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The Nature of Coconut Fibre Fly Ash-Based Mechanical Geopolymer

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Abstract. In order to reduce carbon emissions in the atmosphere, one of the steps is to use environmentally friendly concrete. Environmentally friendly concrete uses industrial waste as a substitute for cement, such as rice husk ash, palm burning ash, coal burning ash or fly ash. Today, the development of the use of fly ash as a substitute for cement has been widely used, especially in geopolymer concrete. This study uses natural fibres such as coconut fibre. Coconut fibre is also an alternative material in the use of natural fibres as geopolymer mortar composites. This research carried out compressive strength and flexural strength test by doing several variations such as the length of coconut fibres 10 mm, 20 mm, and 30 mm and the percentage of fibre used was 0, 0.25% and 0.50% of the weight of the mortar. Geopolymer mortar made from 100% fly ash. The concentration of NaOH solution used was 14 M and 16 M. The results of this study indicate that the fibre length of 30 mm with a percentage of 0.50% fibre at a concentration of 16 M NaOH solution gives a compressive strength of 40.016 MPa and the greatest flexural strength of 8.799 MPa at 28 days mortar age.

1. Introduction

Concrete is a construction material that is widely used in infrastructure development such as bridges, dams, buildings and other infrastructure. The use of concrete structures continues to increase with the increasing need for facilities and infrastructure needed by humans. This is because concrete has advantages such as being able to withstand press, fresh concrete is easy to print as desired, in the process of repairing concrete, fresh concrete can be added to the cracked surface. Increasing the use of concrete structure materials, there are two important factors that must be considered, namely durability and environmental friendliness.

The Efforts to obtain environmentally friendly concrete is through the development of concrete using inorganic binding materials such as alumina-silicate polymers or known as geopolymers which are synthesized from natural geological materials or industrial by-products such as fly ash which is rich in silica content and alumina [1].

Flying ash is one of the industrial by-products that can be used in the manufacture of binders in geopolymer concrete. Fly Ash is a very fine material like dust, originating from the unused coal combustion. Fly Ash has high levels of cement material and has pozzolanic properties, which can react with free lime released by cement during the hydration process and form compounds that are binding at normal temperatures in the presence of water. Fly ash is activated by an alkaline solution in the form of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) as the catalyst.

This combination is used as a material for the construction of infiltration construction in the form of a cube. In the process of geopolomerization of alkaline solutions which are often used is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and calcium silicate (K2SiO3). The type of alkaline solution plays a very important role in the polymerization process. The use of sodium (Na) material which is sodium hydroxide or sodium silicate will be cheaper so that costs can be reduced and the technology used is more flexible [2].

Fine aggregate used ranges from 70 - 75% of the total volume of mortar. Therefore, the quality of the aggregate has a major influence on the quality of the mortar to be produced. The choice to use a good aggregate will make the mortar workable, strong, durable and economical. Sodium silicate and sodium hydroxide are used as alkaline activators [2]. Sodium silicate serves to accelerate the polymerization reaction, while sodium hydroxide functions to react the Al and Si elements contained in the fly ash so that it can produce strong polymeric bonds. Alkaline activator used in this research is a combination of sodium silicate solution and sodium hydroxide.

Geopolymer concrete is an environmentally friendly concrete that is divided into several types, one of which is fibrous geopolymer concrete. Fibre concrete is a composite material consisting of two or more materials that have stronger mechanical properties than its forming material, which is normal concrete and fibre-added material as a composite filler.

Waste from coconut plants, namely coconut fibre, is fibre taken from the outer cover of coconuts and is a plant native to the tropics. Coir is also considered a seed fibre, although it looks similar to fibre from tree bark with cellulose (about 44%), lignin (45%), pectin and related compounds (3%), and water (5%). Coconut coir fibre has an average diameter of 236μm, coconut coir fibre has the most resilient properties (Sunariyo, 2008). Coconut fibre has the most ductile properties. Meanwhile, the strength of valuable coconut fibre is lowest when compared to other natural fibres. One of the causes of the low strength of coconut fibre is its single fibre structure and its large diameter is 236 μm. However, coconut fibre has a high elongation to break> 31%. Composites that use fibre as reinforcement can be classified into two parts, namely short fibre composite (short fibre composite) and long fibre composite (long fibre composite). Long fibre is stronger than short fibre. Long fibre (continuous fibre) is more efficient in its use than short fibre but short fibre is easier to place than long fibre. Fibre length can affect the processing capability of fibre composites. Judging from his theory, long fibres can continue the load and the voltage from the point of tension towards the other fibres [3-6].

High and low strength of the composite is very dependent on the fibre used because the voltage applied to the first composite is received by the matrix and passed to the fibre, so the fibre will withstand the load to the maximum load. Therefore, fibre must also have a higher tensile stress and modulus of elasticity than the composite matrix [7-12].

2. Materials and methods

This geopolymer mortar study uses 100% fly ash as its base material. The combination of sodium silicate and sodium hydroxide is used as an alkaline activator.

The material used in this study is sand, fly ash, sodium silicate, sodium hydroxide, water or aquades, and coconut fibre. The sand that is used comes from the Tanjung Raja area, South Sumatra. Before being used, sand is examined for specific gravity, sludge content, and organic content.

Fly ash used in this study is class F fly ash from PT. Bukit Asam, Muara Enim, South Sumatra. The fly ash used has passed the filter no. 200 which was carried out in the concrete material laboratory of Sriwijaya University, Palembang and SEM tests have been carried out in the geological survey center laboratory, 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

Use of sodium silicate (Na2SiO3) or water glass as polymerization. Sodium hydroxide (NaOH) is a strong alkaline solution when it is dissolved in water. The water used must be clean, non-greasy and free of harmful organic substances, in this study aquades are used.

This study uses natural fibres such as coconut fibre. Coconut fibre are obtained from Blitar farmers in ready-to-use conditions. Coconut fibre fibres before use are treated with immersion in a 5% NaOH solution for 6 hours. After soaking the fibres are washed clean and carried out drying at room temperature. After the fibres are dry, the fibres are cut into 10 mm, 20 mm and 30 mm lengths [13-14].

Mixed composition with NaOH concentrations of 14 M and 16 M. Variants of Na2SiO3 and NaOH ratios of 2. Activator variants and fly ash precursors are 0.417. Fine aggregate variants and fly ash precursors are 2. Using fibre lengths of 10 mm, 20 mm and 30 mm. For the percentage of fibre use of 0%, 0.25%, and 0.50% fibre by weight of the mixture.

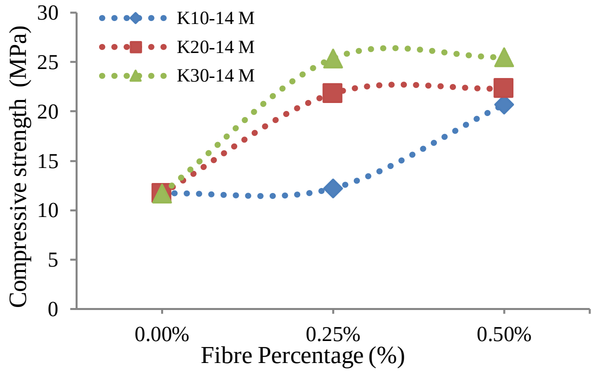
Table 2. Composition of the mixture/m³

Composition	NaOH Concentration	*Fly ash*	Fine aggregate	NaOH	Na_2SiO_3	Fibre percentage	Coconut fibre
		(kg)	(kg)	(kg)	(kg)	%	(kg)
K0-14 M	14 M	577,216	1154,448	120,256	240,512	-	-
K0-16 M	16 M	577,216	1154,448	120,256	240,512	-	-
K10-14 M	14 M	577,216	1154,448	120,256	240,512	0,25%	5,224
K20-14 M	14 M	577,216	1154,448	120,256	240,512	0,25%	5,224
K30-14 M	14 M	577,216	1154,448	120,256	240,512	0,25%	5,224
K10-16 M	16 M	577,216	1154,448	120,256	240,512	0,25%	5,224
K20-16 M	16 M	577,216	1154,448	120,256	240,512	0,25%	5,224
K30-16 M	16 M	577,216	1154,448	120,256	240,512	0,25%	5,224
K10-14 M	14 M	577,216	1154,448	120,256	240,512	0,50%	10,464
K20-14 M	14 M	577,216	1154,448	120,256	240,512	0,50%	10,464
K30-14 M	14 M	577,216	1154,448	120,256	240,512	0,50%	10,464
K10-16 M	16 M	577,216	1154,448	120,256	240,512	0,50%	10,464
K20-16 M	16 M	577,216	1154,448	120,256	240,512	0,50%	10,464
K30-16 M	16 M	577,216	1154,448	120,256	240,512	0,50%	10,464

3. Mortar compressive strength

The sample for compressive strength testing consists of ten samples with 0% fibre variation of 14 M and 16 M, thirty samples with a variation of 0.25% fibre 14 M and 16 M, thirty samples with 0.50% variation of 14 M fibre and 16 M. Compressive strength testing was carried out in the material and concrete laboratory at Inderalaya University, Sriwijaya University.

Figure 1 shows the relationship between the percentage of 14 M fibre with compressive strength and the results show that the fibre length of 30 mm with a percentage of fibre 0.50% compressive strength of 25.472 MPa. Figure 2 shows the relationship between the percentage of 16 M fibre and compressive strength with the result that the fibre length is 30 mm and the percentage of fibre 0.50% results in compressive strength of 40.016 MPa.



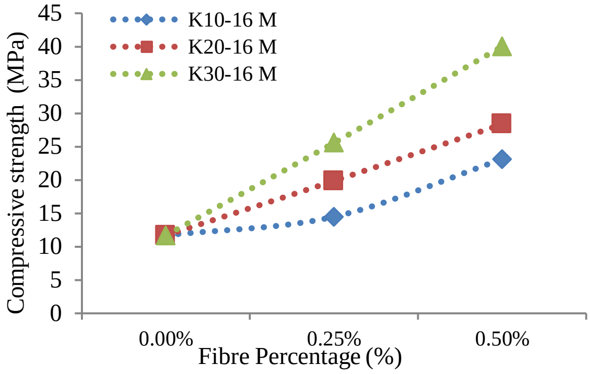
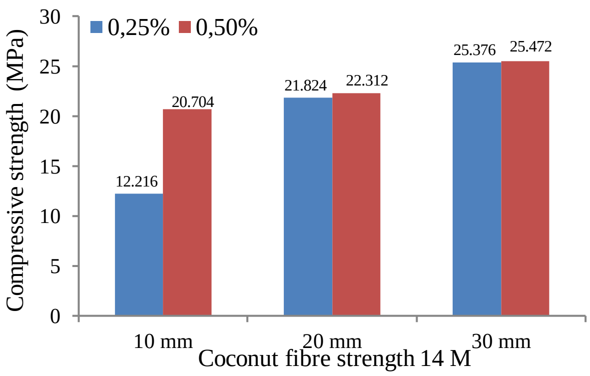


Fig 1. Fibre (%) and Compressive Strength 14M **Fig 2.** Fibre (%) and Compressive Strength 16M

From figure 1 and figure 2 show that the mixture with a percentage of 0.5% fibre at 14 M NaOH concentration and 16 M NaOH concentration results in higher compressive strength compared with 0.25% fibre percentage. This proves that a greater percentage of fibre use will increase the compressive strength value of geopolymer mortars but it must also be known that not all fibre usage with a greater percentage can increase the compressive strength value because it can happen with the use of a greater percentage of fibres which will result in bonding between Other fibres and mortar constituents do not interact properly so that the bonding matrix is weak and the compressive strength value is low. Therefore, it is important to pay attention to the percentage of fibre usage, if too much fibre usage is not balanced with the matrix volume, the strength will be weakened. So the percentage of fibre use must also be limited so that a high compressive strength mortar is obtained, therefore in this study the percentage of fibre is limited to 0.50%.

Figure 3 shows the relationship between the length of the fibre and the compressive strength value with the results of the compressive strength test that the fibre length of 30 mm using a percentage of 0.50% fibre and 14 M NaOH concentration showed a compressive strength result of 25.472 MPa. Figure 4 shows the relationship between fibre length and compressive strength with 16 M NaOH concentration. The results show that the fibre is 30 mm and the percentage of fibre is 0.50% the compressive strength value is 40.016 MPa.



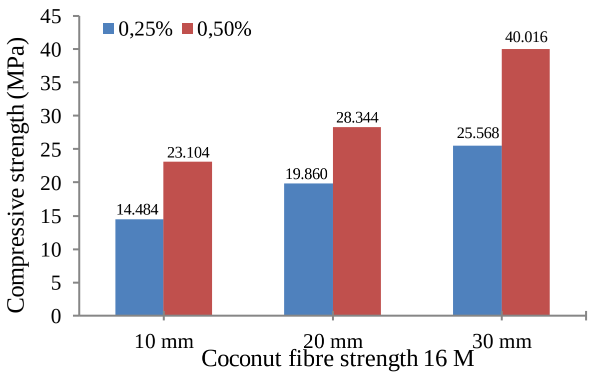


Fig 3. Length and Compressive Strength 14M **Fig 4.** Fibre Length and Compressive Strength 16M

So Figure 3 and Figure 4 show that the fibre length of 30 mm at 16 M NaOH concentration with a percentage of fibre 0.50% compressive strength can be higher than the fibre length of 10 mm and 20 mm. The difference in compressive strength is very significant, this shows that the length of the fibre in the manufacture of fibre composites on the matrix is very influential on its strength. Judging from his theory, long fibres can flow loads and stresses from voltage points to other fibres. In an ideal continuous fibre structure, the fibre will be stress free or have the same stress. During fabrication, some fibres will receive high stress and others may not be exposed to stress so that the above conditions cannot be achieved [3].

Figure 5 shows the relationship between molarity and compressive strength. Fibre length of 30 mm percentage of 0.50% fibre with 16 M NaOH concentration shows a compressive strength value of 40.016 MPa.

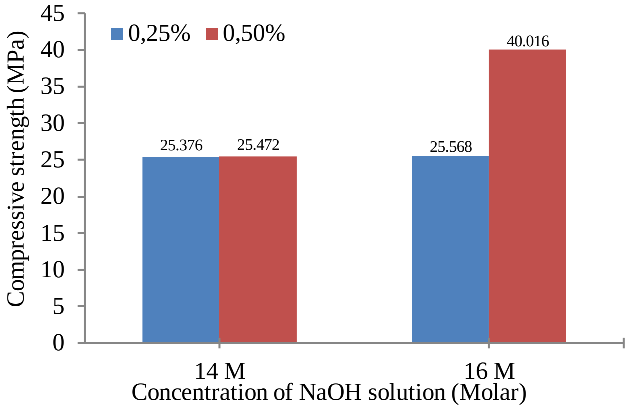


Figure 5. Molarity and Compressive Strength

Figure 5 shows that the concentration of NaOH solution can also affect the compressive strength value, an increase in compressive strength value with increasing concentration of NaOH solution. Concentration of 16 M NaOH solution can make the matrix binding process faster and with increasing time the polymerization process will be more maximal, so that the bond formed can be more solid.

4. Mortar flexural strength

The flexural strength test sample consists of ten specimens with 0% variation of 14 M and 16 M fibres, thirty samples with variation of 0.25% 14 M and 16 M fibres, thirty samples with 0.50% variation of 14 M fibre and 16 M. This flexural strength test was carried out in the material and concrete laboratory of the Inderalaya campus of Sriwijaya University.

Figure 6 shows the relationship between the percentage of 14 M fibre and flexural strength. Fibre with a fibre length of 30 mm and a percentage of 0.50% fibres showed flexural strength results of 7,576 MPa. Figure 7 shows the relationship between the percentage of 16 M fibre and the value of flexural strength. Fibre with a fibre length of 30 mm with a percentage of 0.50% fibre shows a flexural strength of 8.799 MPa.

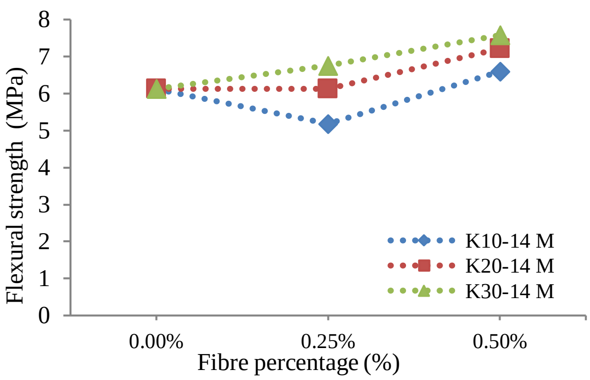


Fig 6. Fibre (%) and Flexural Strength 14M

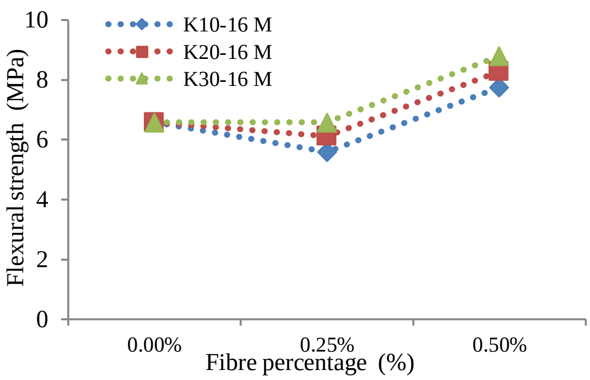


Fig 7. Fibre (%)and Flexural Strength 16M

From the picture of the flexural test results above shows that if the fibre is more fibre then the bending stress will increase. The increasing strength of the flexural strength is due to the greater composite dimensions. The more fibre usage, the bigger the composite dimension will be. However, it should be noted that if the comparison of the percentage of fibre usage is not balanced with the volume of the matrix it can cause the bending value to weaken because the composite only relies on the fibre alone, if the increase in fibre, will automatically reduce the binding material which causes the binding material to weaken as well.

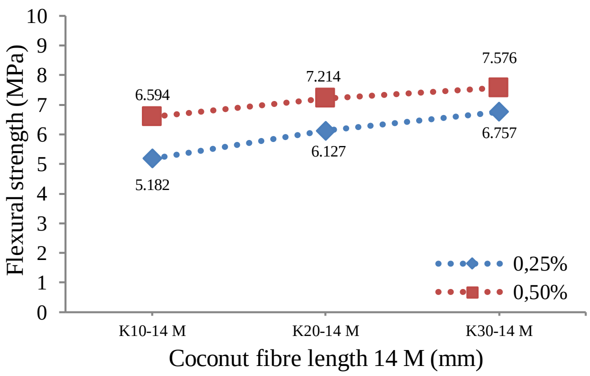


Fig 8. Fibre and Flexural Strength 14M

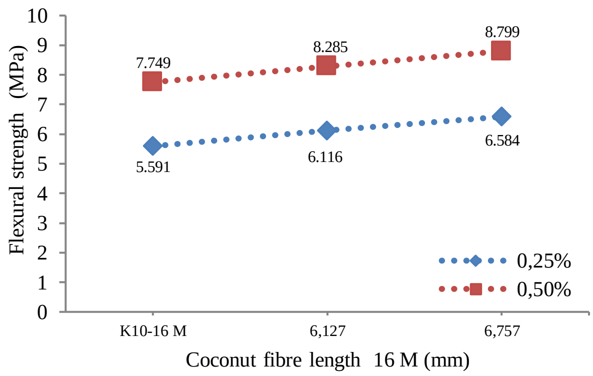


Fig 9. Fibre and Flexural Strength 16M

Composites with 30 mm fibre length have higher flexural strength values than composites with fibre lengths of 10 mm and 20 mm. This is because the 30 mm long fibre can be distributed well and evenly during the process of making composites, so that the bond between the reinforcement ie coconut fibre fibres with the matrix can take place perfectly, so that it will directly increase the value of the flexural strength of the coconut fibre reinforced composites. In the 30 mm long fibre composite with a percentage of 0.50% fibre reaches maximum strength because the amount of fibre is more than the percentage of fibres 0.25% so that it will be better in dividing the load then the matrix bond with the fibre will get better too which causes the value of flexural strength will get higher.

Figure 10 shows the relationship between molarity and flexural strength. The results show the flexural strength of 30 mm fibre length and percentage of fibre 0.50% with a concentration of 16 M molarity of 8,799 MPa.

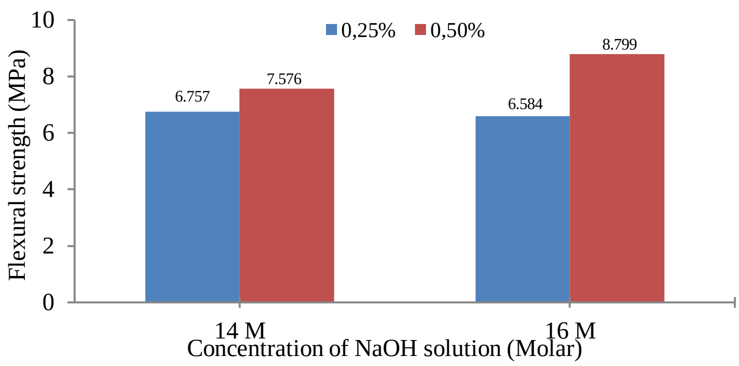


Figure 10. Molarity and Flexural Strength

The results of flexural strength tests show that the use of fibre with a percentage of 0.50% and the concentration of 16 molar NaOH solution will give good flexural test results for natural fibrous geopolymer mortar compared to other variations. This is directly proportional to the compressive strength test results. Increasing the concentration of NaOH solution also affects the increase in the value of flexural strength.

5. Microstructure test

Geopolymer particle morphology analysis was carried out using SEM (Scanning Electron Microscopy) test. The purpose of SEM analysis is to determine the formation of a geopolymer matrix, unreacted material, pores and the entry of coconut fibre fibres into the geopolymer matrix. Micrographs show geopolymers with part or all of the unreacted mortar forming matrix and cracks drawn as lines. The test was carried out at the Bandung geological survey center laboratory. SEM test results of fibre length of 30 mm 16 M with a percentage of 0.50% shows the distribution of coconut fibre fibres more evenly compared to the results of SEM test fibre lengths of 10 mm and 20 mm. The morphology of geopolymer particles which is dominated by solid and homogeneous geopolymer matrices on fibre length 30 mm 16 M 0.50% fibre indicates that the geopolymerization reaction is more perfect and has a higher compressive strength. This is directly proportional to the results of the compressive strength and flexural test results.

Figures 11 through 16 show that both a 0.25% fibre sample and a 0.50% fibre fibre geopolymer matrix are formed. Matrices in geopolymers are the result of reactions of aluminina and silica monomers that form polymers [15]. Figures 11-16 show that examples with 0.25% fibre and 0.50% fibre were observed as unreacted material. The existence of this unreacted material greatly affects the compressive strength and flexural strength. In addition to the unreacting material, the presence of pores also affects the compressive strength and flexural strength values. Pores contained in geopolymers occur due to air bubbles trapped in geopolymer paste during the printing process.

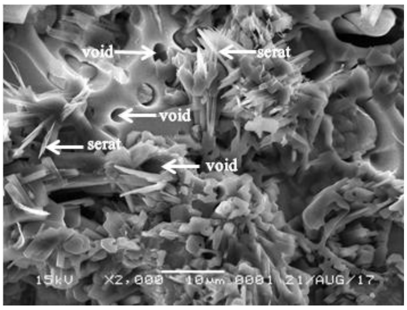


Figure 11. K10-14 M

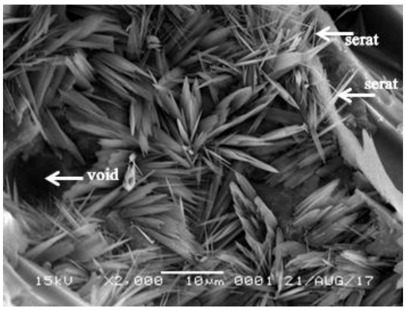


Figure 12. K20-14 M

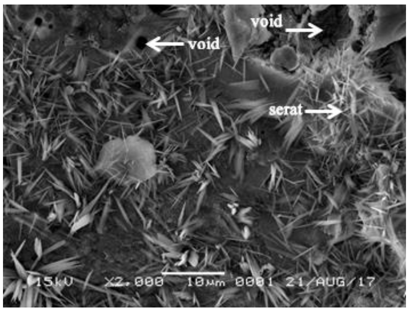


Figure 13. K30-14 M

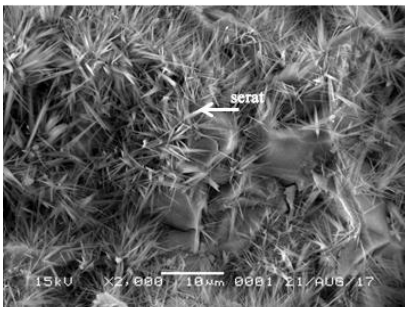


Figure 14. K10-16 M

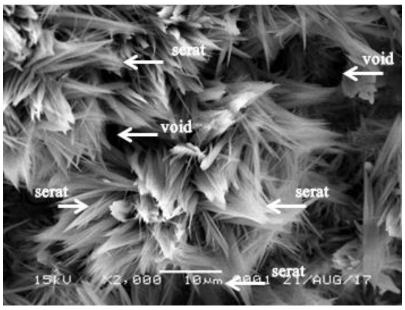


Figure 15. K20-16 M

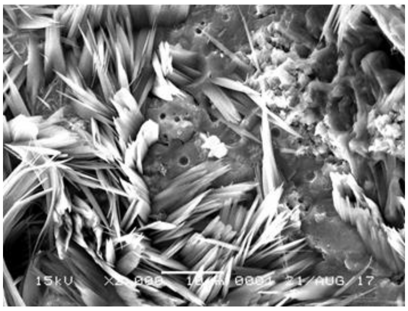


Figure 16. K30-16

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6. Conclusion

There are several conclusions obtained from this study, namely:

i. From the variation of fibre length shows that the fibre length is 30 mm with a percentage of fibre 0.50% and the concentration of 16 M NaOH solution has a higher compressive strength value of 40.016 MPa and a flexural strength value of 8.799 MPa at 28 days.
ii. An increase in compressive strength value from the use of 0% 16 M fibre to the use of 0.50% 16 M fibre is 12,168 MPa to 40,016 MPa.
iii. An increase in the value of flexural strength from the use of 0% 16 M fibre to the use of 0.50% 16 M fibre is 6.584 MPa to 8.799 MPa.
iv. An increase in compressive strength and flexural strength value from the use of 0% fibre to the use of 0.50% fibre, this shows that the fibre has a very good influence for improving the quality of fly ash-based geopolymer mortar.

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