3.2 Concrete testing

3.2.1 Normal concrete

To determine the accuracy of the quality of the design, normal concrete was tested with an f'c of 25 MPa aged 28 days, the testing method was carried out according to SNI 1974-2011 with the results in Table 2.
The results of the test in Table 2 can be seen as the average result of a normal concrete planning of 25 MPa, this proves that the mixture planning is accurate quality.

Table 2. Test results of compressive strength of concrete cylinders.

Density kg/m^3	Load (N)	Cross Section (mm^2)	Compressive Strength f'c (MPa)
2270	420000	17671.46	23.77
2302	450000	17671.46	25.46
2374	460000	17671.46	26.03
Average			25.09

Testing of the modulus of rupture is carried out after the concrete has reached the age of 28 days with a test specimen in the shape of a beam of the size of 15 cm x 15cm x 60 cm, test methods are performed according to SNI 4431-2011 with the results in **Table 3**.

Table 3. Test results of modulus of rupture of concrete beams.

Density (kg/m^3)	Load (N)	Support Distance (mm)	Wide (mm)	high (mm)	*Modulus of Rupture* (MPa)
2467	35500	450	150	150	4.73
2480	35500	450	150	150	4.73
2644	36500	450	150	150	4.87
Average					4.78

3.2.2 Geopolymer Concrete

Testing modulus of rupture of geopolymer concrete is carried out after concrete has reached the age of 28 days with a test specimen in the shape of a beam of size 15 cm x 15cm x 60 cm, test methods are performed in accordance with SNI 4431-2011 with the results in **Table 4.**

Table 4. Test results of modulus of rupture of geopolymer concrete

Curing	*Density* (kg/m^3)	*Modulus of Rupture* (MPa)			AVG MORE (MPa)
		BU 1	BU 2	BU 3	
Steam 60^{0}C room	2450	2.87	2.93	2.33	2.71
Steam 60^{0}C water	2356	2.40	2.33	2.13	2.29
Steam 70^{0}C room	2447	3.67	3.80	3.67	3.71
Steam 70^{0}C water	2303	2.47	2.33	2.27	2.36
Steam 80^{0}C water	2482	4.00	4.00	3.60	3.87
Steam 80^{0}C water	2327	3.87	2.87	3.00	3.24
room	2417	2.00	2.07	2.00	2.02

BU 1 = speciment 1 BU 2 = speciment 2 BU 3= speciment 3

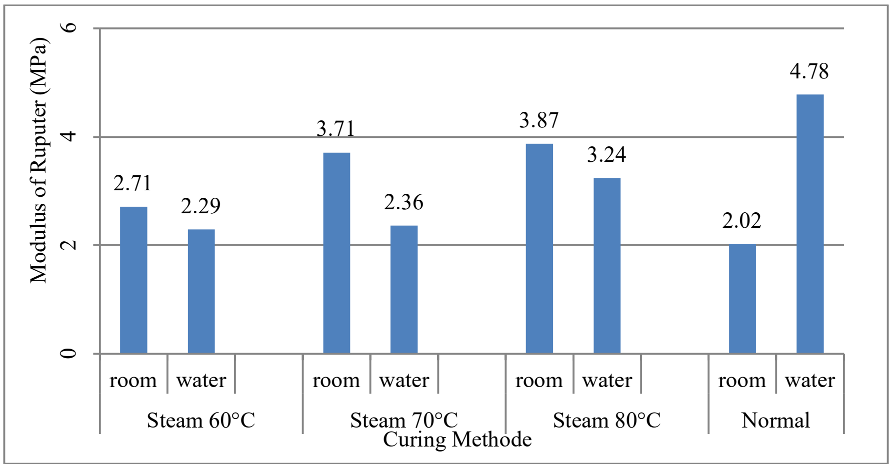

Figure 6. Comparison diagram of MOR values with curing

Figure 6 shows the value of the modulus of rupture of concrete geopolymer with a combination of room-steam and water-steam curing undergoing an increase accompanied by an increase in temperature. The process of copolymerization and high-temperature curing affects the strength of the geopolymer concrete [11], steam curing method 30ºC, 45ºC, 60ºC, and 80ºC. Increased curing temperature affects the elasticity of concrete Geopolymers [12] steam curring method with temperatures 40ºC, 60ºC, and 80ºC.

Based on Figure 1 the highest modulus value of rupture of geopolymer concrete at a combination of steam curing temperature 80ºC, at a steam room of 3.87 MPa and steam-water of 3.24 MPa. Steam curing with a temperature of 80ºC for 24 hours obtains the highest pressure strength value [13], curing method by keeping concrete in an indoor room at a temperature of 40ºC, 60ºC, and 80ºC.

The values modulus of rupture of concrete geopolymers with room-steam curing are lower than steam curing, this is because the room temperature is lower than that of steam temperature curing [14].
Test results of curing values with lower room temperature compared to oven temperatures [15] oven curing method with 60ºC and 90ºC temperatures.

4 Conclusion

Based on the results of this analysis, some conclusions can be drawn. First, the value of the test result of the modulus of rupture is a direct relative to the steam curing temperature, the higher the steam curing temperature the higher the value of the modus of breakage. Second, the highest modulus of rupture test results at 80oC temperature steam curing, both on combination steam curing with room and water, with an average increase of 21% on room steam as well as 20% on water steam. Third, the value of the modulus of rupture at room temperature under steam temperature curing is due to the reaction between materials at room temperature longer than steam curing temperature. Fourth, the test results of the modulus of rupture of normal concrete are larger than the geopolymer concrete, with a value of 4.78 MPa. This result has a decline of 19% compared to the highest value of 3.87 MPa.

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