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The Influence of Kaolin as an Additive on Concrete Compressive Strength

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Abstract: Kaolin is a clay soft, white mineral which can be found in nature and is known as clay stones. This research aimed to investigate the effect of using kaolin as an additive material toward compressive strength of concrete. This was qualitative experimental research which the object being a concrete K-350. The researchers planned K-350 based on the concrete standard for building structure four floors. The kaolin mixture used was at a percentage of 5%, 10%, and 15% of the cement weight according to the job mix formula for K-350 concrete quality. After 28 days, the resulting concrete samples were tested in the laboratory using a compressive strength testing machine. The results showed that the average compressive strength of kaolin 5%, 10%, and 15% were 27.27 MPa, 30.15 MPa and 24.48 MPa. The optimum result of the kaolin mixture was 15%. Based on the result, the researchers did not recommend applying kaolin as an additive material for building structure four floors.

Keywords: Kaolin, Concrete, Additive Material

1. Introduction

Nowadays, the Indonesian government is developing equitable infrastructure development which is in accordance with the government's mission to accelerate planned and sustainable infrastructure development. With limited funds owned by the government, President Prabowo also emphasized the importance of adjusting priorities so that development remains effective where priority must be given to projects that have a major impact on economic growth and community welfare [1]. In supporting the government's mission, constructors must be able to create innovations that can reduce production costs but still produce high quality.

One of the building materials that is often used today is concrete. Concrete is a composite material made from a mixture of paste (Portland cement and water), and admixtures of aggregates (fine and coarse aggregate or sand and gravel or crushed stone) which hardens with time [10], [11], [12]. The quality of concrete is closely tied to the types and characteristics of the materials utilized, as well as the methods of placement, finishing, and curing employed [11]. Supplementary cementitious materials and chemical additives might also be incorporated into the paste [10].

Numerous studies and experiments on concrete have been conducted to enhance its quality, specifically by incorporating additive materials to improve workability. These additive materials are typically added in proportions that do not surpass 2% of the cement content, usually ranging from 1% to 2% [13].

In this research, the researchers used kaolin as additive material in cement. Kaolin is a type of white clay which is a rock mass composed of clay minerals with a low iron content occur as a result of hydrothermal processes [14] and kaolin has similar contents to the chemical elements that make up cement [15]. Based on the explanation above, this study focused on to investigate the effect of using kaolin as an addictive material toward compressive strength of concrete.

2. Literature Review

2.1. Concrete

Concrete, as a composite material, relies on two main component types: a hard matrix (binder), typically cement mixed with water, and coarse granular material (aggregates), which serve as fillers. The binder encases and adheres to the aggregates, creating a solid unit. Its specific mixture ratio is adjusted to suit diverse regional material availability and project requirements [4], [5]. In building structure constructions like foundations, columns, beams, slabs and other load-bearing elements are made from concrete. Concrete is used for base construction materials to build roads, buildings, bridges, dams, airports, stations, etc. There are some advantages of using concrete as building material, namely:

a. Strong, durable, and fire resistance [7], [8], [9];
b. Economical means concrete is cheaper than other building materials, such as steel, brick or wood. Then, concrete also requires little maintenance if used properly. In normal conditions, concrete structures do not need coating or painting as protection for weathering [7], [8], [16];
c. Versatility means concrete can be mixed with various aggregates and additives to produce different varieties of concrete with unique characteristics [16];
d. Concrete can be shaped into variety forms and sizes for structural, architecture and ornamental applications while preserving its strength and stability [7], [9];
e. Sustainability means concrete can be made by using recycled materials and can also be repurposed after its life cycle, which makes it a sustainable building material [16].

2.2. Kaolin

Kaolin, a common white clay formed through the natural decomposition of feldspar, is highly valued for its versatility. Its primary applications include the production of porcelain, serving as a filler in materials like paper and textiles, and acting as an absorbent in pharmaceutical products [2]. A recent innovation in manufacturing has resulted in kaolin being utilized as a material in construction as well. Kaolin also enhances the strength and longevity of concrete. The cement, created by blending kaolin with cement, water, and fine aggregates, exhibited strong cohesive properties [17]. Kaolin from Pawangi Village, Capkala District, Bengkayang Regency, West Kalimantan Province was used in this study. Since kaolin is a naturally formed clay, which is kaolin is composed of a chemical and mineralogical makeup that is influenced by three main factors, they are its parent rock, the climate during its formation, and any subsequent purification processes [2].

The study used kaolin and Styrofoam as additive materials in lightweight concrete [6]. This study used kaolin mixture of 5%, 10% and 15% and 60% of Styrofoam. The result was kaolin mixture 15% and 60% of Styrofoam had the concrete compressive strength and mass results more than 5% and 10% that was 10.11 MPa. So, it could conclude that kaolin could be used as an additive in lightweight concrete. While the other research used kaolin from Belitung as an additive material in making concrete [15]. They used variation of kaolin mixture 0%, 15%, 30% and 45%. As the result, concrete with 15% kaolin mixture had the highest concrete compressive strength value, namely 22.56 MPa. Based on the result, they concluded that concrete with a 15% kaolin mixture can be applied in the construction. Then, other researcher investigated the use of kaolin and waste marble dust in self-compacting concrete [18]. The result of their study was the use of 10% kaolin and 15% waste marble dust as substitutes for cement led to enhanced early strength development in self-compacting concrete.

3. Methodology

3.1. Research Method

This research used experimental design. In civil engineering experimental design refers to an approach for carrying out research and test through investigate and comprehend the behavior of materials, structures, or processes. Experimental research as a type of research that sometime cost more than the potential advantages that are achieved is a successful outcome is ultimately achieved. Experimental research can be conducted in laboratory or field setting. Laboratory experiment is carried out in a laboratory (artificial) environment often exhibit strong internal validity; however, this strength comes with a drawback of weak external validity (generalizability), as the artificial setting may not accurately represent real-world conditions. In contrast, field experiments take place in real-world environments, such as actual organizations, and tend to possess both high internal and external validity. Nonetheless, these types of experiments are relatively uncommon due to the challenges involved in manipulating variables and controlling for extraneous factors in a field situation [19].

This research was laboratory experiment. This research was conducted in Civil Engineering Laboratory Polytechnic State of Pontianak for four months.

3.2. Preparation and Maintenance the Sample

The research involved 12 cube-shaped samples (15 cm x 15 cm x 15 cm). These samples were fabricated using Type 1 cement, fine aggregate sourced from the Kapuas River, coarse aggregate (crushed stone) from Mount Semaoeng, and water from local sources. Fabrication and testing utilized standard equipment: a mold, concrete mixer, slump testing equipment, and a pressure testing machine. The assessment of aggregates strictly followed the technical specifications presented in the table below:

Table 1. *Procedure Aggregate Assessment.*

No	Assessment	nspection Standards	Unit
A	Coarse Aggregate		
1	Gradation	SNI 03-1968-1990	%
2	Abration	SNI 03-2417-1991	%
3	Specific Gravity	SNI 03-1969-1990	
4	Moisture Content	SNI 03-1971-1990	
5	Bulk Density	SNI-03-4804-1998	
B	Fine Aggregate		
1	Gradation	SNI 03-1968-1990	%
2	Specific Gravity	SNI 03-1970-1990	
3	Moisture Content	SNI 03-1971-1990	
4	Bulk Density	SNI-03-4804-1998	

After the aggregate assessment, the research stage was continued by making a job mix formula for the K-350 concrete mixture. The making of samples included the activities of making concrete mixtures and molding the samples with a mixture of 0%, 5%, 10% and 15% kaolin, for each as many as 3 samples, so that the total samples were 12 samples.

3.3. Compressive Strength Testing

Once the samples were cast, they were left to set for 24 hours. Afterward, the molds were opened, and the specimens were cured by soaking them in a water bath for 14 days. They were then maintained at room temperature until the target testing age of 28 days. Before testing, the compressive strength machine was calibrated and verified for proper condition and capability.

The compression test machine provides data in the form of the maximum force (P) sustained by the test object just before failure. The compressive strength of the concrete is then determined from this force value and the cross-sectional area of the cube using the formula:

$$f = \frac{P}{A} \qquad (1)$$

Where f is compressive strength (kg/cm2), P is compressive force (kg), and A is cubic cross-sectional area (cm2)

After obtaining the concrete compressive strength score, the next stage was analysing the data using regression analysis to obtain a relationship model between the addition of kaolin and the concrete compressive strength score.

4. Result and Discussion

4.1. The Result of Cement Examination

Based Visually, the Portland cement used was in good condition and there were no lumps of granules so that the cement could be used as a material for making concrete.

4.2. The Result of Fine Aggregates and Coarse Aggregates Examination

The results of material testing on fine aggregate and coarse aggregate can be tabulated in the table below:

Table 1. *Material Testing for Fine Aggregate and Coarse Aggregate.*

Materials Testing	Fine Aggregate	Coarse Aggregate
Specific Gravity (SSD)	2,65	2,57
Absorption	0,45%	1,34%
Gradation	Zone 2	-
Unit Weight	1260 kg/m^3	1430 kg/m^3
Moisture Content	3,31%	2,07%
Abration	-	22,42%

Based on the data above, it can be explained that the results of fine aggregate testing were only carried out on sand, because kaolin, used as an additional material for fine aggregate in the concrete mixture in this study, was not washed first. The people in Pawangi Village also directly used kaolin in the concrete mixture without washing it first, so this study aims to determine the actual strength obtained by kaolin as an additive in the concrete mixture directly.

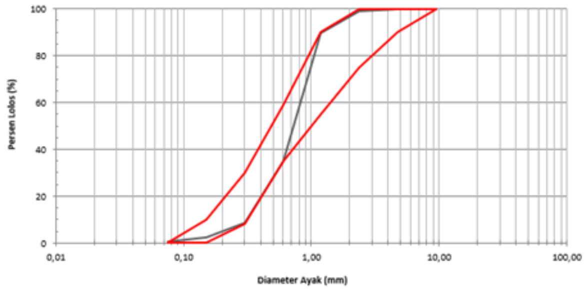

Figure 1. *Sand Gradation Test Graph.*

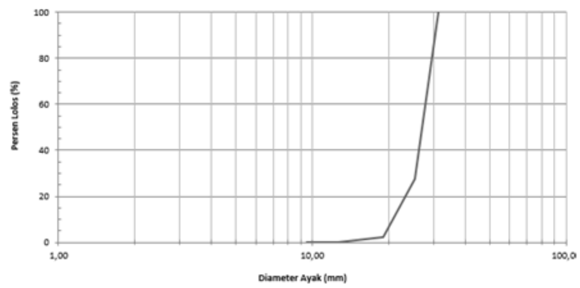

Figure 2. *Gravel Gradation Test Graph.*

4.3. The Result of Water Examination

The water used in this research was water from the Civil Engineering concrete laboratory reservoir, Pontianak State Polytechnic which visually observed was colourless and odourless, so based on the SNI-S04-1989-F, the water was suitable for used as a material for making test objects.

4.4. Job Mix Formula

Based on the data from the concrete mix planning results, the material requirements for making the Fc'30 concrete mix could be determined.

Table 3. *Material Requirements for Making Sample Test.*

No	Fc' (Mpa)	Quantity Requirements for Materials			
		Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (lliter)
1	30	50	83,7366	125,605	21,46

4.5 Concrete Compressive Strength Results

The 28-day compressive strength values for each concrete type, obtained from tests at the Civil Engineering Concrete Laboratory, Pontianak State Polytechnic, are presented in the table below:

Table 4. *Concrete Compressive Strength Results*.

Kaolin 0%	Weight (kg)	Compressive Force (kN)	Compressive Strength (Mpa)
1	8,3	752,17	33,43
2	7,8	605,39	26,91
3	8,1	857,00	38,09
		Σ	**98,43**

$$\sigma_{bm}' = \sum_{1}^{n} \frac{\sigma b'}{n} \qquad = 32,81 \text{ Mpa}$$

Table 5. *Concrete Compressive Strength Results.*

Kaolin 5%	Weight (kg)	Compressive Force (kN)	Compressive Strength (Mpa)
1	8,1	605,54	26,91
2	8.0	548,19	24,36
3	7,8	686,90	30,53
		Σ	**81,81**

$$\sigma_{bm}' = \square_{1}^{n} \frac{\sigma b'}{n} \qquad = 27,27 \text{ Mpa}$$

Kaolin 10%	Weight (kg)	Compressive Force (kN)	Compressive Strength (Mpa)
1	7,9	734,73	32,66
2	7,8	639,72	28,43
3	7,9	660,84	29,37
		Σ	**90,46**

$$\sigma_{bm}' = \sum_{1}^{n} \frac{\sigma b'}{n} \qquad = 30,15 \text{ Mpa}$$

Kaolin 15%	Weight (kg)	Compressive Force (kN)	Compressive Strength (Mpa)
1	7,6	525,71	23,37
2	7,7	490,09	21,78
3	7,8	636,59	28,29
		Σ	**73,44**

$$\sigma_{bm}' = \sum_{1}^{n} \frac{\sigma b'}{n} \qquad = 24,48 \text{ Mpa}$$

Based on the compressive strength tests of concrete, different average compressive strength results were obtained for each concrete mix group, which was designed with varying proportions of kaolin admixture. The comparison of compressive strength for each concrete mixture and the regression model for the relationship between compressive strength and the proportion of kaolin admixture can be observed in the graph below:

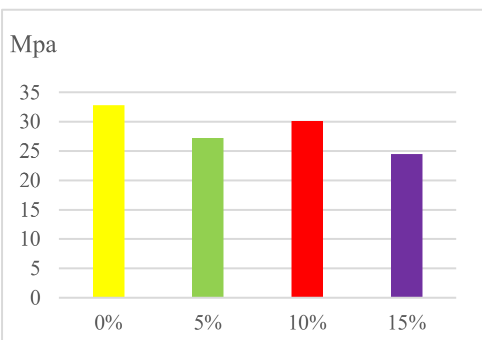

Figure 3. *Graph of Average Compressive Strength Test Results.*

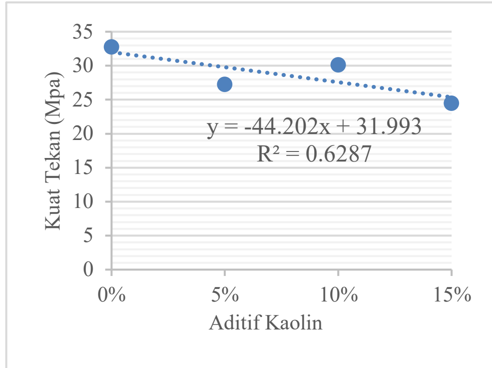

Figure 4. *Linear Regression Model for the Relationship between Compressive Strength and Kaolin Content.*

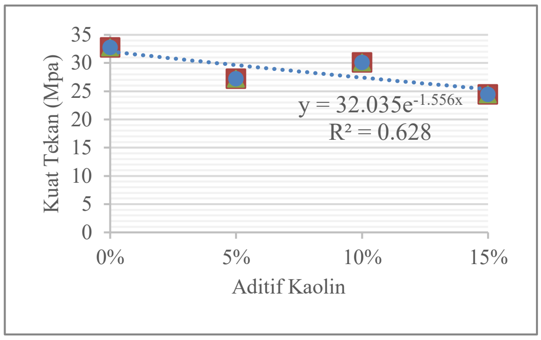

Figure 5. *Nonlinear Regression Model of Compressive Strength Relation with Kaolin Mixture Content.*

As illustrated in Figure 3, the compressive strength values of kaolin-admixed concrete generally display a decreasing trend despite variations with increasing kaolin content. The concrete mix containing 0% kaolin yielded the highest compressive strength value, which was 32.81 MPa at 28 days, significantly surpassing the values recorded for the other kaolin mix ratios. At a 5% kaolin admixture, the concrete's compressive strength decreased to 27.27 MPa at 28 days. Subsequently, an increase was noted for the 10% kaolin mix, achieving 30.15 MPa at 28 days. However, the compressive strength then dropped again for the 15% kaolin admixture to 24.48 MPa.

The regression model presented in Figure 4 is a simple linear regression. From this equation, the negative value of the regression coefficient indicates a decrease in the dependent variable corresponding to an increase in the independent variable. Specifically, this suggests that an increase in the kaolin admixture will lead to a reduction in compressive strength values. Furthermore, the coefficient of determination (R2) is 0.6287. This value is far from 1, implying that the relationship between the kaolin additive content and the concrete's compressive strength is not definitively established as a consistent decrease. Additionally, the coefficient demonstrates that the influence of the kaolin admixture on the reduction of the concrete's compressive strength value accounts for only 62.87 of the total variability.

Figure 5 presents the non-linear regression model, specifically a 2nd-order polynomial regression model. The coefficient of determination, R2, is 0.628. This value is nearly identical to that obtained from the linear regression analysis. Since the R2 value is significantly lower than unity (1.0), the relationship between the kaolin mixture content and the concrete compressive strength cannot yet be definitively established. This coefficient indicates that the kaolin mixture only accounts for 62.8% of the variability observed in the reduction of concrete compressive strength.

The relationship model can be employed to estimate the reduction in concrete compressive strength using a kaolin admixture as a partial replacement for fine aggregate. From Table 4, Table 5, and Table 6, the percentage reduction in concrete strength utilizing kaolin as a fine aggregate replacement can be calculated.

Table 8. *Tabulation of Concrete Compressive Strength Reduction Percentage Calculation.*

Kaolin	Compressive Strength (Mpa)	Deviation (Mpa)	Persentage (%)
5%	32,81	-	-
5%	27,27	5,54	16,88%
10%	30,15	2,66	8,11%
15%	24,48	8,33	25,39%

Based on Table 8, it can be observed that the largest percentage reduction in concrete strength using a kaolin mixture occurred in the mix containing 15% kaolin as a replacement for cement, resulting in a reduction of 25.39% compared to the compressive strength of the normal concrete mix. Furthermore, the coefficient of determination obtained from both linear and non-linear regression models did not approach unity. This result indicates that the correlation between the kaolin substitution percentage and the reduction in concrete compressive strength cannot be definitively established. The relationship observed suggests that an increase in the kaolin mixture percentage is not directly proportional to the magnitude of the percentage reduction in concrete compressive strength. This is evidenced by the fact that the concrete mixture containing 10% kaolin additive actually exhibited an increase in compressive strength.

The reduction in the compressive strength value of concrete at kaolin percentages of 5%, 10%, and 15% can be attributed to the silt content present in the kaolin. Kaolin is a type of clay mineral (aluminosilicate) composed of several layers of aluminum silicate. Essentially, kaolin is a clay containing a very large proportion of the mineral kaolinite, and it is classified as a primary clay [4]. The reduction in concrete compressive strength can also be attributed to the kaolin gradation not meeting the required gradation specifications and Fineness Modulus (FM) of the fine aggregate used in the concrete mix. Finer aggregates in the mix increase the required cement content for the mixture, consequently leading to an increase in the water-to-cement ratio of the mix. A higher water-to-cement ratio results in a decrease in concrete strength [20].

5. Conclusion

Based on the experimental investigation and testing performed, the following conclusions were drawn:

1. The average compressive strength of the concrete mix without kaolin (0% kaolin) was determined to be 32.81 MPa. The average compressive strengths for mixes incorporating kaolin at 5%, 10%, and 15% replacement levels were 27.27 MPa, 30.15 MPa, and 24.48 MPa, respectively, all measured at the age of 28 days.
2. The optimum replacement percentage of cement with kaolin as a supplementary cementitious material is 10%.
3. The resulting regression model, when expressed in a linear regression form, is given by y = -44.202x + 31.993 with a coefficient of determination R^2 = 0.6287; cconversely, the non-linear regression model is defined by the equation y = 32.035e-1.556x with R^2 = 0.628.8.

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