International Research Journal of Engineering, IT & Scientific Research
Available online at https://sloap.org/journals/index.php/irjeis/
Vol. 10 No. 4, July 2024, pages: 66-76
ISSN: 2454-2261
https://doi.org/10.21744/irjeis.v10n4.2440

The Effect of Temperature on Compressive Strength of Concrete with the Addition of Kaolin as a Substitute Some Fine Aggregate

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Article history:

Submitted: 27 April 2024
Revised: 18 May 2024
Accepted: 09 June 2024

Keywords:

compressive strength;
concrete;
fine aggregate;
kaolin;
temperature;

Abstract

This research aims to; (1) Determine the feasibility of using kaolin from Pawangi Village, Capkala District, Bengkayang Regency, West Kalimantan Province when used as a substitute for some fine aggregate (sand). (2) To find out the description of compressive strength after burning and the model of the relationship between temperature and compressive strength of concrete with the mixture, kaolin is used as a substitute for some fine aggregate (sand). (3) Determine the most optimal composition of kaolin mixture against the compressive strength of normal concrete and also due to the influence of temperature. The type of research used in this study is a qualitative experiment on the structure of concrete materials using kaolin as a substitute for fine aggregate. The concrete that is planned is of K-250 quality, in line with the quality standards of concrete used in residential structures (1 to 2 floors). The kaolin mixture used is a percentage of 0%, 25%, and 50% of the weight of sand according to the job mix formula for the quality of K-250 concrete. After 28 days the resulting concrete sample is fired in an oven (kiln). Combustion is carried out at room temperature of 27º C to 100º C then with an interval increase of 100º C until the target temperature is 300º C. The result of this study is 1) The feasibility of kaolin to be used as a substitute for some fine aggregates in concrete mixtures needs to be done more deeply study related to the gradation, content, and properties of kaolin compounds, from the test results of every increase in the percentage of kaolin mixture in normal concrete there is a decrease in the compressive strength of concrete, but for concrete with the influence of temperature of 100º - 300º C there is an increase in concrete quality, (2) Simple regression of the relationship between temperature and compressive strength of concrete shows that if the temperature increases, it will cause an increase in the compressive strength value, and (3) The optimal composition of kaolin mixture as a fine aggregate substitute is at 25%.

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1 Introduction

The development in the construction industry at this time has grown rapidly and concrete material is the most widely used material in the construction of buildings, houses, bridges, bending, and other types of construction (Naderpour et al., 2018). Concrete is a mixture of fine aggregate and coarse aggregate (sand, gravel, crushed stone, or other types of aggregate) with cement as an adhesive that is united by water in a certain ratio. Fine aggregate is natural sand as a result of the natural disintegration of rocks or sand produced by the stone crushing industry and has a grain size of 5.0 mm (SNI 2847-2019). The use of fine aggregate as a concrete mixture in building construction is certainly inseparable from the availability of sand material in the quarry (Pacheco-Torgal & Jalali, 2011). The limitation of fine aggregate (sand) with good quality in various regions is still a major obstacle, so it is necessary to alternative other natural products as a substitute for fine aggregate (sand). One of the fine aggregate substitutes that can be used is kaolin (white clay) (Bribián et al., 2011).

Pontianak City is the capital of West Kalimantan Province with an area of 118.31 km^2 consisting of 6 sub-districts and 29 villages. Pontianak City is passed by the equator, and during the dry season, the temperature can reach 36^o C. Very high temperatures often trigger building fires in the Pontianak City area because the area is quite densely populated. In terms of the type of building where fire disasters occur, residential houses are the type of building where fires often occur, where data on the number of fire incidents in settlements can be seen in the graph below:

Data on Fire Incidents in Settlements in the Last 3 Years Years 2019, 2020, and 2021

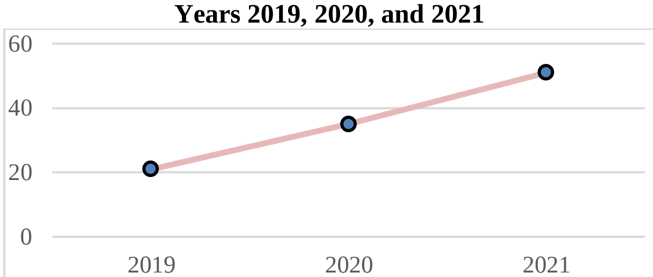

Figure 1. Fire incidents in residential areas

The heating experienced by concrete due to burning will result in fundamental changes in the properties of concrete. In this condition, the construction structure experiences a decrease in the ability to support the existing load even under certain conditions the concrete construction is no longer able to support the working load. Therefore, it is necessary to investigate the innovation of concrete material mixture with kaolin addition. Kaolin is known as a ceramic base material where the basic compounds in kaolin will melt at high temperatures. It is expected that the addition of kaolin base to the concrete mixture can produce stronger concrete material after the fire, to reduce the risk of structural failure after the fire in residential houses (Aıtcin, 2003; Basheer et al., 2001).

 ISSN: 2454-2261

2 Materials and Methods

The type of research used in this study is a qualitative experiment on the structure of concrete materials using kaolin as a substitute for fine aggregate (Zhang et al., 2012). The concrete is planned with a quality of K-250, following the standard quality of concrete used in residential structures (1 to 2 floors). The kaolin mixture used is the percentage of 0%, 25%, and 50% of the weight of sand according to the *job mix formula* for K-250 concrete quality. After 28 days, the resulting concrete samples were burned in the oven (furnace). Burning starts at room temperature 27º C to 100º C then with an increase in 100º C intervals until the targeted temperature is 300º C, and the total burning time is 180 minutes (3 hours). In each concrete mixture, 3 (three) test pieces were made with variables without burning, burning to 100º C, burning to 200º C, and burning to 300º C, so that a total of 36 test pieces were made with a cube size of 15 cm x 15 cm x 15 cm. The stages of the implementation procedure are depicted in a flow chart below:

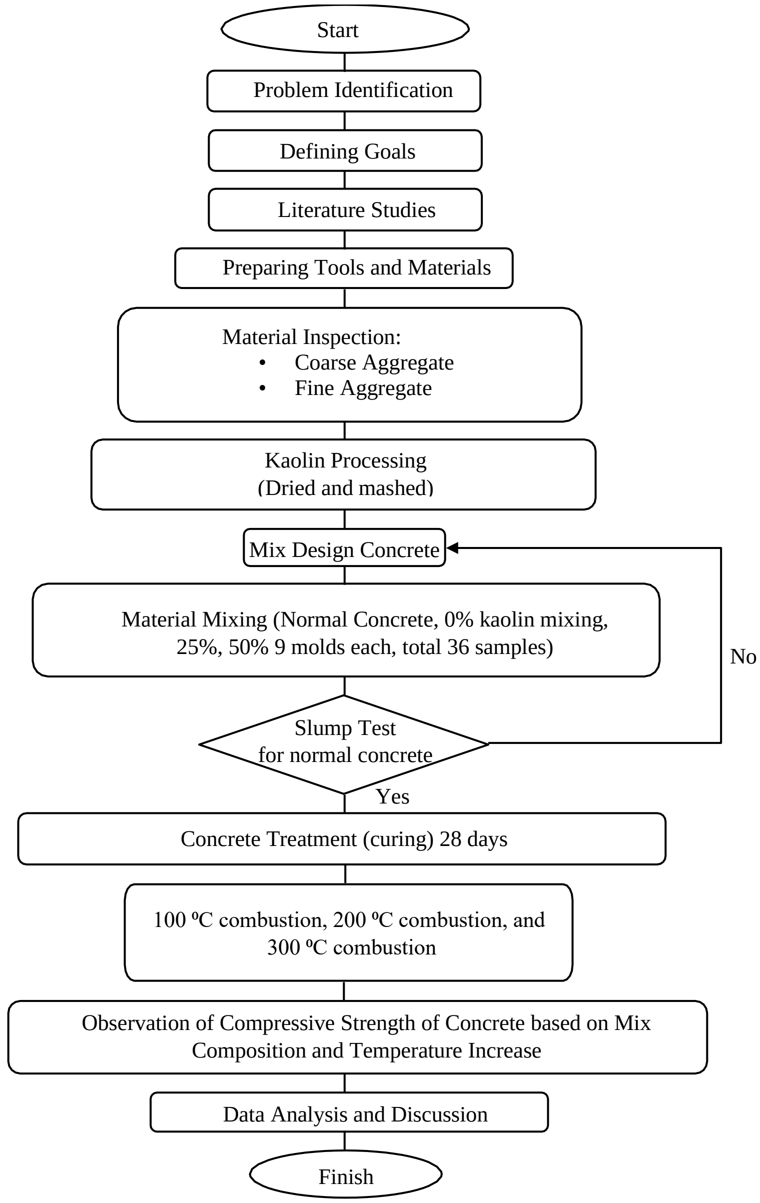

Figure 2. Research flow chart

Figure 3. Kaolin material

The materials used in this study consisted of type 1 cement, fine aggregate from Kapuas River, coarse aggregate derived from crushed stone from Gunung Semaoeng and water from local sources. The tools used were *mold, concrete mixer, slump test, oven* (kiln), and compressive testing machine. To check the aggregates, procedures were followed according to the technical specifications, as shown in the table below:

Table 1
Aggregate inspection procedure

No.	Examination	Unit Inspection Standards	Unit
A	Coarse Aggregate		
1	Gradations	SNI 03-1968-1990	%
2	Abrasion	SNI 03-2417-1991	%
3	Weight Density	SNI 03-1969-1990	
4	Water Content	SNI 03-1971-1990	
5	Contents Weight	SNI-03-4804-1998	
B	Fine Aggregate		
1	Gradations	SNI 03-1968-1990	%
2	Weight Density	SNI 03-1970-1990	
3	Water Content	SNI 03-1971-1990	
4	Contents Weight	SNI-03-4804-1998	

After aggregate inspection, the *job mix formula* for the K-250 concrete mix was prepared. In this section, the concrete mixers are used to produce the concrete, and the concrete mixers are used to produce the concrete. In this section, slump testing is also carried out to maintain the quality and workability of the concrete.

The compressive strength test equipment used in this study had previously been checked for condition and capability and had been calibrated beforehand (Demirboğa, 2007; Ng et al., 2018). After 24 hours, the mold was opened and then treated by soaking in a water bath for 28 days. Furthermore, the test specimens were stored (1-2 days) at room temperature until the concrete samples were dry and then put into the oven. The test specimens were then burned for three hours at a temperature of 100º - 300º C with an interval increase of 100º C, for each of 3 pieces. The remaining 9 specimens were not burned but were used as control specimens for normal concrete. Data were obtained through laboratory compressive testing using a compressive testing machine for all specimens. The result is the force (P) that occurs when the specimen is destroyed. Based on the compressive force data and the cross-sectional area of the cube, the compressive strength of the concrete can be calculated using the formula:

$$f = \frac{P}{A}$$

where:
f = Compressive strength (kg/cm) ^{2}
P = Compressive force (kg)
A = Cross-sectional area of the cube (cm) ^{2}

Data analysis was carried out in descriptive statistical analysis, used to determine the average compressive strength of concrete before and after baking. Furthermore, regression analysis was carried out to obtain a model of the relationship between temperature and compressive strength of concrete (Supardi et al., 2023).

3 Results and Discussions

Semen examination results

Based on the results of the visual inspection, the Portland cement composite used is in good condition and there are no lumps of granules so the cement can be used as a concrete-making material.

Inspection results for Fine Aggregates and Coarse Aggregates
The results of the materials testing of fine and coarse aggregates are tabulated in the table below:

Table 2
Material testing for fine aggregates and coarse aggregates

Material Testing	Fine Aggregate	Coarse Aggregate
Weight Density SSD	2,65	2,56
Absorption	0,45%	0,45%
Gradations	Zone 2	-
Contents Weight	1290 kg/m^3	1380 kg/m^3
Water Content	3,26%	1,19%
Abrasion	-	22,42%

Based on Table 2, it can be explained that the results of the fine aggregate test were only carried out on the sand because in this study white soil was used which was directly taken from the quarry originating from Pawangi Village, Capkala District, Bengkayang Regency, West Kalimantan Province. The reason is that people in the village directly use this white soil in concrete mixes without washing it first. So in this research, the original white soil without washing will also be used as a substitute for fine aggregate in concrete mixes, to know the actual strength obtained by white soil as a substitute for fine aggregate in concrete mixes (Kirthika & Singh, 2020; Prabhu et al., 2014).

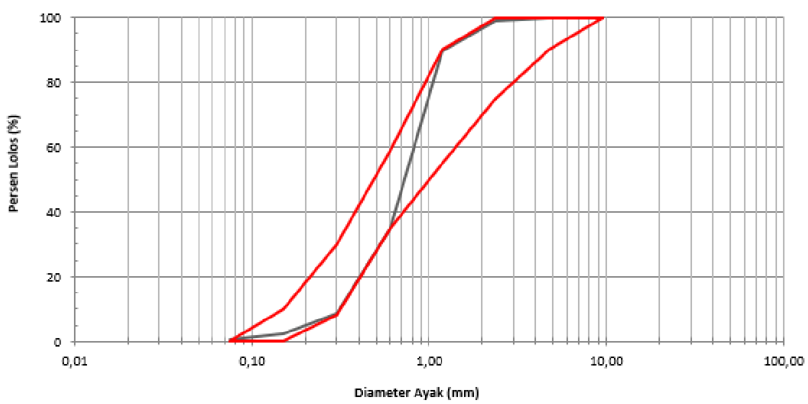

Figure 4. Sand Gradation test chart

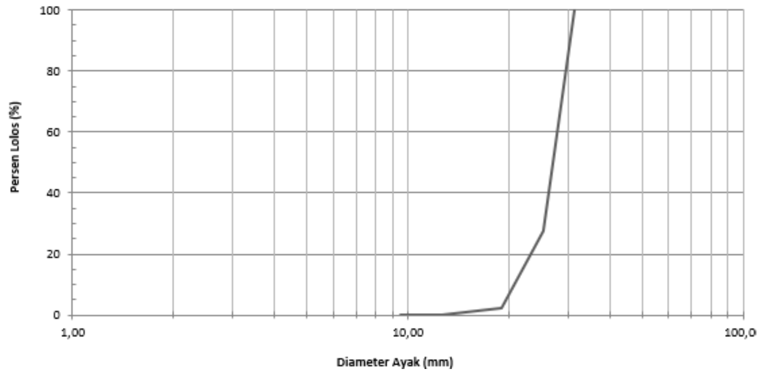

Figure 5. Gravel Gradation test chart

Water inspection results

Based on visual observation, the water used is water from the Pontianak State Polytechnic Civil Engineering Concrete Laboratory reservoir which is colorless and odorless, so based on SK SNI-S-04-1989-F, the water is suitable for use as a material for making test objects.
Job Mix Formula for K-250 Concrete mix
We are a family-owned business and have been involved in supplying ready-mix concrete batching plants and equipment to the industry over the last 25 years.

Table 3
Material requirements for making test objects

No.	Fc' (Mpa)	Material Requirements			
		Cement (kg)	Sand (kg)	Coarse (kg)	Water (lt)
1	21,7	500	502,5	1172,5	197,78

Soaking and burning of concrete cubes

After 24 hours, the mold was opened and then treated by soaking in a water bath for 28 days. Next, the test specimens were stored (1-2 days) at room temperature until the concrete samples were dry and then put into the oven. The test specimens were then burned for three hours at a temperature of 100º - 300º C with an interval increase of 100º C, for each of 3 pieces. The remaining 9 specimens were not burned but were used as control specimens for normal concrete.

Concrete compressive strength results

Based on the test results conducted at the Civil Engineering Laboratory of Pontianak State Polytechnic, the compressive strength value of each type of concrete for compressive strength at the age of 28 days was obtained. The average compressive strength value for each test is tabulated in the following table:

Table 4
Concrete compressive strength test results

Types of Concrete	Age	Temperature (º C) 3 hours	Wide (mm)^2	Weight Average (kg)	Axial Average (kN)	Compressive Strength Average (Mpa)
Kaolin 0%	28 days	27	22500	7,97	379,1	31,46
		100		7,9	384,79	31,93
		200		7,7	342,6	28,43
		300		7,47	422,7	35,08
Kaolin 25%	28 days	27	22500	7,8	355,44	29,05
		100		7,67`	384,28	31,89
		200		7,67	378,6	31,42
		300		7,33	415,18	34,45
Kaolin 50%	28 days	27	22500	7,43	265,18	22,01
		100		7,37	269,45	22,36
		200		7,23	289,65	24,04
		300		7,03	326,2	27,07

Discussion

Based on the testing of concrete compressive strength results, different average compressive strengths were obtained for each group of planned concrete grades at each kaolin admixture level. A comparison of compressive strength for each concrete mix and the relationship between compressive strength and temperature can be seen in the graph below:

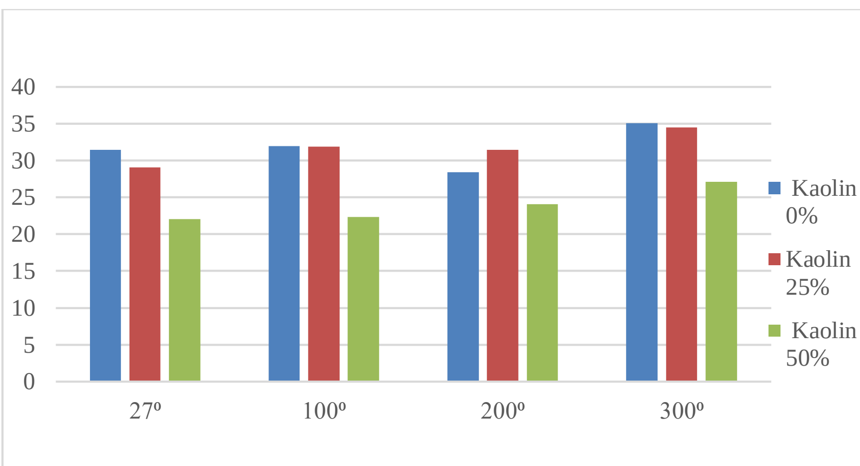

Figure 6. Comparison of concrete compressive strength for each type of mix with temperature

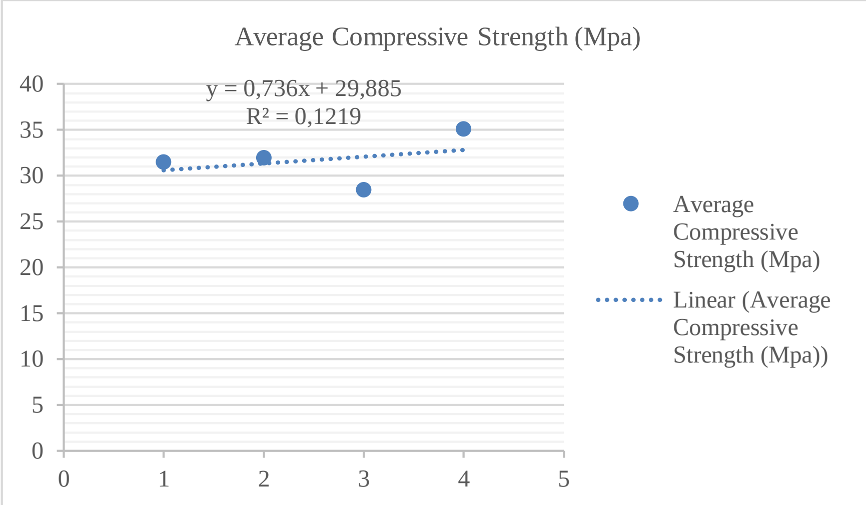

Figure 7. Linear regression model of temperature on concrete compressive strength for 0% kaolin admixture

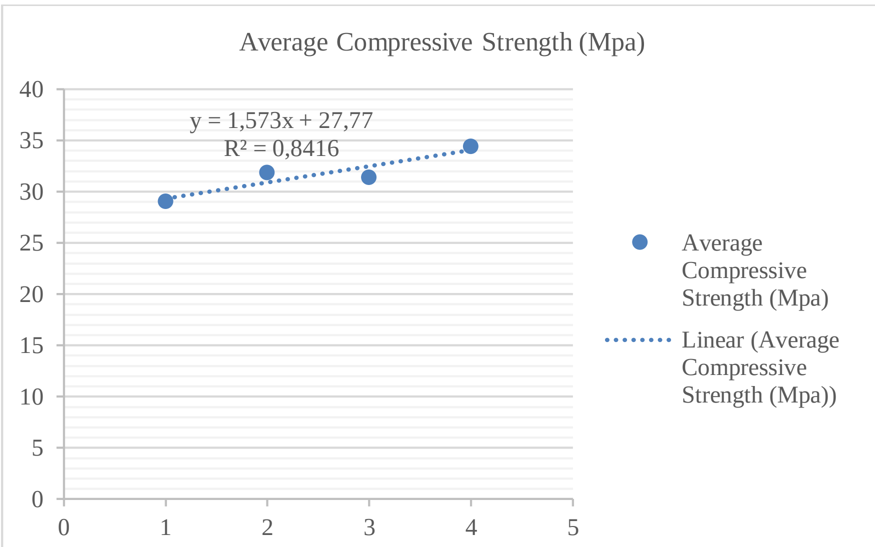

Figure 8. Linear regression model of temperature with concrete compressive strength for 25% kaolin admixture

ISSN: 2454-2261

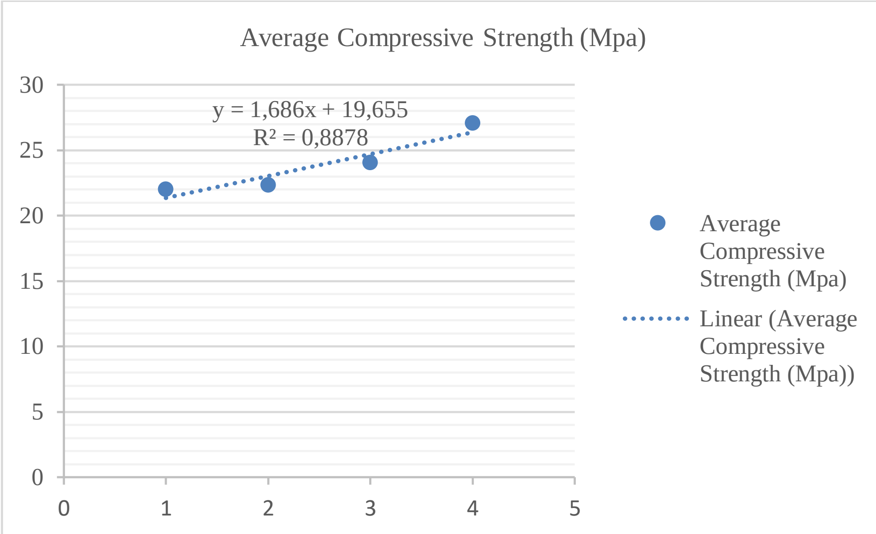

Figure 9. Linear regression model of temperature with concrete compressive strength for 25% kaolin admixture

From the graph above, it can be seen that:

1) In normal concrete without kaolin mixture for no heating average compressive strength of 31.46 Mpa, heating at 100º C average compressive strength of 31.93 Mpa, heating at 200º C average compressive strength of 28.43 Mpa, and heating at 300º average compressive strength of 35.43 Mpa. For the increase in temperature from 0º - 300º C for normal concrete there is a tendency for the compressive strength value of concrete to increase, this is in line with Tjokrodimulyo (2000) when cement paste is heated, from room temperature to about 200º C, the strength seems to increase slightly, because when slightly above 100º C free water and water absorbed in the paste evaporates, then when auh above 100º C water that is chemically tightly bound in the paste also evaporates.
2) In concrete, without heating for mixture K-250 obtained for a 0% kaolin mixture with 28 days of age average compressive strength of 31.46 Mpa, a 25% kaolin mixture obtained an average compressive strength of 29.05 Mpa, and for a 50% kaolin mixture obtained average compressive strength of 22.0 Mpa. Where according to Hunggurami et al. (2015), the optimum percentage of white soil that can be used as a substitute for fine aggregate concrete is at a percentage of 25%-50%. From the graph above, the optimum percentage of white soil used as a substitute for fine aggregate is at a percentage of 25%.
3) Simple linear regression analysis was performed to obtain a regression model describing the relationship between temperature and compressive strength of concrete. The regression model in Figure 7 for 0% kaolin admixture is a simple linear regression. From this equation, it can be seen that the value of the regression coefficient indicates a (positive) increase in the dependent variable based on the independent variable. This means that if the temperature increases, it will cause an increase in the compressive strength value. Furthermore, the coefficient of determination R2 is 0.1219, this number is close to the value of 1, meaning that there is a strong relationship between temperature and compressive strength of concrete. In addition, the coefficient shows a linear regression that the effect of temperature on the compressive strength value of concrete is 12.19%.
4) The regression model in Figure 8 for the 25% kaolin blend is a simple linear regression. From this equation, it can also be seen that the value of the regression coefficient indicates a (positive) increase in the dependent variable based on the independent variable. This means that if the temperature increases, it will cause an increase in the compressive strength value. Furthermore, the coefficient of determination R2 is 0.8416, this number is close to the value of 1, meaning that there is a strong relationship between temperature and compressive strength of concrete. In addition, the coefficient shows a linear regression that the effect of temperature on the compressive strength value of concrete is 84.16%.

The regression model in Figure 9 for the 50% kaolin blend is a simple linear regression. From this equation, it can also be seen that the value of the regression coefficient indicates a (positive) increase in the dependent variable based on the independent variable. This means that if the temperature increases, it will cause an increase in the compressive strength value. Furthermore, the coefficient of determination R2 is 0.8878, this number is close to the value of 1, meaning that there is a strong relationship between temperature and compressive strength of concrete. In addition, the coefficient shows a linear regression that the effect of temperature on the compressive strength value of concrete is 88.78%.

4 Conclusion

Based on the results of data analysis and discussion, the following conclusions can be drawn:

1) The value of the compressive strength of concrete at each temperature increase is:
    a) In normal concrete without kaolin mixture for no heating, the average compressive strength is 31.46 Mpa, in heating at 100º C average compressive strength is 31.93 Mpa, heating at 200º C average compressive strength is 28.43 Mpa, and in heating at 300º C average compressive strength is 35.43 Mpa.
    b) In concrete with a 25% kaolin mixture without heating, the average compressive strength is 29.05 Mpa, heating at 100º C average compressive strength is 31.89 Mpa, heating at 200º C average compressive strength is 31.42 Mpa, and heating at 300º C average compressive strength is 34.45 Mpa.
    c) In concrete with a 50% kaolin mixture without heating, the average compressive strength is 22.01 Mpa, heating at 100º C average compressive strength is 22.36 Mpa, heating at 200º C average compressive strength is 24.04 Mpa, and heating at 300º C average compressive strength is 27.07 Mpa.

    The feasibility of kaolin being used as a partial replacement of fine aggregate in concrete mixes needs to be studied more deeply related to the gradation, content, and properties of kaolin compounds. From the test results of each increase in the percentage of kaolin mixture in normal concrete there is a decrease in compressive strength of concrete, but for concrete with the influence of temperature 100º - 300º C there is an increase in concrete quality.
2) Based on the results of this study, there is a relationship between the comparison of compressive strength of concrete with kaolin mixture after being affected by temperature, namely:
    a) For concrete without kaolin admixture, the linear regression form y = 0.7362x +29.885 with values of R2 = 0,1219.
    b) For concrete with 25% kaolin admixture the linear regression form y = 1.573x +27.77 with a value of R2= 0,8416.
    c) For concrete with 50% kaolin admixture the linear regression form y = 1.686x +19.655 with values of R2 = 0,8788.

    Simple regression modelling of the relationship between temperature and compressive strength of concrete shows that if the temperature increases, it will cause an increase in the compressive strength of concrete for concrete mix compositions with 0%, 25%, and 50% kaolin.
3) From the graph above, the optimum percentage of white soil used as a substitute for fine aggregate in the percentage with or without heating is at 25% for temperatures of 27º - 300º C.

Conflict of interest statement
The authors declared that they have no competing interests.

Statement of authorship
The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

Acknowledgments
Special thanks are due to the research funders or donors. Thanks are also due to those who assisted in the implementation of the research.

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