# Mechanical Properties of Fly Ash-Based Geopolymer with Natural Fiber

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# Mechanical Properties of Fly Ash-Based Geopolymer with Natural Fiber

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**Abstract**. Geopolymer concrete is an eco-friendly concrete that can reduce carbon emissions on the earth's surface because it uses industrial waste materials such as *fly ash*, rice husk ash, bagasse ash, and palm oil fuel. The development of *fly ash* as a cement replacement material is now widely used, especially on geopolymer concrete. In this study the natural fiber used is pineapple fiber. Pineapple fiber is an alternative use of natural fibers in geopolymer mortar composites. This research performed compressive strength test and flexural strength test with variations of pineapple fiber length 10 mm, 20 mm, and 30 mm with percentage of fiber used 0%, 0.25% and 0.50% of mortar weight. The mortar geopolymer is made from 100% fly ash. The concentration of NaOH solution used was 14 M and 16 M. The study revealed that the fiber length of 30 mm at a percentage of 0.50% fiber at the concentration of NaOH 16 M results a compressive strength of 41.468 MPa and the largest flexural strength of 9.209 MPa.

## 1. Introduction
Concrete is a construction material used for infrastructure development such as bridges, dams, buildings and other urban infrastructure facilities. The use of concrete continues to increase along with the increasing needs of facilities and infrastructure that are needed. This is because the concrete offers advantages such as being able to withstand stress, fresh concretes may be easily printed as desired, fresh concrete can be added to the cracked surface during a reparation process. As the use of concrete materials increases, there are two important aspects that must be considered; they are durability and sustainability (being environmentally friendly). Production of every ton of clinker cement results in the release of carbon dioxide ($CO_2$) by one ton into the atmosphere.

The effort to produce eco-friendly concrete is through the development of concrete by using inorganic binder such as polymer alumina-silicate — or known as geopolymer — which is a synthesis of geological material contained in natural or industrial by-products such as *fly ash*, which is rich in silica and alumina [1, 3]. *Fly ash* is one of the industrial by-products that can be used in making binders in geopolymer concrete. *Fly ash* is one of the industrial by-products that can be used in making binders in geopolymer concrete. *Fly Ash* is a very fine material such as dust, which comes from unused coal burning remains. This material has a high content of cement and has a pozzolanic nature, which can react with free lime released by cement during the hydration process and forms a binding compound at normal a temperature in the presence of water.

*Fly ash* is activated with an alkaline solution of sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$) as the catalyst. This combination will be used as a material to make a recharge construction

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with a cube shape. In the geopolymerization process a frequently used of alkaline solution is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and calcium silicate ($K_2SiO_3$). The type of alkali solution plays an important role in the polymerization process. The use of sodium (Na) materials such as sodium hydroxide or sodium silicate will be cheaper so that costs can be reduced and the used technology is more flexible [7, 11].

The fine aggregate occupies 70 - 75% of the total mortar volume. Therefore, aggregate quality has a major influence on the quality of mortar that will be produced. The selection and use of good aggregates will make the mortar workable, robust, durable, and economical.

Sodium silicate and sodium hydroxide are used as alkaline activators [5, 9]. Sodium silicate serves to speed up the polymerization reaction, while sodium hydroxide serves to react Al and Si elements contained in *fly ash* so as to produce strong polymer bonds. The activator alkali used in this study was a combination of sodium silicate and sodium hydroxide solution.

The eco-friendly geopolymer concrete is divided into several types, one of which is fiber concrete. Fiber concrete is a composite material consisting of two or more materials that have stronger mechanical properties than their normal concrete forming material and additional materials such as fibers as composite fillers.

On the other hand, pineapple plants produce waste — their leaves. If processed properly, those leaves can be a product that has a high value, in terms of both function value and economic value. The waste of pineapple plants is unavoidable since — when harvested — their leaves automatically have to be entirely discarded. If not removed, such leaves can inhibit the growth of the shoots or fruits of the future pineapple plants.

[4] states that in pineapple fibers there is cellulose 69.5 – 71.5%, pentosane 17 - 17.8%, lignin 4.4 – 4.7%, pectin 1 – 1.2%, and fat and wax 3-3.3%. The high cellulose content in pineapple fibers causes the geopolymer chain bond to increase so that the geopolymer strength increases.

Fiber-reinforced composites can be classified as two parts: short-fiber composite and long fiber composite. Long fibers are stronger than short fibers. The long fibers (continuous fiber) are more efficient in their laying than the short fibers but the short fibers are easier in their laying than the long fibers. The fiber length affects the processing ability of fiber composites. Judging from the theory, long fibers can pass on the load and voltage from the voltage point to another fiber [10].

The composite strength strongly depends on the fiber used because the voltage applied to the first composite is received by the matrix and transmitted to the fiber, so the fiber will withstand the load to the maximum load. Therefore, the fiber must have higher tensile stress and elastic modulus than the composite matrix [9].

## 2. Materials and methods

This research used 100% fly ash as the basic material of mortar geopolymer. The combination of sodium silicate and sodium hydroxide was used as an alkaline activator.

The materials used in this research were sand, fly ash, sodium silicate, sodium hydroxide, water or aquades, and pineapple fibers. The sand used was taken from Tanjung Raja area, South Sumatra. Before being used, the sand had been checked for its specific gravity, mud content, organic content.

*Fly ash* used in this research was *fly ash* class F from PT. Bukit Asam, Muara Enim, South Sumatra. *Fly ash* used already passed two tests; they were: sieve analysis — conducted in the laboratory of concrete material of University of Sriwijaya, Palembang, and a SEM test — conducted in laboratory of geological survey center, Bandung.

**Table 1.** Composition of *fly ash*

| Oxida | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MnO | CaO | MgO | $Na_2O$ | $K_2O$ | $P_2O_5$ | $SO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount (%) | 53.490 | 0.782 | 29.350 | 5.980 | 0.063 | 3.330 | 1.350 | 0.680 | 0.509 | 0.424 | 0.506 |

Sodium silicate ($Na_2SiO_3$) or waterglass is used as polymerization agent. Sodium hydroxide (NaOH) forms a strong alkaline solution when dissolved into water. The water used should be clean, non-greasy and free of disturbing organic matter. This research used aquades.

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This research used natural fibers in the form of pineapple leaf fibers. Pineapple leaf fibers were obtained from Blitar farmers in a readily already-made condition. Before the use, the pineapple fibers had been treated by immersion in 5% NaOH solution for 6 hours. After being soaked, the fibers were washed and dried at room temperature. After drying out, the fibers were cut in lengths of 10 mm, 20 mm, and 30 mm.

The mixed composition with NaOH concentration was 14 and 16 M. The variant ratio of $Na_2SiO_3$ and NaOH was 2. The variant of activator and fly ash precursor was 0.417. The fine aggregate variant and fly ash precursor were 2. The fiber lengths used were 10 mm, 20 mm, and 30 mm. The percentage of fiber consumption was 0%, 0.25%, and 0.50% fiber from a mixed weight.

**Table 2.** Composition of the mixture

| Comp. | NaOHConce nt. | *Fly ash* (kg/m$^3$) | Fine aggregate (kg/m$^3$) | NaOH (kg/m$^3$) | $Na_2SiO_3$ (kg/m$^3$) | Fiber percent. % | Pineapple fiber (kg/m$^3$) |
|---|---|---|---|---|---|---|---|
| N0-14 M | 14 M | 577.216 | 1,154.448 | 120.256 | 240.512 | - | - |
| N0-16 M | 16 M | 577.216 | 1,154.448 | 120.256 | 240.512 | - | - |
| N10-14 M | 14 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.25% | 5.224 |
| N20-14 M | 14 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.25% | 5.224 |
| N30-14 M | 14 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.25% | 5.224 |
| N10-16 M | 16 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.25% | 5.224 |
| N20-16 M | 16 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.25% | 5.224 |
| N30-16 M | 16 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.25% | 5.224 |
| N10-14 M | 14 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.50% | 10.464 |
| N20-14 M | 14 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.50% | 10.464 |
| N30-14 M | 14 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.50% | 10.464 |
| N10-16 M | 16 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.50% | 10.464 |
| N20-16 M | 16 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.50% | 10.464 |
| N30-16 M | 16 M | 577.216 | 1,154.448 | 120.256 | 240.512 | 0.50% | 10.464 |

## 3. Compressive strength

The tested sample of the compressive strength comprised of ten samples with variations of 0% fiber 14 M and 16 M, thirty samples with variations of 0.25% fibers 14 M and 16 M, thirty samples with variations of 0.50% fiber 14 M and 16 M. This compressive strength test was performed in the laboratory of materials and concrete of Inderalaya campus at the University of Sriwijaya.

Figure 1 shows the relationship between the fiber percentage of 14 M and the compressive strength with the result that the fiber length of 30 mm percentage of 0.50% fiber shows a compressive strength of 29.52 MPa. Figure 1.shows the relationship between the fiber percentage of 16 M and the compressive strength with the result that the fiber length of 30 mm percentage of 0.50% fiber shows a compressive strength of 41.47 MPa.

From figure 2, it is seen that compressive strength of 0.5% fiber percentage at 16 M NaOH concentration is higher than the compressive strength of0.25% fiber, which implies that a large percentage of fiber usage can increase the compressive strength of mortar geopolymer. Nevertheless, it should also be noted that not all fiber usage with a large percentage can increase the compressive strength as the likelihood of the bond between the fibers and the matrix of the other mortar composers interacting well is low — and such occurrence may cause the bond to becomes weak and the compressive strength to becomes low. Thus, the percentage of fiber used has to be carefully estimated; putting too much fiber and not balancing it with the volume matrix will cause the strength of mortar geopolymer to weaken. This means that the percentage of fiber usage should be limited also in order to obtain high compressive strength mortar. Thus, in this research the percentage of fiber was limited to 0.50% only.

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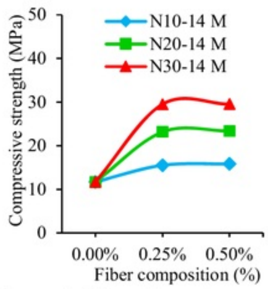


**Figure 1.** Fiber Percentage vs Compressive Strength (14 M)

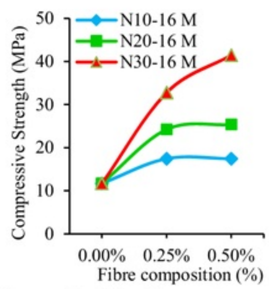


**Figure 2.** Fiber Percentage vs Compressive Strength (16 M)

Figure 3 shows the relationship between the fiber length of 14 M and the compressive strength with the test result that the fiber length of 30 mm percentage of 0.50% fiber shows a compression strength of 29.520 MPa. Figure 2shows the relationship between the fiber length of 16 M and the compressive strength. It can be seen that the length of 30 mm percentage of 0.50% fiber shows a compressive strength of 41.468 MPa.

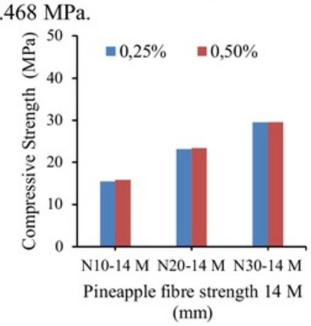


**Figure 3.** Fiber Length and Compressive Strength

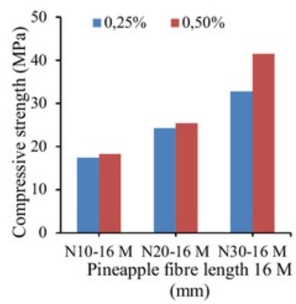


**Figure 4.** Fiber Length and Compressive Strength

From Figure 4 it can be seen that the length of the 30 mm fiber at the concentration of NaOH 16 M with the percentage of fiber 0.50% of compressive strength is higher than the fiber length of 10 mm and 20 mm. The difference in value of compressive strength is very significant, showing that fiber length of fiber composite matrix will affect its strength significantly. Judging from the theory, a long fiber can drain the load and stress from the stress point to another fiber. In an ideal continuous fiber structure, the fiber will be stress-free or have the same stress. During fabrication, some fibers will receive high stress and others may not be exposed to stress so that the aforementioned condition cannot be achieved [9]. Figure 5 shows the relationship between molarity and compressive strength. The fiber length of 30 mm percentage of 0.50% fiber with a concentration of 16 M NaOH shows a compressive strength of 41.468MPa.

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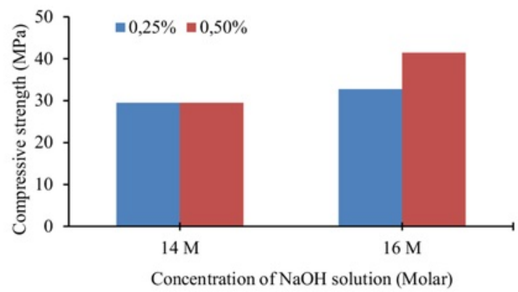


**Figure 5**. Molarity and compressive strength

Figure 5 shows that the concentration of NaOH solution also affects the compressive strength; there is an increase in compressive strength as the NaOH solution concentration increases. The concentration of NaOH solution of 16 M makes the binding process faster and over time so that the polymerization process gets to its maximum, causing the bonds more solid.

## 4. Mortar flexural strength

The samples tested for flexural strength consisted of ten samples with variations of 0% fiber 14 M and 16 M, thirty samples with variations of 0.25% fiber 14 M and 16 M, thirty samples with variations of 0.50% fiber 14 M and 16 M. This compressive strength test was performed in the laboratory of materials and concrete at Inderalaya campus of University of Sriwijaya.

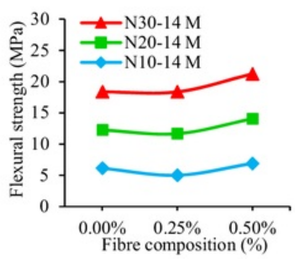


**Figure 6**. Fiber composition and flexural strength (14 M)

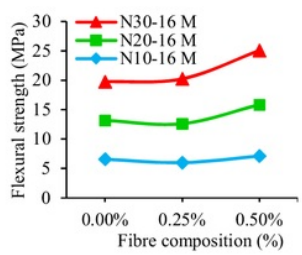


**Figure 7**. Fiber composition and flexural strength (16 M)

Figure 6 illustrates the relationship between the fiber composition of 14 M and the flexural strength. The length of the 30 mm fiber with the percentage of 0.50% fiber shows the flexural strength of 7.187 MPa. Figure 7 shows the relationship between the fiber percentage of 16 M and the flexural strength. The length of 30 mm fiber with a percentage of 0.50% fiber shows a flexural strength of 9.209 MPa.

From the results above, it is shown that if more fiber is used, the stronger the flexural strength is. The increase in the flexural strength is generated by the larger composite dimensions. The more the fiber is used, the greater the composite dimension is. However, it should be noted that if the percentage ratio of the fiber usage is not balanced with the matrix volume, it can cause the flexural strength to weaken

— because the composite is only based on fiber. When the fiber amount is greater than it should be, it automatically reduces the bonding material and causes the weakening of the binder.

Figure 8 shows the relationship between the fiber length of 14 M and the flexural strength; and it indicates the yield of flexural strength at 30 mm fiber length and percentage of 0.50% fiber of 7.187 MPa. Figure 9 shows the relationship between the fiber length of 16 M and the flexural strength; and it indicates the result of flexural strength at 30 mm fiber length and 0.50% fiber percentage of 9.209 MPa.

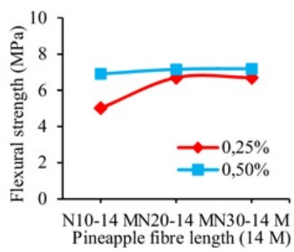


**Figure 8**. Fiber strengthand flexuralstrength

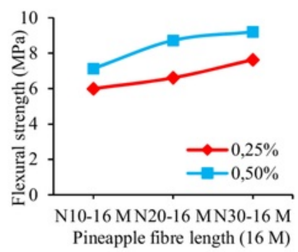


**Figure 9**. Fiber strengthand flexuralstrength

Composites with a length of 30 mm fibers have a higher flexural strength than composites with a fiber length of 10 mm and 20 mm. This is because the length of 30 mm fiber can be distributed well and evenly at the time of composite making process, enabling the bond between the reinforcement of pineapple fiber fibers with the matrix to take place perfectly. Such process can directly increase the flexural strength of the pineapple fiber-reinforced composite. The 30 mm composite with 0.50% fiber percentage makes its maximum strength because more fibers are used than those within the percentage of fiber 0.25%. That way, the load distribution will be better and the matrix bond with the fiber will also be better, leaving the value of flexural strength getting higher.

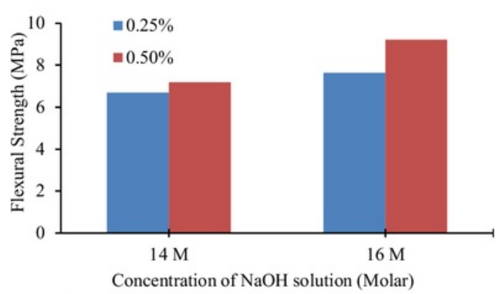


**Figure10**. Molarity and Flexural Strength

Figure 10 shows the relationship between molarity and flexural strength; and it also indicates the result of flexural strength at 30 mm fiber length and percentage of 0.50% fiber with molarity concentration 16 M reaching 9.209 MPa

From the result of flexible strength test, it is shown that the use of fiber with a percentage of 0.50% and the concentration of 16 molar NaOH solution gives good flexural test results for natural fiber-based mortar geopolymer compared to the other variations. This is in line with the compressive strength test results. Increasing the concentration of NaOH solution also affects the increase of flexural strength.

## 5. Conclusion

This research has a number of conclusions as follows:

a. Variation of 30 mm fiber length with fiber percentage 0.50% and concentration of NaOH 16 M solution gives greater compressive strength with value 41.468 MPa and flexural strength with value 9.209 MPa at age 28 days.

b. The increase of compressive strength obtained in a fiber length of 30 mm 16 M, ranges from 11.700 MPa to 41.468 MPa.

c. There is also an increase in flexural strength in fiber length of 30 mm 14 M, which ranges from 6.584 MPa to 9.209 MPa.

d. The increase in compressive strength and flexural strength by increasing fiber use from 0% to 0.50% indicates that the fiber provides a good influence to increase strength of fly- ash based mortar geopolymer.

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