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Predicting of geopolymer concrete compressive strength using multiple linear regression method

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ABSTRACT

Concrete is a construction material that has uncertain quality and must be designed with such a composition to achieve the expected quality. Geopolymer concrete is an environmentally friendly concrete obtained by replacing Portland cement with fly ash as a binder. Geopolymer concrete requires an alkaline solution as an activator in the polymerization of aluminum and silica. The determining process of the concrete mix composition is called mix design. Mix design for normal concrete is regulated in SNI 7656:2012 while for geopolymer concrete there is no specific standard that regulates it. With the development of technology and information, existing geopolymer concrete data can be used for mix design modeling. With the data of the geopolymer concrete mixture processed using the SPSS multiple linear regression method, the regression model obtained is $Y = 0.165x_1 + 0.055x_2 + 0.037x_3 - 0.053x_4 + 0.263x_5 - 0.288x6 - 137.18$. This regression model states that the variables x_4 (NaOH) and x_6 (water) have a negative effect on the compressive strength of concrete. The effect of independent variables on the compressive strength of concrete simultaneously is 29.6% while the remaining 70.1% is influenced by other factors with the standard error of the estimate value of the model is 9,60179.

Keywords: Concrete, Geopolymer, Multiple linear regression, SPSS.

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1. INTRODUCTION

Concrete work that uses Portland cement as a base material has a fairly large adverse impact on the environment. Based on global emissions data from Our World in Data in 2016, cement production is the largest producer of CO_2 emissions from the industrial sector, accounting for 5.2% of total global emissions, with 3% being the result of the cement industry. The chairman of the Indonesian Cement Association stated that the cement industry has produced at least 45.9 million tons of CO_2 in the cement production process in 2018. Research in the field of concrete that is growing is marked by a breakthrough in replacing Portland cement with fly ash as the main binder of concrete. This kind of material is often referred to as geopolymer concrete. Some other materials that can be used as a substitute for cement in geopolymer concrete including fly ash, Ground Granulated Blast Furnace Slag (GBFS), rice husk ash, and silica fume. This research focuses only on the use of fly ash as a substitute for cement in geopolymer concrete materials. Fly ash, which is a waste material that is a by-product of the coal combustion process, is one of the materials that is widely used as the main binder in non-cement concrete or geopolymer concrete.

1.1 Geopolimerization Process

Geopolymer is inorganic polymer which is the result of the synthesis of the reaction between solid aluminosilicate material and alkali hydroxide/alkali consisting of repeating 3-dimensional units of sialate monomer (-Si-O-Al-O-) (Duxon et.al, 2007), in the form:

$$M_n[-(SiO_2)_z - AlO_2]n.\ wH_2O \quad (1)$$

Where M is an alkaline element or a cation such as potassium, sodium or calcium, n is the degree of polycondensation or polymerization, and z equals 1,2,3, or higher, up to 32.

Reaction between silica (SiO_2) and alumina (Al_2O_3) is the first step in a series of geopolymerization reactions. This process called as dissolution, which is followed by geopolymerization or namely polymerization of aluminosilicate oligomers to form amorphous aluminosilicate gels. The polymerization of these oligomers is irregular or amorphous. According to Davidovits (1991) the framework formed is called polysalat, where sialate stands for silicon-oxo-aluminate building unit. Figure 1 below shows the differences in the results of chemical reactions in normal concrete and geopolymer concrete. Fig. 1.(a) shows the hydration reaction product in normal concrete, while Fig. 1.(b) shows the geopolymerized product. The hardening of portland cement concrete is obtained through hydration of Calcium Silicate to Calcium di-Silicate Hydrate (CSH) and $Ca(OH)_2$. Meanwhile, hardening of the geopolymer resin obtained through a poly condensation reaction of Potassium Oligo-(sialate-siloxo) to form sialate-siloxo crosslinks.

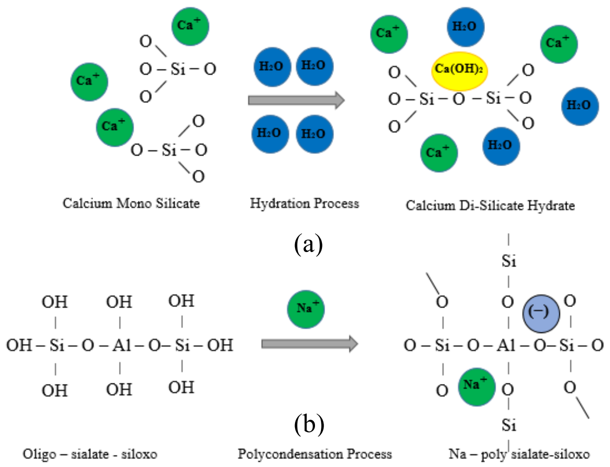

Fig. 1. (a) the hydration reaction of Portland cement; (b) geopolymerization reaction products

Determination of the quality of concrete is done by determining the composition of the ingredients of the concrete mixture. This process is called the concrete mix design. In the mix design process, the composition of the ingredients in the concrete mixture is determined such as cement, a combination of aggregates, water, and other additives. Mix design in Indonesia is regulated in SNI 7656:2012. This standard describes the procedure for selecting mixtures for normal concrete, heavy concrete, and mass concrete using various types of cement. Unlike the mix design for normal concrete that has been regulated in SNI, non-cement geopolymer concrete does not yet have standard rules in Indonesia. The absence of standard rules governing the composition of non-cement geopolymer concrete in Indonesia is the underlying reason for this geopolymer concrete mix design modeling. With the development of technology and information, existing data can be used for mix design modeling.

2. METHODS

2.1 Research Variable

The object of this research is the composition of the non-cement geopolymer concrete mixture data. The data used are obtained from studies that have been done. After the required data has been obtained, the data is then combined to be processed using the multiple linear regression method using SPSS 24 software. After the output is obtained, the model validation is carried out using non-cement geopolymer concrete data which was made directly at the Laboratory of Pembangunan Jaya University by looking how is the relationship between the compressive strength results from the test and the predicted compressive strength results from the model. The variables in this study were the compressive strength and composition of non-cement geopolymer concrete, such as the amount of fly ash, coarse aggregate, fine aggregate, sodium hydroxide (NaOH), sodium silicate (Na_2SiO_3), and water. These variables are divided into two types; the dependent variable (Y) which is the compressive strength of non-cement geopolymer concrete and the independent variables (X) consisting of fly ash (x_1), coarse aggregate (x_2), fine aggregate (x_3), NaOH (x_4), Na_2SiO_3 (x_5), and water (x_6).

2.2 Data Collection

Data collection in this study is divided into 2, the primary and secondary data. Secondary data collection is done by looking for research data from journals published on the internet. The data is then processed by multiple linear regression method using SPSS 24 software to obtain a regression model. The amount of data that will be used is 340 data as shown in table 1. Primary data collection will be carried out by taking data from the manufacture of non-cement geopolymer concrete at the Laboratory of Pembangunan Jaya University. The primary data in the form of non-cement geopolymer concrete data made at the Laboratory of Pembangunan Jaya University will be used to validate the output of the regression model which is the result of secondary data processing.

Table 1. Secondary data - composition of geopolymer concrete mix design from published research data

No.	Fly Ash (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)	NaOH (kg)	Na_2SiO_3 (kg)	Water (kg)	*f'c* (MPa)	Source
1	520	1050	760	31.2	25	240	38	Pham et al., 2020
2	520	1050	760	31.2	25	240	41	
3	520	1050	760	31.2	25	240	38	
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
338	366.9	1152.6	677	11.7	137.6	34.2	31.95	Salsabila, 2021
339	366.9	1152.6	677	11.7	137.6	34.2	33.09	
340	366.9	1152.6	677	11.7	137.6	34.2	32.46	

2.3 Geopolymer Concrete Manufacturing Procedure

The stages of making geopolymer concrete in the laboratory, to provide primary data, are as follows:

1. Calculating Concrete Mix Design, according to SNI 7656-2012 regarding the procedure for selecting normal concrete mixtures.
2. Replacement of Water-Cement with Fly Ash-Alkali Activator, modification is done by replacing water and cement in normal concrete with fly ash and alkali activator for geopolymer concrete.
3. Weighing Material and NaOH Solutions. Geopolymer concrete materials such as Fly ash, Coarse Aggregate, Fine Aggregate, NaOH, Na2SiO3 and Water are weighed according to the needs of the mix design. For NaOH material, it must be made into a solution according to its molarity beforehand. The process of making NaOH solution by mixing NaOH grains with water. The NaOH solution made was then allowed to stand for 24 hours before being used in the manufacture of geopolymer concrete.
4. Making Geopolymer Paste. The manufacture of geopolymer paste begins by mixing the NaOH solution with Na2SiO3 into an activator solution for 3 minutes, then mixing fly ash into the activator solution for 3-8 minutes.
5. Mixing Geopolymer Paste with Aggregate. Put the geopolymer paste into the mixer and stir. Next, put the fine aggregate into a mixer containing geopolymer paste and stir until evenly distributed. Then lastly add the coarse aggregate and mix again until evenly distributed.
6. Molding Geopolymer Concrete. The concrete mixture that has been homogeneous and has been tested for slump, as soon as possible is put into the mold and compacted. The concrete mixture in the mold that has been compacted and leveled is then placed on a flat, rigid surface, free from vibration and other disturbances. Avoid interference, impact and scratches on the concrete surface when transferring to storage areas. Concrete is stored at room temperature for 24 hours.
7. Curing Concrete. After being stored for 24 hours and opened from the mold, concrete curing is carried out. In this study, the concrete was cured in an oven at 100°C for 2 hours. then remove the concrete from the oven and leave it in a water-saturated room with a normal temperature until it is time for the concrete compression test.

2.4 Data Processing

Data processing is carried out using SPSS 24 software with multiple linear regression analysis. Before processing research data, the regression model must meet several classical assumption tests including normality test,

Table 2. Primary Data - Composition of geopolymer concrete mix design made at the Laboratory of Pembangunan Jaya University

Fly Ash (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)	NaOH (kg)	Na_2SiO_3 (kg)	Water (kg)	*f'c* (MPa)
366.9	1152.6	677	6.4	137.6	39.4	27.85
366.9	1152.6	677	6.4	137.6	39.4	27.58
366.9	1152.6	677	6.4	137.6	39.4	26.77
366.9	1152.6	677	9.2	137.6	36.7	29.49
366.9	1152.6	677	9.2	137.6	36.7	31.06
366.9	1152.6	677	9.2	137.6	36.7	30.13
366.9	1152.6	677	11.7	137.6	34.2	32.7
366.9	1152.6	677	11.7	137.6	34.2	31.93
366.9	1152.6	677	11.7	137.6	34.2	32.87

multicollinearity test, and heteroscedasticity test. Prior to data processing, outliers will be detected and removed. Outlier detection is done by looking at the value of Mahalanobis Distance, Cook's Distance, and *Z*-score. The output of this modeling is expressed in the regression equation formula $Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6$. After getting the output, the model will be validated using non-cement geopolymer concrete data that was made directly at the Laboratory of Pembangunan Jaya University.

3. RESULTS AND DISCUSSION

Data processing is done by using SPSS software. After testing the classical assumptions on the initial 340 data, outlier detection was carried out on the data and it was found that 74 data were outliers. Thus, the data analyzed is the remaining 266 data. The results of the analysis are shown in the following table 3, 4, and 5.

Table 3. Model summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.544[a]	.296	.280	9.60179

a. Predictors: (Constant), Water, Fly Ash, NaOH, Fine Aggregate, Na2SiO3, Coarse Aggregate

Table 4. ANOVA

ANOVA[a]						
	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10032.214	6	1672.036	18.136	.000[b]
	Residual	23878.337	259	92.194		
	Total	33910.550	265			

a. Dependent Variable: fc

b. Predictors: (Constant), Water, Fly Ash, NaOH, Fine Aggregate, Na2SiO3, Coarse Aggregate

Table 5. Coefficients

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-137.180	38.898		-3.527	.000
	Fly Ash	.165	.028	.425	5.876	.000
	Coarse Aggregate	.055	.015	.538	3.608	.000
	Fine Aggregate	.037	.021	.165	1.721	.086
	NaOH	-.053	.062	-.070	-.857	.392
	Na2SiO3	.263	.048	.565	5.471	.000
	Water	-.288	.046	-.410	-6.216	.000

a. Dependent Variable: Kuat Tekan

3.1 Interpretation of the Regression Model

3.1.1 Simultaneous Significance Test (Simultaneous F Test)

Simultaneous significance test or simultaneous F test aims to determine whether the independent variable (X) simultaneously affects the dependent variable (Y). According to Imam Ghozali (2011) if the value of Sig. less than 0.05, then the independent variable (X) simultaneously affects the dependent variable (Y). The hypotheses in this study are:

- H_0 = The independent variable simultaneously affects the dependent variable;
- H_1 = The independent variable simultaneously has no effect on the dependent variable;

with decision making:

- If the value of Sig < 0.05, then H_0 is accepted.
- If the value of Sig > 0.05, then H_1 is accepted.

Based on the SPSS output in table 4, it can be seen that the value of Sig. is 0.000 or less than 0.05. Thus, it can be said that H_0 is accepted and H_1 is rejected or in other words the variables of Fly Ash (x_1), Coarse Aggregate (x_2), Fine Aggregate (x_3), NaOH (x_4), Na_2SiO_3 (x_5), and Water (x_6) simultaneously has an effect on the Compressive Strength variable (Y).

3.1.2 Individual Parameter Significance Test (Partial t Test)

The individual parameter significance test or partial t test aims to determine the effect of the independent variable (X) partially on the dependent variable (Y). According to Imam Ghozali (2011) if the value of Sig. less than 0.05, then the independent variable (X) partially or separately affects the dependent variable (Y). The hypotheses in this study are:

- H_0 = The independent variable partially affects the dependent variable;

- H_1 = The independent variable partially has no effect on the dependent variable;

with decision making:

- If the value of Sig < 0.05, then H_0 is accepted.
- If the value of Sig > 0.05, then H_1 is accepted.

Based on the SPSS output in table 5, it can be seen that:

- The Fly Ash variable has a significance value of 0.000 < 0.05 so it can be concluded that H_0 is accepted and H_1 is rejected or in other words the Fly Ash variable has a partial effect on Compressive Strength.
- The Coarse Aggregate variable has a significance value of 0.000 < 0.05 so it can be concluded that H_0 is accepted and H_1 is rejected or in other words, the Coarse Aggregate variable has a partial effect on the Compressive Strength.
- The Fine Aggregate variable has a significance value of 0.086 > 0.05 so it can be concluded that H_0 is rejected and H_1 is accepted or in other words the Fine Aggregate variable has no partial effect on Compressive Strength.
- The NaOH variable has a significance value of 0.392 > 0.05 so it can be concluded that H_0 is rejected and H_1 is accepted or in other words the NaOH variable has no partial effect on the Compressive Strength. This is quite contrary to the results of research in general which states that the higher the concentration of NaOH, the higher the compressive strength.
- The Na_2SiO_3 variable has a significance value of 0.000 <0.05 so it can be concluded that H_0 is accepted and H_1 is rejected or in other words the Na_2SiO_3 variable has a partial effect on the Compressive Strength.
- The Water variable has a significance value of 0.000 <0.05 so it can be concluded that H_0 is accepted and H_1 is rejected or in other words the Water variable has a partial effect on Compressive Strength.

Thus, it is concluded that the variables that have a partial effect on the Compressive Strength are Fly Ash (x_1), Coarse Aggregate (x_2), Na_2SiO_3 (x_5), and Water (x_6) while Fine Aggregate (x_3), NaOH (x_4) are declared not has a partial effect on the Compressive Strength.

1. Coefficient of Determination

The coefficient of determination is useful for predicting and seeing how much influence all the independent variables simultaneously contribute to the dependent variable. The coefficient of determination is expressed by R Square at the SPSS output as can be seen in Table 3. Model Summary. The table shows that the value of R Square is 0.296 or 29.6%. This means that the effect of Fly Ash (x_1), Coarse Aggregate (x_2), Fine Aggregate (x_3), NaOH (x_4), Na_2SiO_3 (x_5), and Water (x_6) variables on the Compressive Strength (Y) variable simultaneously is 29.6 % which can be said to be unsatisfactory because the expected value of R Square is close to 1.0 or 100%.

3.2 Regression Equation Model

The output of this model is taken from the *B* value in the Unstandardized Coefficients section in the Coefficients output table and is expressed in the following regression equation formula:

$$Y = 0.165x_1 + 0.055x_2 + 0.037x_3 - 0.053x_4 + 0.263x_5 - 0.288x_6 - 137.18 \quad (2)$$

with:
Y = compressive strength of concrete
x_1 = Fly Ash
x_2 = Coarse Aggregate
x_3 = Fine Aggregate
x_4 = NaOH
x_5 = Na_2SiO_3
x_6 = Water

3.3 Model Validation

The validation of the regression model is done by substituting the primary data in the table 2 into the regression model. The compressive strength resulted from compression testing procedure in laboratory, Y result, compared to the compressive strength predicted from Equation (2), presented in Table 6. The relationship between $Y_{predict}$ and Y_{result} is shown in Fig. 2. with $Y_{predict}$ on the Y axis and Y_{result} on the X axis.

The accuracy of the test results can be measured using the Root Mean Square Error (RMSE) method. How to calculate RMSE is by squaring the absolute difference value then divided by the amount of data and take the root or can be expressed by the following formula.

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(A_t - F_t)^2}{n}} \quad (3)$$

Where A_t is actual value or Y_{result}, F_t is Predicted value or $Y_{predict}$, n is amount of data. Table 7 shows the calculation of RMSE value.

By looking at the results of the RMSE calculation in table 7, it can be seen that the accuracy or proximity of the Y_{result} and $Y_{predict}$ values is 7.076. RMSE values ranged from 0 - ∞. The RMSE value is 7,07 which is closer to 0, then the result value can be said to be more accurate to the predicted value.

4. CONCLUSION

1. The independent variables which include Fly Ash (x1), Coarse Aggregate (x2), Fine Aggregate (x3), NaOH (x4), Na2SiO3 (x5), and Water (x6) simultaneously or jointly affect the Compressive Strength variable.
2. Variables that have a partial effect on Compressive Strength are Fly Ash (x1), Coarse Aggregate (x2), Na2SiO3 (x5), and Water (x6) while Fine Aggregate (x3), NaOH (x4) are declared to have no partial effect on Compressive Strength.
3. The effect of the independent variables namely Fly Ash (x1), Coarse Aggregate (x2), Fine Aggregate (x3), NaOH (x4), Na2SiO3 (x5), and Water (x6) on the compressive strength variable (Y) simultaneously is

29.6% while the remaining 70.1% is influenced by other factors.

4. The resulting regression equation model is Y = 0.165x1 + 0.055x2 + 0.037x3 - 0.053x4 + 0.263x5 - 0.288x6 - 137.18.

Table 6. $Y_{predict}$ Calculation with Primary Data

0.165 x1	0.055 x2	0.037 x3	-0.053 x4	0.263 x5	-0.288 x6	-137.18 constant	Ypredict	Yresult
60.5385	63.393	25.049	-0.3392	36.1888	-11.3472	-137.18	36.3029	27.85
60.5385	63.393	25.049	-0.3392	36.1888	-11.3472	-137.18	36.3029	27.58
60.5385	63.393	25.049	-0.3392	36.1888	-11.3472	-137.18	36.3029	26.77
60.5385	63.393	25.049	-0.4876	36.1888	-10.5696	-137.18	36.9321	29.49
60.5385	63.393	25.049	-0.4876	36.1888	-10.5696	-137.18	36.9321	31.06
60.5385	63.393	25.049	-0.4876	36.1888	-10.5696	-137.18	36.9321	30.13
60.5385	63.393	25.049	-0.6201	36.1888	-9.8496	-137.18	37.5196	32.7
60.5385	63.393	25.049	-0.6201	36.1888	-9.8496	-137.18	37.5196	31.93
60.5385	63.393	25.049	-0.6201	36.1888	-9.8496	-137.18	37.5196	32.87

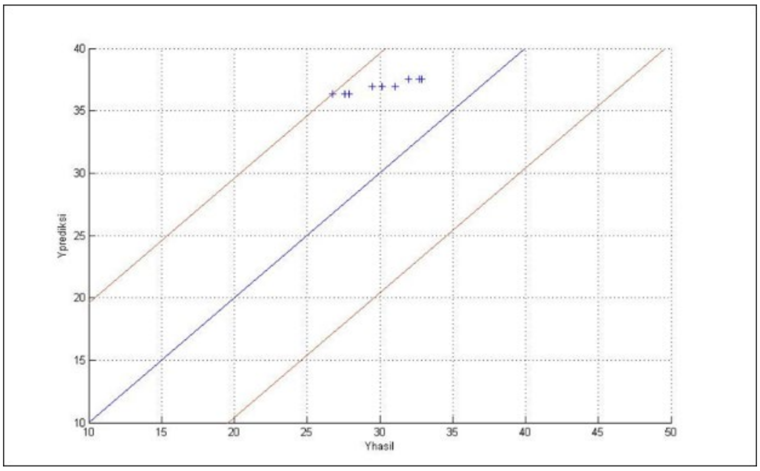

Fig. 2. Relation between Y_{result} and $Y_{predict}$

Table 7. RMSE Calculation

No. t	Y_{result} A_t	$Y_{predict}$ F_t	Absolute difference $\mid A_t - F_t \mid$	Square absolute difference $\mid A_t - F_t \mid^2$
1	27.85	36.3029	8.4529	71.45
2	27.58	36.3029	8.7229	76.08
3	26.77	36.3029	9.5329	90.87
4	29.49	36.9321	7.4421	55.38
5	31.06	36.9321	5.8721	34.48
6	30.13	36.9321	6.8021	46.26
7	32.7	37.5196	4.8196	23.22
8	31.93	37.5196	5.5896	31.24
9	32.87	37.5196	4.6496	21.61
		Total		450.64
		RMSE		7.07

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