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Design of Low Alkali activator Geopolymer concrete mixtures

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ABSTRACT

This paper presents the results of research on the design of geopolymer concrete mixes. The main objective of this research is to develop an efficient and easy design of low-alkaline activator geopolymer concrete mixture, which until now has been the biggest obstacle in the use of geopolymer concrete. The variables reviewed were the amount of alkaline activator was quite low at 4%, room temperature and 60oC ratio of alkaline activator/fly ash (AAS/FA) were 0.35, 0.4, 0.5, 0.6. The test results show the parameters of geopolymer concrete with low alkali activator 4%, sodium silicate/sodium hydroxide ratio 2.5%, sodium hydroxide molarity 14M, type F fly ash and the discovery of the relationship model of compressive strength and the ratio of alkali activator/fly ash with a very high correlation as basic development of geopolymer concrete mix design. The design of the geopolymer concrete mix developed is easy because it is application-based and efficient because it only requires 4% alkaline activator.

Keywords: mix design; low alkaline; activator geopolymer; concrete.

INTRODUCTION

The use of portland cement in concrete requires enormous energy and produces very high CO2 which contributes significantly to the greenhouse effect, to reduce the negative impact of cement use, it is necessary to replace all cement with other materials that are more environmentally friendly, namely geopolymer concrete. By utilizing geopolymer concrete, we will indirectly reduce environmental pollution that occurs, because it can reduce CO2 gas emissions produced by the cement industry.

Geopolymer concrete is a concrete mixture that is totally without the use of cement. Geopolymer concrete is produced by completely replacing portland cement with binding materials in the form of alkaline activator consisting of sodium hydroxide solution, sodium silicate solution, and precursors consisting of industrial and agricultural wastes such as fly ash and husk ash, while geopolymer is a material produced from polymeric aluminosilicates and alkali-silicate which produces a tetrahedral bonded SiO4 and AlO4 polymer framework (Davidovits, 1991). Aluminum and silicate cannot be a binding material, but in the presence of alkaline activators such as NaOH, Na2SiO3 and water, the silica oxide in the pozzolanic material will chemically react to form polymer bonds.

Geopolymer concrete with fly ash from the research of Hardjito, et al., (2005) has a high strength reaching fc '45 Mpa. Several studies concluded that there are several parameters that affect the compressive strength of geopolymer concrete, both in terms of the proportion of the mixture, the duration of mixing, the type of precursor, activator, curing temperature and so on. One thing that needs to be considered is the relationship between the water-precursor ratio and the compressive strength of geopolymer concrete as well as the water-cement ratio in concrete. The value of the water-precursor ratio of geopolymer concrete is influenced by the amount of water and precursors in the concrete mixture, where the water content is affected by the amount of extra water and the water content of the alkaline activator (NaOH and sodium silicate).

According to Ning Li (2019) Cement concrete, standards and principles have existed for decades to support design, but the design of geopolymer concrete mixes has always been difficult to standardize and imitate due to the many influencing variables and the lack of consistent guidelines that are widely accepted, geopolymer concrete requires suitable mixture to obtain the desired strength and workability. Based on his research, there are three geopolymer concrete design methods in the world that are currently developing, namely, performance-based methods, statistical modeling methods and target strength methods.

1. Performance-based methods in determining the performance of geopolymer concrete are based on the chemical elements contained in alkaline activators and precursors, such as a study conducted by Simatupang (2015) finding a relationship between the compressive strength of geopolymer concrete and the molarity ratio of H2O]/[Na2O + SiO2+ Al2O3] and Bondar (2018), found a relationship between the compressive strength of geopolymer concrete with the percentage of Na2O, the ratio of SiO2/Na2O molarity and the ratio of water/sodium silicate binder.
2. The statistical modeling method in determining geopolymer concrete performance is based on the determinants of geopolymer concrete performance such as sodium silicate/sodium hydroxide molarity, activator/precursor ratio, treatment temperature and so on. Lie (2018) uses the Taguchi method, Lokuge (2018) uses a multivariate adaptive regression model. Zaid (2018), Hadi's response surface methodology (2019) uses a multivariable polynomial regression method, the two methods above have the disadvantage of being too complicated and unable to determine the desired or planned concrete strength,
3. The target strength method is widely used in the geopolymer concrete industry today because it is simple, it can determine the desired strength. This method is based on the planned compressive strength with a design procedure including steps to determine the compressive strength of the plan, selecting the ratio of alkali/fly ash activator, determining the amount of alkali activator, the ratio of sodium silicate/sodium hydroxide, calculating the need for fly ash, fine aggregate and coarse aggregate. Some researchers who use this method such as Anuradha et al. (2011), Ferdous et al. (2013, 2015), Pavithra et al. (2016), Reddy et al. (2018).
4. Ferdous et al. (2013) in the design of geopolymer concrete using fly ash, sodium hydroxide 16M molarity, sodium silicate/sodium hydroxide ratio 2.5 and alkaline activator 10.8%. Pavithra et al. (2016) used fly ash, 16M sodium hydroxide molarity, sodium silicate/sodium hydroxide 1.5 ratio alkaline activator 8.5%. . Reddy et al. (2018) using GBBS (ground granulated blast furnace slag) 14M sodium hydroxide molarity, sodium silicate/sodium hydroxide ratio 1.5 and alkaline activator 8.5% treatment temperature 60oC with 10 x10 cm cube specimens.

One of the disadvantages of geopolymer concrete is that it is still expensive to manufacture because of the large use of alkaline activator. In this study an attempt has been made to propose an efficient fly ash-based geopolymer concrete mix design using an alkaline activator which is quite low at 4% which has not been done by other researchers.

Research significance

The design of geopolymer concrete mixtures that have been carried out so far using alkaline activator (6 – 15%), Alkaline activator is the most expensive material in the manufacture of geopolymer concrete.

RESEARCH METHODS

Experiments carried out in the laboratory to obtain the necessary data in accordance with the standards of SNI and ASTM testing. According to the study of the design method and the parameters of the geopolymer concrete stacking material above, based on the level of convenience and efficiency in this study, the target strength design method was chosen with a minimum alkali activator of 4%, sodium hydroxide molarity of 14M and in accordance with the research of Al Bakri et al (2012) Sodium ratio The optimum silicate/Sodium hydroxide is 2.5.

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Ingredient

Fly ash comes from PLTU Lontar Banten including type F with SiO2, Al2O3 and Fe2O3 levels of 79.56% more than 70%, NaOH in the form of white flakes and Sodium silicate in the form of clear gray gel. Sodium silicate is a very viscous, gel-like solution obtained from over-the-counter chemists. Composition of sodium silicate from the test results in GIS with a specific gravity of 1714 Kg/m3 : Na2O : 12.75%; SiO2: 43.75% and H2O: 43.5%. Sodium hydroxide (NaOH) is a white flake that is sold over-the-counter at chemical stores. NaOH solution with a concentration of 14 M can be made by dissolving sodium hydroxide flakes as much as 14 x 40 = 560 grams into water so that the volume becomes 1 liter.

Fine aggregate using Bangka white sand, which has been washed beforehand so that the mud content is less than 5%, the results of the specific gravity test are 2527 kg/m3 as required by ASTM C128-78. Coarse aggregate uses crushed stone from rumpin that has been washed first so that the mud content is less than 1%, the specific gravity test results are 2542 kg/m3 as required by ASTM C128-88, the wear test results with the Los Angelos machine get a wear rate of 19.1% . according to ASTM C 131-89 requirements. The mixed aggregate gradation meets British standards, with a ratio of 37% sand and 67% crushed stone. Fine and coarse aggregate in SSD condition.

The composition of the ratio of alkali activator/fly ash (AAS/FA), Fly ash, Sodium Hydroxide (NaOH), Sodium Silicate (Na2SiO3) fine and coarse aggregate is presented in Table 1

Mix design

Weight of low alkaline activator used 4% or 100 kg/m3, sodium hydroxide molarity 14M. Ratio of sodium silicate/sodium hydroxide 2.5 Ratio of alkali activator/fly ash 0.35, 0.4, 0.5, and 0.6 specific gravity from laboratory test results for sodium hydroxide of 1301 kg/m3, sodium silicate 1714 kg/m3, fly ash 2070 kg/ m3, the specific gravity of sand is 2527 kg/m3 and the specific gravity of crushed stone is 2542 kg/m3, the ratio of sand and crushed stone from the results of the sieve test is in accordance with the British standard of 37% sand and 63% crushed stone. Air content in concrete is 2% and aggregate is in SSD condition

The composition of low-alkaline activator geopolymer concrete in this study was determined based on the following steps: The first step was to determine a fairly low alkali activator at 4% or 100 kg/m3. The second step was to calculate the fly ash requirement with the formula WFA= W_AAS/((AAS/FA)) = 100/0.4 = 250 kg/m3. The third step calculates the sodium hydroxide requirement with the formula WNh = W_AAS/((1+2.5)) = 100/3.5 = 29 kg/m3, the fourth step calculates the sodium silicate requirement with the formula WNs = 100 - WNh = 100 – 29 = 71 kg/ m3 / 〖Bj〗_Ns . The seventh step is to calculate the combined aggregate with the formula Vaggregate = Vbeton – VFly ash – VSodium hydroxide –VSodium silicate. step . Vaggregate = 0.98 - 250/2070 – 29/1301 – 71/1714 = 0.796. the eighth step calculates the need for fine aggregate Vagh = % Ps x Vaggregate = 0.37 x 0.796 = 0.294 and the weight of fine aggregate Wagh = VPs x BjPs = 0.294 x 2527 = 743 kg/m3, step Nine calculates the need for coarse aggregate Vagk = % Bp x Vaggregate = 0.63 x 0.796 = 0.502 and weight of coarse aggregate Wagk = VBp x BjBp = 0.502 x 2542 = 1275 kg/m3. The composition of low-alkaline activator geopolymer concrete with various ratios of alkaline activator / fly ash is presented in table 1.

Table 1. Composition of 4% alkaline activator geopolymer concrete

AAS/FA	0,35	0,4	0,5	0,6
FA (kg/m3)	286	250	200	167
W NaOH (kg/m3)	29	29	29	29
W Na2SiO3 (kg/m3)	71	71	71	71
W aggregat halus	728	744	766	782
W Aggregat kasar	1.246	1.274	1.313	1.339
Tambahan air	35	35	35	35

Specimen Preparation And Test Method

The compressive test object as carried out by Pavitra and Redy is in the form of a cube measuring 100 x 100 mm, made according to the standard procedure of ASTM C192 and SNI 2493. The manufacture of the test object begins with the manufacture of alkaline activator the day before the manufacture of the test object by mixing sodium silicate and sodium hydroxide with a ratio of 2.5 Then fine aggregate, coarse aggregate and fly ash are added to the mixer, stir until blended, the last is the alkaline activator solution. After the mixture is completely homogeneous, take the mixture and do a slump test then put the mixture into a cube mold size of 100x100x100 mm, after that it is wrapped in plastic so that there is no excessive evaporation. The specimens were treated for 28 days at room temperature.

RESULTS AND DISCUSSION

Compression and slump test results

The results of the compressive and slump test of 4% alkaline activator geopolymer concrete aged 28 days at room temperature of 33oC and treatment temperature of 60oC were 24 test objects, each of the 3 test specimens for each value of the alkali activator/fly ash ratio is presented in Figure 1 and Table 2.

Figure 1 compressive test of 4% alkaline activator geopolymer concrete at 28 days

Table 2. Compressive strength of 4% alkaline activator geopolymer concrete aged 28 room temperature treatment day and 60ºC

AAS/FA	f'_c (MPa) Suhu perawatan 33ºC		Suhu perawatan 66ºC	Rata-rata	Slump (mm)
0.6	19.1	120	23.2	24.1	120
0.6	21.7		23.1		
0.6	24.2		25.9		
0.5	21.1	100	32.9		
0.5	27.0		25.9	30.6	100

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0.5	22.8		32.9		
0.4	32.7	40	32.6	35.0	40
0.4	32.9		40.0		
0.4	26.9		32.5		
0.35	32.5		41.2		
0.35	36.8	20	35.4	36.8	20
0.35	30.8		34.0		

Compressive Strength Relationship Model with Alkali/fly ash Activator Ratio

The model of the relationship between compressive strength and the ratio of alkaline activator/fly ash of geopolymer concrete with low alkali activator 4% at room treatment temperature of 60oC is presented in Figure 2. with the equation: fc' = 16.967(AAS/FA)-0.769, obtained from the power regression results. Validation is done by using a correlation with the number R^2 = 0.9401 close to number one, meaning that the relationship between compressive strength and the ratio of alkali/fly ash activator is very strong or valid.

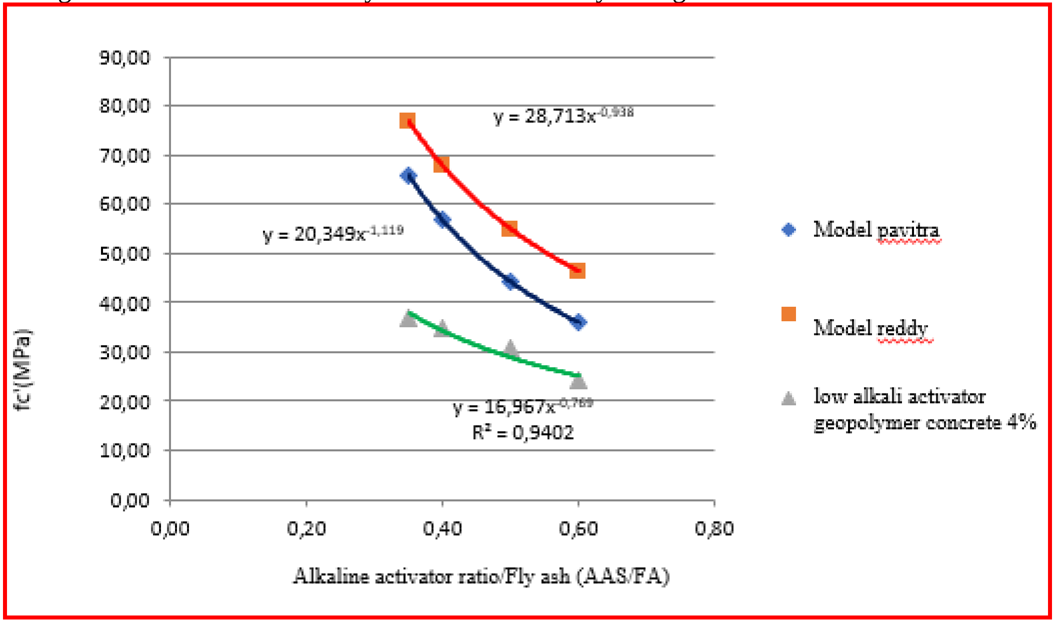

Figure 2. Model of the relationship between compressive strength and the ratio of alkali activator/fly ash low geopolymer concrete 4% alkali activator temperature treatment 60oC

The relationship model of compressive strength with the ratio of alkaline activator/fly ash of geopolymer concrete with low alkali activator 4% treatment temperature 60oC has the same pattern as the model of Pavitra et al. (2016) fc' = 20, 352 (AAS/FA)-1,119 and Reddy et al. al.(2018) using GBB, fc' = 28.713(AAS/FA)-0.9384 difference at lower compressive strength values.

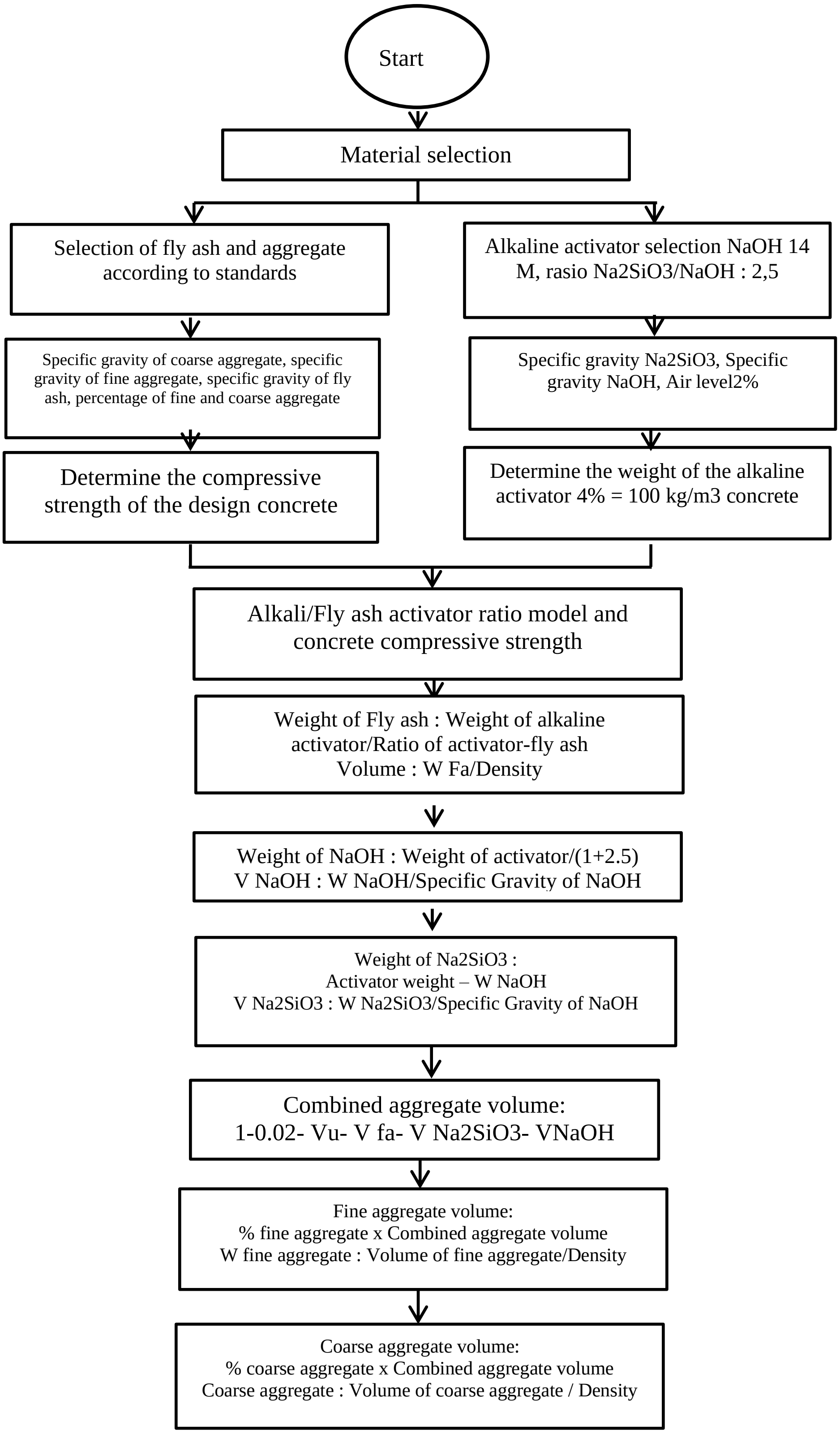

Figure 3. Flowchart of low-alkaline activator concrete mix 4%

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The most important findings as the basis for proposing the design of low-alkaline activator geopolymer concrete mixtures are the discovery of a new model of the relationship between compressive strength and the ratio of alkaline activator/fly ash fc' = 16.967(AAS/FA)-0.769, and the use of an alkaline activator which is quite low at 4%. . The design procedure of the proposed low alkaline activator geopolymer concrete mix is presented in the form of a flowchart (figure 3) and an excel-based application (figure 4). The advantage of the application of low-alkaline activator geopolymer concrete mix design is that the desired concrete compressive strength and composition of the concrete stacking material can automatically be obtained.

The use of low-alkali activator geopolymer concrete mix design applications is very easy by entering data on the weight of the alkali activator 100 kg/m3, the ratio of Sodium silicate/Sodium hydroxide 2.5, NaOH molarity 14 M, concrete compressive strength plan age 28 days room treatment temperature, specific gravity NAOH, Na2SiO3, fly ash, fine and coarse aggregates are obtained automatically the composition of the required geopolymer concrete material.

Mix DeSigN
Beton Geopolimer

Booking	....
Project	....
Request date	....

Input	
Heavy AAL 4%	**100**
Ratio NS/NH	**2,5**
Air volume	0,02
Specific gravity NaOH 14M	1310
Specific gravity Na2Sio3	1714
Specific gravity of Fly Ash	2060
Specific gravity of fine aggregate	2527
Specific gravity of coarse aggregate	2542
% fine aggregate	0,37
Average compressive strength (room temperature)	20

Output	
Rasio AAS/FA	0,63
Weight comparison of stacking materials	
NaOH	29
Na2SiO3	71
Fly Ash	158
Fine aggregate	785
Coarse aggregate	1.345
Water	24

Figure 4. Application of low-alkaline activator concrete mix design 4%

CONCLUSION

The development of the design of the geopolymer concrete mixture that was developed was easy because it was application-based and efficient because it only needed 4% alkaline activator. Parameters of low-alkaline activator geopolymer concrete materials required consist of 4% alkaline activator, sodium silicate/sodium hydroxide ratio 2.5%, sodium hydroxide molarity 14M, type F fly ash, fine and coarse aggregate according to SNI standards.

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