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CHARACTERIZATION OF GEOPOLYMER CONCRETE MADE FROM PEJATEN ROOF TILE WASTE AS PRECURSOR

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ABSTRACT
This research focused on fabricating geopolymers using roof tile waste from the Pejaten area, which has high alumina (Al_2O_3) and silica (SiO_2) content. Binder-to-aggregate ratios of 35:65, 40:60, and 45:55 were tested to examine their effects on structural and mechanical properties. The characterization revealed that the geopolymers had water absorption capacities and compressive strengths of 12.59% and 12.43 MPa, 15.36% and 10.99 MPa, and 18.43% and 6.21 MPa, respectively. Results indicated that increasing the binder ratio raises water absorption capacity but lowers compressive strength. Augite, the main mineral in ferro-sialate type geopolymer, increased from 0% in the precursor to 24% in the binder. Recycling roof tile waste is currently limited and requires optimization. XRD tests confirmed that the Pejaten roof tile waste's high alumina and silica content meets geopolymer precursor requirements. Consequently, geopolymers were made with binder-to-aggregate ratios of 35:65, 40:60, and 45:55. The tests showed that the 35:65 ratio had a water absorption rate of 12.59% and compressive strength of 12.43 MPa; the 40:60 ratio had a water absorption capacity of 15.36% and compressive strength of 10.99 MPa; and the 45:55 ratio had a water absorption capacity of 18.42% and compressive strength of 6.21 MPa. The main mineral in the geopolymer concrete specimens was augite, which grew from 0% in the precursor to 24% in the binder. The findings suggest that higher binder ratios result in higher water absorption capacities and lower compressive strengths.
Keywords: Pejaten Roof Tile Waste; Precursor; Binder; Augite; Geopolymer Concrete
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INTRODUCTION

Geopolymers are inorganic polymer materials obtained by mixing a dry solid aluminosilicate with an alkaline solution and other constituent materials containing silica and alumina.[1,2] Geopolymers can be used to form concrete, and this geopolymer concrete can be made without cement as a binding material. By replacing cement with this geopolymer material, environmental damage due to climate change can be reduced.[3] Since cement manufacturing produces CO_2 gas, a relatively large amount of greenhouse gas.[4] As with normal concrete, the manufacture of geopolymer concrete involves materials such as aggregates and binders. If the binder is cement in normal concrete, then the binder is made from a mixture of precursors and alkali activators in geopolymer. Geopolymer precursors are a group of inorganic pastes with small particle sizes, typically no larger than 20 μm.[5] They have low bulk density, ranging from 0.54 to 0.86 g/cm^3, a high surface area from 300 m^2/kg to 500 m^2/kg, a bright texture, and a round shape.[6] Materials containing silica and alumina elements, such as fly ash, rice husk ash, bagasse, egg shells, pumice[7], dolomite[8], red mud, laterite[9,10], slag, and other materials containing metakaolin, can be used as precursors. One material that can be considered for use as a precursor is roof tile waste (RTW). Recycling RTW as a substitute for geopolymer material is still not widely used. Most RTW is only used for backfilling or compaction, road foundation layers, and so on.[11,12,13] The main use of RTW is for aggregate. However, some reports using RTW as aggregate in making concrete experienced decreased compressive strength [14,15] so further effective utilization is needed. In order to effectively utilize the RTW, this research aims to use RTW as a geopolymer precursor. RTW has been obtained locally from the Pejaten area, Tabanan, Bali province. Notably, this material has not been previously utilized as a geopolymer material. Pejaten RTW is difficult to use as a good aggregate, considering that the aggregate used must have hard and strong properties.[16,17] Good aggregate will have a water absorption rate with a maximum value of 2.3% or less than 3%.[18] While, Pejaten roof tiles have a higher water absorption rate and are even above 20%. Apart from that, aggregate hardness

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is generally at number 7 on the Mohs scale, while Pejaten roof tiles only range from 3 to 5. Compared to Karangpilang roof tiles, East Java has a water absorption value below 5%, a hardness of 6 on the Mohs scale, and a flexural strength of more than 120 kgf.[19] That Pejaten RTW characteristic indicates that this roof tile waste contains relatively high amounts of aluminosilicate compounds suitable for geopolymer precursors.

EXPERIMENTAL

Chemical Characterization of Pejaten Roof Tile Waste

The obtained Pejaten roof tile waste was cleaned with water, dried, and ground. The ground waste was then sieved until it passed a 200-mesh sieve. The chemical content of elements and oxides from Pejaten roof tile waste was identified using XRF. XRF analysis was carried out using Epsilon 4 Benchtop Malvern Panalytica.

Preparation of Geopolymer Concrete

The basic mix design for geopolymer concrete was based on the formulation presented in Table-1. The NaOH used was NaOH flakes, which were then made into a solution with a concentration of 12 M. The sodium silicate, Na_2SiO_3, used was water glass BE 52. Coarse and fine aggregates were obtained from local building materials stores. Each composition is given a 2% superplasticizer Beton Mix brand.

Mineral Characterization of Geopolymer binder

Mineral identification of Geopolymer binder uses XRD with semi-quantitative calculations. XRD analysis was conducted using X-ray Diffraction Panalytical Xpert 3 Powder. In addition, the surface analysis of geopolymer concrete was also analyzed using a scanning electron microscope, Thermo Fisher Scientific Quattro S, which was equipped with EDS.

Mechanical Characterization of Geopolimer Concrete

Geopolymer concrete specimens were fabricated as cubes with side lengths of 6 cm. These objects will be used to test the water absorption (WA) and compressive strength after 28 days. Geopolymer concrete specimens with Pejaten roof tile waste were tested for water absorption (WA) using standard gravimetric methods after 28 days. The water absorption test is essential as it directly correlates with the quality of the concrete produced. Specifically, it is linked to the concrete's porosity and capacity to absorb water, which are critical factors in determining the concrete's overall performance. The water absorption of geopolymer concrete specimens is calculated using the eqn.-1.[20]

$$WA = \frac{2 - w1}{w1} x100\%$$

Where WA is water absorption in %, $w1$ and $w2$ is the dry weight of the sample after drying in an oven at 105˚C and soaking in water for 24 hours in grams? The WA value is presented as a deviation range, taken at a confidence level of 95%.[21] The compressive strength value of geopolymer concrete obtained after 28 days is similar to Portland cement curing time using analog electric hydraulic pump compression machine equipment.[22] The compressive strength of the test specimen is determined by applying eqn.-2, which provides a mathematical formula for calculating this critical property.

$$CS = 10\frac{P}{A}$$

Where CS is the compressive strength of the specimen in MPa, P is the compressive load given to the specimen in kN, and A is the area specimen of compression in cm^2.

RESULTS AND DISCUSSION

Chemical Characteristics of Pejaten Roof Tile Waste

Geopolymer precursors contain high amounts of silica, SiO_2, and alumina, Al_2O_3. Therefore, it is necessary to ensure that the materials used here are rich in these elements.[23] The test results show that roof tile waste contains a high amount of the mineral anorthite, $CaAl_2Si_2O_8$, which can also be written as $CaO.Al_2O_3.2SiO_2$. Both materials contain sufficient amounts of calcium and CaO. Identification results of the mineral content of Pejaten roof tile waste using XRD show that anorthite is the main element that can be used to make geopolymers.[24] Based on semi-quantitative analysis, the anorthite content in Pejaten roof tile waste reached

94%. At the same time, the rest is in the form of hematite mineral, Fe_2O_3. The mineral anorthite contains relatively large amounts of silica oxide and alumina. The results for the element and oxide content of Pejaten roof tile waste are shown in Table-2.

Table-1: Basic Formula for Geopolymer Concrete Composition

Binder: Aggregate	Binder		
	Pejaten RTW (%)	Na_2SiO_3 (%)	NaOH 12 M (%)
35:65	23.80	7.95	3.25
40:60	27.20	9.09	3.71
45:55	30.60	10.22	4.18

Table-2: Identification Results of the Element and Oxide Content of Pejaten Roof Tile Waste

No	Elements		Oxide	
	Components	Value	Components	Value
1	Si	33.4850%	SiO_2	46.1710%
2	Al	17.4980%	$A1_2O_3$	21.6800%
3	Ca	3.2600%	CaO	2.4050%
4	K	2.7310%	K_2O	1.7760%
5	Fe	35.9270%	Fe_2O_3	23.9340%
6	Ti	2.2520%	TiO_2	1.9190%
7	Mn	1.1140%	MnO	0.6880%
8	p	0.6830%	P_2O_3	0.8740%
9	Eu	0.2990%	Eu_2O_3	0.1620%
10	Sr	0.1480%	SrO	0.0719%
11	Zr	0.1200%	ZrO_2	0.0666%
12	Ba	0.1180%	BaO	0.0569%
13	Others	0.3654%	Others	0.2098%

Mechanical Characteristics of Geopolymer Concrete

The water absorption and compressive strength test results can be seen in Table-3. The water absorption value of geopolymer concrete will increase along with the increase in the binder used. The WA value shows how much water can be absorbed by the concrete and how many empty cavities there are in the body of the concrete, especially open cavities, namely cavities connected to outside air.[25] This cavity will fill with water if the concrete is soaked. Thus, the higher the WA value, the more shaft the concrete body will be.[26] To a certain extent, the WA value is still acceptable. Based on SNI 03-0349-1989 concerning Concrete Bricks for Masonry, the maximum average WA value limit is 25%. Meanwhile, based on ASTM C62-12: Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale), a WA value of less than 22% is still acceptable as a brick in moderate weathering environments.[27] Based on these standards, geopolymer concrete made from Pejaten roof tile waste with compositions of 35:65, 40:60, and 45:55 is still acceptable or meets the requirements.

Table-3: Mechanical Characterization of Geopolimer Concrete

Binder: Aggregate	Water Absorption (%)	Compressive strength (MPa)
35: 65	12.5987 ± 0.8216	12.4283 ± 1.0805
40: 60	15.3605 ± 1.0275	10.9917 ± 1.2380
45: 55	18.4226 ± 1.8236	6.2101 ± 0.7259

Meanwhile, geopolymer concrete with a binder composition: of aggregate 45:55 is acceptable according to the SNI 03-0349-1989 standard but cannot be accepted by ASTM C62-12 in moderate weathering conditions, only accepted in non-weathering conditions. The compressive strength value is presented as a deviation range at % a confidence level of 95%. The higher WA value and open cavities resulted in the decreased interaction between the granules that make up the concrete, so its strength also decreased.[28] Apart from that, the strength of concrete was greatly influenced by the amount of the aggregate. Aggregate acts as reinforcement (reinforcement) for the concrete, so the more aggregate is used, the greater its strength will be. Additionally, if the fine aggregate size distribution varies, the strength of the resulting concrete will be increased. Fine aggregate will fill the voids between coarse aggregate so that the density of the concrete increases; this causes its strength to increase as well.

Mineral Analysis of Geopolymer Binder

The binder of geopolymer concrete specimens was analyzed for its mineral content using XRD. The diffractogram is then analyzed to look for the compounds or minerals that make up this material and how much it contains, the result is shown in Fig.-1. Augite has common chemical formula of (Ca, Na) (Mg, Fe, Al, Ti) (Si, Al)$_2$O$_6$. In this research, Augite is seen to have the chemical formula of $Al_{0.342}$ $Ca_{0.616}$ $Fe_{0.21}$ $Mg_{0.902}$ $Na_{0.09}$ O_6 $Si_{1.82}$ $Ti_{0.02}$. This formula can be seen from the Crystallography Open Database (COD) by the identification code of 1000035. The results of the semi-quantitative analysis show that the Anorthite content in the geopolymer concrete binder is 72.6%, the Augite is 24.0%, and the hematite is 3.4%. Compared to the precursor, it can be inferred that the occurrence of mineral amount changes in it. The precursor of this research contains 94% of anorthite and 6% of Hematite, while the geopolymer binder contains 72.6% of Anorthite, 3.4% of Hematite, and 24.0% of Augite. The presence of this compound indicates that geopolymerization has formed in the concrete material being made.

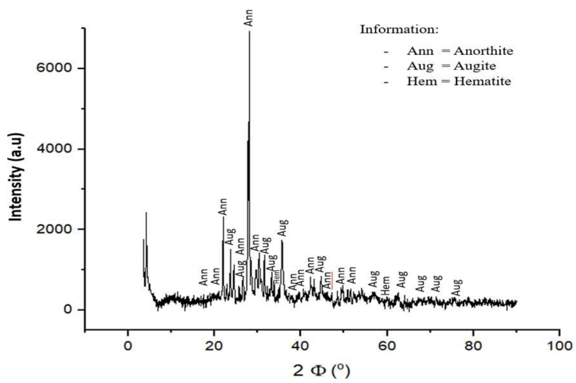
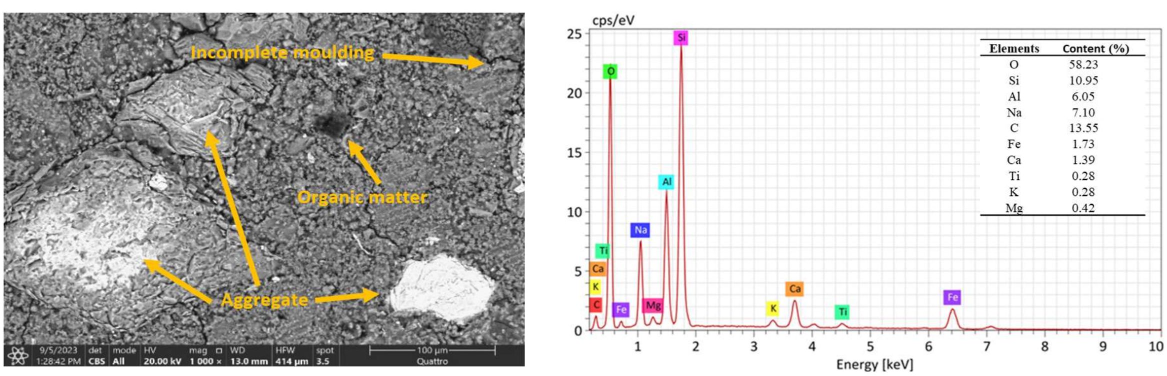


Fig.-1: Diffractogram Of Geopolymer Concrete Binder

Surface Analysis of Geopolymer Concrete

Specimens made from geopolymer concrete with a binder: aggregate ratio = 35: 65 had their surfaces analyzed using SEM-EDS equipment. One specimen was chosen because it has the strongest compressive strength. Dark spots in Fig.-2 indicate the existence of organic compounds. It is indicated by the presence of the carbon element (C) in the results of SEM-EDS analysis in relatively large quantities. The material phase looks quite even, indicating that the geopolymerization process and binding of the aggregate by the binder are going well.



(a) (b)

Fig.-2: (a) SEM Results of Geopolymer Concrete with a Binder: Aggregate Ratio = 35: 65 with 1000x Magnification (b) SEM-EDS Spectrum and Elemental Content of Geopolymer Concrete

CONCLUSION

Based on the research that has been carried out, it can be concluded that Pejaten roof tile waste can be used as a precursor in making geopolymers. Pejaten roof tile waste contains large amounts of alumina (Al_2O_3)

and silica (SiO_2). Pejaten roof tile waste also contains high amounts of Hematite (Fe_2O_3). The main mineral of ferro sialate type geopolymer in the geopolymer concrete specimens in this research is augite. Augite grew from 0% in the precursor to 24.0% in the geopolymer binder. Geopolymer concrete has a fairly even phase with lines due to the lack of water used. Apart from that, in the binder range of 35 to 45%, the higher the value of the binder used, the higher the water absorption value and the lower the compressive strength value.

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CONFLICT OF INTERESTS

The authors confirm that no competing interests or financial disclosures that could potentially influence the results or interpretation of this study.

AUTHOR CONTRIBUTIONS

All authors made substantial contributions to the development of this manuscript, including reviewing and editing, and have given their approval for the final version. The research profile of the authors can be verified from their ORCID ids, given below:

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