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Assessment of Fly Ash-Rice Straw Ash-Laterite Soil Based Geopolymer Mortar Durability

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Abstract

Geopolymer is an inorganic form of alumina-silica that is synthesized through materials containing lots of silica (Si) and alumina (Al) originating from nature or from industrial by-products. The geopolymer binder is a two-component inorganic system consisting of solid components that have sufficient amounts of SiO_2 and Al_2O_3 to form compounds such as fly ash, rice straw ash, pozzolan, laterite soil, slag, etc. This study aims to analyze the compressive strength, chemical compositions, and geopolymerization process of geopolymers produced from fly ash, rice straw ash, and lateritic soil bound with an alkaline activator, sodium hydroxide (NaOH), with a concentration of 12 M. The durability of the geopolymer mortar was determined by soaking for 3, 7, and 28 days using water curing and sulphate curing (Sodium Sulphate, Na_2SO_4, and Sulfuric Acid, H_2SO_4). The results showed that sodium hydroxide (NaOH) can release silica and alumina in the amorphous phase and can be used as a binder for geopolymer mortar made from straw ash, fly ash, and laterite soil without using oven heat, according to compressive strength, chemical compositions, and the geopolymerization process. The results of this study can be used to support the use of waste materials (fly ash and laterite soil) and local materials (straw ash) as geopolymer mortar-forming materials. Furthermore, it can aid in the development of eco-friendly (environmentally friendly) national infrastructure by eliminating the need for oven heat to initiate the polymerization reaction. However, this research can also be developed to increase the compressive strength of geopolymer mortar, which resembles that of conventional concrete in general.

Keywords: Fly Ash; Rice Straw Ash; Laterite Soil; Geopolymer; Durability.

1. Introduction

Mortar and concrete have long been used both in structural and non-structural buildings [1, 2]. In general, sand and cement are the two main ingredients in the mortar that is frequently used for building construction. As time and technology progressed, so did mortar materials. In addition to employing sand as aggregate and cement as an aggregate binder, they started to use geopolymer as an alternative to cement as an aggregate binder [3–6]. One type of material used to produce geopolymer is fly ash and rice straw ash. Fly ash is one of the by-products of coal combustion in a steam power plant (PLTU) [7–9]. The use of geopolymer fly ash and rice straw ash as material binders has also been developed in order to provide environmentally friendly products, bearing in mind that the cement factory, in addition to producing cement, also produces quite large carbon dioxide emissions into the atmosphere [10, 11]. Fly ash is rich in silica and

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alumina. The content of silica and alumina in fly ash can react with alkaline liquids to produce binders. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) are used as alkaline activators [12, 13].

Sodium silicate functions to accelerate the polymerization reaction, while sodium hydroxide functions to react with the Al and Si elements contained in fly ash so as to produce strong polymer bonds. In addition to the activators of sodium silicate and sodium hydroxide, the strength of the fly ash geopolymer bond is also influenced by the concentration and ratio of the alkaline activator used [14, 15]. Other alternatives that can be used as geopolymer materials other than fly ash, which comes from by-products or is waste from a product, include silica fume, slag, rice-husk ash, rice-straw ash, and others [16]. These materials have been tried in several studies that have been carried out both in mortar and in concrete. Rice straw ash is a waste from agricultural products containing silica, which can be used as a partial substitute for cement in concrete mixes. In addition to the types of geopolymer materials that have been developed, mortar and concrete aggregate types have also been developed [17]. Mortar aggregate material, which usually uses sand, has begun to be developed using other materials, namely material from laterite soil, in place of sand material. Trying to replace the use of cement and sand in mortar with other alternative materials, namely by using geopolymer fly ash, rice straw ash, and laterite soil.

This is possible due to the availability of quite a lot of laterite soil in Indonesia, especially in Kalimantan and Papua. Laterite soil is a group of highly weathered soils in tropical or sub-tropical areas [18]. Formed from the results of the hydration concentration of iron and aluminum oxides, which contain relatively high clay minerals [19, 20]. This laterite soil, along with geopolymer fly ash and rice straw ash, is being tried to be used as a mortar material and binder and is expected to be developed to become one of the existing mortar materials.

An aggressive environment is one that contains aggressive compounds such as acids, sulfates, chlorides, etc. that can damage concrete. This aggressive environment is usually found in areas such as swamps, rivers, or soil contaminated with waste or aggressive chemicals, or in atmospheric environments such as exposure to clouds containing acids [21]. One of the compounds in an aggressive environment that can damage mortar and concrete materials is a compound containing sulfate ions. Mortar and concrete that have been exposed to sulfate environments will experience a decrease in quality and a reduction in volume. Almost all types of sulfates found in aggressive environments will damage the binder in mortar and concrete [22].

In several research studies using geopolymer fly ash as a binding material to replace cement, it seems that it always requires a curing oven temperature to be able to develop and increase the strength of mortar or concrete. Of course, this is a difficult thing to implement in the field. This study examines the compressive strength, chemical compositions, and geopolymerization process of geopolymers made from fly ash, rice straw ash, and lateritic soil bonded with sodium hydroxide (NaOH) at a concentration of 12 M, an alkaline activator. Using water curing and sulphate curing (Sodium Sulphate, Na2SO4, and Sulfuric Acid, H2SO4), the geopolymer mortar's durability was assessed by soaking for 3, 7, and 28 days.

Previous research has used mortar geopolymer fly ash from sand and oil ash. While laterite soil has been used in the form of laterite gravel with cement as a binder for pavement and soil stability, laterite soil has also been used in the form of laterite gravel with cement as a binder for pavement and soil stability. Whereas in this study, the novelty lies in the use of laterite soil as a mortar material and the use of geopolymer fly ash and rice straw ash as binder materials. Geopolymer is produced without using oven heat for the geopolymerization reaction to take place. Of course, this research can also support the development of national infrastructure based on environmentally friendly practices.

2. Previous Empirical Research Studies

Geopolymer concrete was studied by Matalkah et al. in 2016 [23] using a binder composition of hot straw ash, coal fly ash, metakaolin, and gypsum at a weight ratio of 0.50: 0.25: 0.05. A thorough experimental study was conducted using Portland cement as the control material and straw-ash-based concrete as the experimental subject. In comparison to conventional Portland cement concrete, the experimental results demonstrate that non-wood ash-based geopolymer concrete materials can offer the requisite mechanical characteristics, moisture equality, durability, and fire resistance with the proper binder formulation.

According to Detphan & Chindaprasirt (2009) [24], materials such as fly ash (FA) and rice husk ash (RHA) were used to create geopolymer. There were differences in the burning temperature of rice husk, the fineness of RHA, and the proportion of FA to RHA. The mass ratios of RHA and FA in geopolymer mortar were 0/100, 20/80, 40/60, and 60/40, respectively. Heat, sodium silicate, and sodium hydroxide are used to activate the geopolymer. With a sodium silicate/NaOH mass ratio of 4.0, the sample was heated in the oven for an hour before being baked for 48 hours at 60ºC. The result was a mortar with a moderately high FA-RHA content. According to Rosello et al. (2017) [25], there are various management issues with waste biomass from rice straw, including field burning, which results in severe air pollution, and natural organic decomposition, which produces methane emissions. This trash may be repurposed in the production of geopolymers after being converted into ash. The RSA: hydrated lime paste's results showed that the pozzolanic reactivity of the ash was significant (82% hydrated lime fixation for 7 days and 87% for 28 days), and they cemented the CSH gel created after 7 and 28 days at room temperature. After 28 days of curing, the compressive strengths of Portland cement mortar with 10% and 25% substitution by RSA produced 107% and 98%, respectively, of the strengths of the control mortar. The pozzolanicity of the cement made with RSA-mixed is confirmed by the Frattini test. In terms of the possibility of reusing ash as a raw material for creating geopolymers, the results of this reactivity are highly encouraging.

Using sodium hydroxide and sodium silicate, Kim et al. (2014) [26] carried out an experimental inquiry to create geopolymer concrete based on alkaline husk ash (RHA) activated waste. The influence on the geopolymer mortar's compressive strength, NaOH content, curing process, and ideal mix proportions was examined. The findings indicate that increasing the oven time and alkaline activator concentration can boost compressive strength. Studies on resistance were conducted using sulfate and acidic media such as H_2SO_4, HCl, Na_2SO_4, and $MgSO_4$. RHA has a lot of potential as a substitute for regular Portland cement concrete because investigations using fluorescence optical microscopy and X-ray diffraction (XRD) have shown the generation of new peaks and improved polymerization processes, which are responsible for strength development.

Al-Akhras et al. (2007) [27] studied the impact of wheat straw ash (WSA) on concrete performance in response to thermal cycling. The concrete specimens' compressive strength, electrical resistivity, and fracture visibility were measured and analyzed. The findings demonstrated that numerous cracks dispersed over the specimen's surface caused the heat cycle of WSA concrete. In addition, the performance of WSA concrete in response to thermal cycling improved with increasing WSA content. WSA concrete was found to be more resistant to the effects of thermal cycling than plain concrete. Tough aggregate-containing WSA shows greater resistance to thermal cycling.

It appears that the ability to grow and increase the strength of concrete always requires a strong oven temperature, according to various research investigations using fly ash geopolymer as a binding agent to substitute cement. Therefore, oven heat is needed to make geopolymer concrete or mortar made from straw ash, laterite soil, and fly ash. This should be able to supply the heat required for each application of fly ash geopolymer to increase concrete strength to normal levels.

3. Materials and Method

Rice straw ash, fly ash, and laterite soil were the materials employed in this investigation. In order to ascertain the physical qualities and chemical characteristics of these materials in the form of the dominating chemicals contained therein, testing of physical characteristics and chemical characteristics using XRF was conducted. An experimental laboratory procedure was used for this study. The Indonesian province of South Sulawesi provides the laterite soil, straw ash, and fly ash needed to make geopolymer mortar, as well as the alkaline activator sodium hydroxide (NaOH). After the treatment (durability), which involved soaking in water, Na_2SO_4, and H_2SO_4, the compressive strength assessment and chemical composition tests (XRD) were conducted.

3.1. Rice Straw Ash

After the seeds have been removed, straw is agricultural waste in the shape of dried leaves, stalks, and plant leaves. Burning rice straw, one of the main agricultural wastes in Indonesia, produces rice straw ash. In Gowa Regency, South Sulawesi Province, rice cutting waste is converted into rice straw ash by burning it at a temperature of 500ºC. The physical characteristics of the rice straw ash employed in this study are depicted in Figure 1. The laboratory tests on rice straw ash are shown in Table 1 together with the results of those tests, and the laboratory tests on the chemical characteristics of rice straw ash are shown in Table 2.

Figure 1. Physical appearance of rice straw ash

Table 1. Physical characteristics of rice straw ash

No.	Type of examination	Method of examination	Result of examination
1	Specific gravity	SNI 03-1964-2008	2.36
2	Fine Aggregate water absorption	SNI 1970:2008	172.78%
3	Sieve analysis	SNI 03-1968-1990	> 50 % pass sieve no. 200

Table 2. Chemical characteristics of rice straw ash (XRF test)

No.	Oxide Content	Result of examination	Malasyi et al. (2014) [28]
1	Fe_2O_3	2.31%	0.2%
2	Al_2O_3	-	1.78%
3	SiO_2	70.80%	65.92%
4	K_2O	15.89%	-
5	CaO	5.34%	2.4%
6	P_2O_5	3.61%	
7	MgO	-	3.11%
8	SO_4	-	0.69%

According to the results of the examination, the specific gravity was 2.36. The percentage value of straw ash water absorption was 172.78% based on the findings of the fine aggregate water absorption test. As can be observed, straw ash is a bigger substance that can pass through filter no. 200 at 50%. As can be observed, silica compounds (SiO_2), which make up 70.80% of straw ash, are the main component. Other significant components include K_2O, which makes up 15.89%; CaO, which makes up 5.34%; P_2O_5, which makes up 3.61%; Fe_2O_3, which makes up 2.31%, and Cl, which makes up 1.45%. It is envisaged that the silica in the straw ash will be able to solidify into crystals in the geopolymer mortar by joining with other substances.

3.2. Fly Ash

Fly ash is used as a solid substance in this investigation. One industrial by-product called fly ash is the leftovers from the coal-burning process in steam power plants. Fly ash is classified as a "*pozzolon*" material, which is a siliceous or aluminous material with little to no cementious ingredient, like Portland cement, in it. At specific temperatures, fly ash material may chemically react with alkaline liquids to produce substances with cement-like characteristics. The physical characteristics of the fly ash employed in this study are shown in Figure 2. The physical and chemical properties of the fly ash created by the laboratory XRF test are displayed in Tables 3 and 4, respectively. Fly ash was obtained from the PLTU's trash in South Sulawesi Province's Jeneponto Regency, Punagayya Village, and Bangkala District.

Figure 2. Physical appearance of fly ash

Table 3. Physical characteristics of fly ash

Type of examination	Method of examination	Result of examination
Specific gravity	SNI 03-1964-2008	2.65
Fine Aggregate water absorption	SNI 1970:2008	26.42%
Sieve analysis	SNI 03-1968-1990	> 50 % pass sieve no. 50

Table 4. Chemical characteristics of fly ash (XRF test)

No.	Oxide Content	Result of examination	ASTM C 618-03, 2003 [29]		
			Class N	Class F	Class C
1	Fe_2O_3	19.96%			
2	Al_2O_3	19.16%	Min. 70%	Min. 70%	Min. 50%
3	SiO_2	34.63%			
4	MnO	0.25%	-	-	-
5	TiO_2	1.26%	2.4%	-	-
6	K_2O	1.33%	-	-	-
7	CaO	12.74%	3.11%	-	-
8	SrO	0.13%	-	-	-
9	Cr_2O_3	0.07%	-	-	-
10	MgO	8.1%	-	-	-
11	SO_3	1.80%	Max. 4.0%	Max. 5.0%	Max. 5.0%
12	CoO	0.05%	-	-	-
13	BaO	0.21%	-	-	-
14	Pr_6O_{11}	0.05%	-	-	-
15	Nd_2O_3	0.07%	-	-	-
16	Moisture	-	Max. 3.0%	Max. 3.0%	Max. 3.0%
17	Loss of Ignition (LOI)	-	Max. 10.0%	Max. 6.0%	Max. 6.0%

According to the inspection of the fly ash's specific gravity, it was 2.88, which was higher than the specific gravities of straw ash and laterite soil. According to ACI Committee 226, fly ash has fine grains that pass sieves No. 200 (>90%) and No. 325 (45 microns) (27%). Fly ash is divided into three groups by ASTM C 618-03 [29]: class N, class F, and class C. Fly ash in the class N and class F categories must include a minimum of 70% SiO_2, Al_2O_3, and Fe_2O_3 compounds, whereas the content in the class C category must range from 50% to 70%.

As a result, compared to the class C category, where the CaO concentration is greater than 10%, fly ash in the class N and F categories has a considerably lower CaO content [29]. Meanwhile, fewer than 20% of fly ash with a class F category contains the CaO element, according to Temuujin et al. (2009) [30]. The fly ash utilized in this work is type F (low calcium fly ash) according to ASTM C618-03, 2003 [29] and Temuujin et al. (2009) [30].

3.3. Laterite Soil

Red soil, sometimes referred to as laterite soil, is a red to brown soil that develops in a moist, chilly environment with standing water. Red soil, in particular, is beneficial for building foundations because it rapidly absorbs water, has a deep soil profile, a moderate amount of organic matter, a neutral to acidic pH, and contains a lot of iron and aluminum. The Latosol soil type includes laterite soil. In the humid equatorial and tropical regions, latosol soils are created. Latosol is relatively low in plasticity (stickiness) and very brittle due to the mineral presence of silicate clay (clay), which allows water to easily penetrate this soil. Actually, latosols are only found in warm, humid climates, which makes them ideal for the equatorial region's temperature. Because all of these soil layers have lost their plant nutrients due to extreme heat, latosol soil types rapidly lose their fertility. Latosol soils, on the other hand, are ideal for the expansion of vast tropical rain forests. The tropical wet-dry climate regime is intimately related to areas of dense forest.

In Gowa Regency, South Sulawesi Province, laterite soil was collected from the area surrounding the Hasanuddin University Faculty of Engineering campus. The findings of assessing the physical and chemical features of lateritic soils obtained from laboratory XRF testing are shown in Tables 5 and 6, respectively. The physical characteristics of the laterite soil are shown in Figure 3.

Table 5. Physical characteristics of laterite soil

No.	Type of examination	Method of examination	Result of examination
1	Specific gravity	ASTM D-162	2.65
2	Plastic limit (PL)	ASTM D-424	33.90%
3	Liquid limit (LL)	ASTM D-423-66	65.46%
4	Plastic index	ASTM D-427	31.57%

Table 6. Chemical characteristics of laterite soil (XRF test)

No.	Oxide Content	Result of examination	Todingrara et al. (2017) [31]
1	Fe_2O_3	12.49%	5.61%
2	Al_2O_3	49.38%	17.49%
3	SiO_2	34.81%	73.74%
4	MnO	0.10%	-
5	TiO_2	1.39%	1.82%
6	K_2O	0.35%	0.14%
7	Mgo	-	0.70%
8	CaO	0.85%	3.11%
9	P_2O_5	0.44%	0.69%
10	V_2O_5	0.06%	-
11	SO_3	-	0.10%
12	ZrO_2	0.05%	0.82%
13	Cl	-	0.05%
14	SrO	0.03%	-
15	Cr_2O_3	0.02%	-
16	CuO	0.02%	-
17	ZnO	0.011%	-

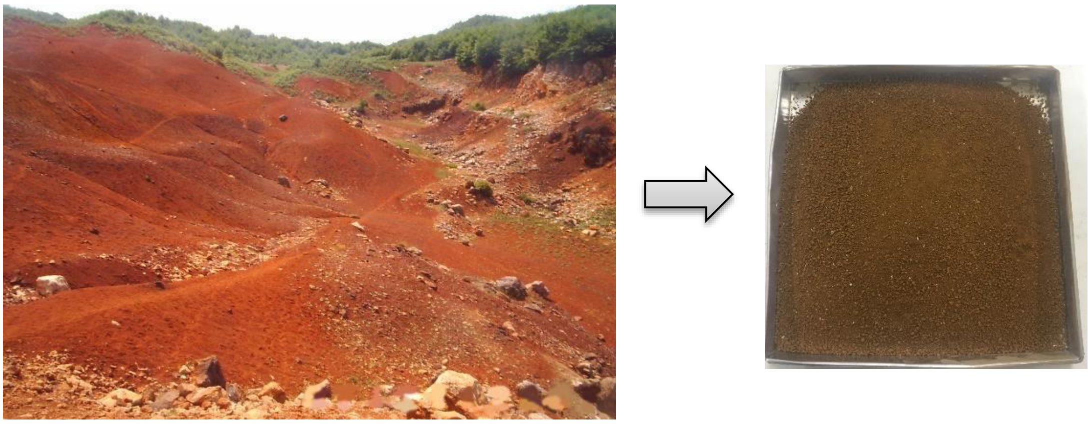


Figure 3. Physical appearance of laterite soil

Results of assessing lateritic soil's physical qualities According to the findings of the sieve analysis test, soil can be categorized into groups A-4, A-5, A-6, and A-7 if more than 76.03% of it passes through a No. 200 sieve (0.075 mm). Liquid limit (LL) = 46.10%; if > 41%, the area is classified as belonging to group A-5. It belongs to groups A-5 (PI 10%) and A-7 (PI > 11%) and has a plasticity index (PI) of 21.79%. Both categories A-7-5 (PL > 30%) and A-7-5 (PL > 30%) can be used to categorize these soils. The area belongs to group A-7-5 because the plastic limit (PL) is greater than 30%, at 30.29%. The lateritic soils employed in this study are classified as clays with high plasticity and are in group A-7-5.

The results of the XRF test were used to determine the chemical properties of the laterite soil. As can be seen, SiO_2 (55.51%), Fe_2O_3 (25.93%), Al_2O_3 (15.01%), TiO_2 (1.38%), K_2O (2.31%), and Cl (1.29%) made up the majority of the laterite soil used in this study.

3.4. Liquid Alkaline Activator

Caustic metallic bases include sodium hydroxide (NaOH), commonly referred to as caustic soda or sodium hydroxide. When basic sodium oxide is dissolved in water, sodium hydroxide is created. When sodium hydroxide is dissolved in water, a potent alkaline solution is created. NaOH is utilized in many different industrial sectors, primarily as a base in the manufacture of textiles, drinking water, soaps, and detergents, as well as wood pulp and paper. In chemical labs, sodium hydroxide is the most widely used basic. The white solid form of pure sodium hydroxide can be found as pellets, flakes, granules, or as a 50% saturated solution. It is a wet liquid that ingests carbon dioxide from the atmosphere on its own. It is particularly soluble in water and, when dissolved, releases heat. Additionally, ethanol and methanol can dissolve it. On paper and textiles, sodium hydroxide solutions will leave yellow stains. The elements Al and Si present in fly ash are reacted by sodium hydroxide in geopolymers, enabling them to form robust polymer bonds and bind well. Figure 4 shows the physical appearance of the sodium hydroxide (NaOH) used in this study. A sodium hydroxide (NaOH) solution with a concentration of 12 Molar was used as the liquid alkalin activator.

Figure 4. Physical appearance of sodium hydroxide (NaOH)

3.5. XRF Analysis

Semi-quantitative assessments of the samples are an alternative to the empirical tests used to assess geopolymer mixes. The XRD (X-Ray Diffraction) test is in dispute. To detect elements, compounds, phases, and crystal structures that are generated qualitatively, XRD testing is used. Atoms organized to create crystal formations and micro- or phase structures can essentially be analyzed using experimental methods based on diffraction. The fired wave will strike the substance in the diffraction experiment and be detected by the detector. The detector determines the wavelength and power of the waves that are reflected or emitted from the substance. Waves emitted by atoms of various sorts and places can interfere with one another. In crystals and complex structures, the diffraction pattern created by the geometry represented by the wave direction can be utilized to identify the unit cell [32, 33]. XRF (X-Ray Fluorescence) test results for rice straw ash, fly ash, and laterite soil's chemical composition.

3.6. Mixtures Design

Lateritic soil, Rice Straw Ash, Fly Ash, and sodium hydroxide activator are all components of the Lateritic Soil-Rice Straw Ash-Fly Ash geopolymer. The Fly Ash content in this study was set at 41.60% of the total mix. Fly Ash ratios were 41.66: 16.66: 41.66 in Lateritic soil:Rice Straw Ash. The composition of the mortar geopolymer design was determined by the early mixed experiments. Table 7 shows the components of the mortar mixture design.

Table 7. Geopolymer mortar mixtures (1 m^3)

Water (kg)	NaOH (kg)	Rice straw ash (kg)	Fly Ash (kg)	Laterite Soil (kg)
655.71	7548.95	7548.95	18872.37	18872.37

3.7. Mixing Procedure

The goal of this study was to identify the mechanical and chemical properties of using fly ash, rice straw ash, and laterite soil in geopolymer mortar using silinder mold with a size of 5×10 cm. The following is the mixing procedure employed in this study:

1. Making a mix design silinder mold with a size of 5×10 cm.
2. Making alkaline activators.
3. Test samples made from laterite soil, fly ash, and rice straw ash were mixed under dry conditions for 1 minute (slow speed).
4. Enter the activator solution (Sodium Hydroxide, NaOH) and water; mix for 2 minutes.
5. Stir manually for 1 minute, and after that, mix the laterite soil, fly ash, rice straw ash, activator solution, and water for 2 minutes at high speed for 10 minutes. So the total mixing time is 14 minutes.

Figure 5, shows the flowchart of the research methodology through which the objectives of this study were achieved.

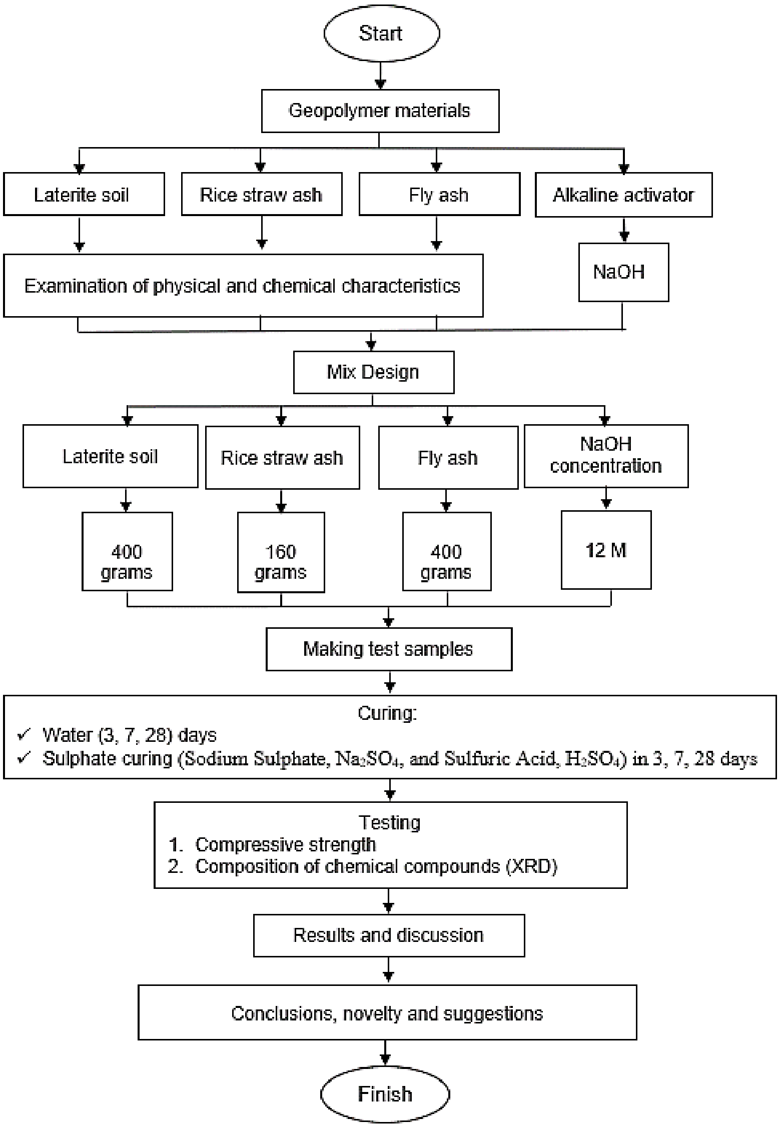


Figure 5. Research flowchart

3.8. Consistency Flow

The goal of flow consistency testing is to establish the ideal water content for producing mortar that is simple to work with. The workability of a mortar mixture is highly correlated with the amount of water utilized. Traceability, or workability, refers to how easily a combination can be manipulated. According to SNI 03-6825-2002 [34], the mortar traceability test was conducted using a melting table and melting ring. The mortar was fed into a melting ring that was set on a melting table and had dimensions of 100 mm on the bottom, 70 mm on top, and 50 mm on the height (300 mm in diameter and 20 mm in thickness). The mortar mix becomes thinner as the spread value increases. The formula indicated in Equation 1 is used to calculate the consistency of the mix flow.

$$K = \frac{Di}{D_0} \times 100\ \% \tag{1}$$

where K is consistency of mix flow (%), D_i is diameter of mortar after lifting tronconique (cm), and D_0 is diameter in tronconique (cm).

3.9. Compaction and Curing Method

This study's design utilized a silinder mold with a mortar geopolymer that was 5 × 10 cm in size. All specimens underwent treatment (curing), which entails room cooling. After being removed from the silinder mold, the specimen can be treated in one of two ways. The first is an air treatment, in which the test object is kept in the specimen's storage area at room temperature. A typical test object is a test specimen that is handled at room temperature. For 24 hours, the second treatment is cooled to room temperature. The test sample should be taken out of the mold and submerged in sulfate salt (Na_2SO_4), sulfuric acid (H_2SO_4), fresh water, sulfuric brine, and sulfuric acid water until it reaches the test time depicted in Figure 6. Sulfuric acid and salt were both soaked in water that had a 2% by weight concentration of sulfuric acid. The specimens that were immersed in sulfate had the highest molarity concentrations. Compressive strength tests are performed on the specimen at ages 3, 7, and 28 days after it has been submerged in water with Na_2SO_4 and H_2SO_4 solutions for curing. The test component underwent treatment up until compressive strength testing was done.

Figure 6. Curing in water, Na_2SO_4 and H_2SO_4 solutions

3.10. Compressive Strength Test

According to SNI 03-6825-2002 [34] and SNI 1974-2011 [35], the specimen is loaded between two loading rods with a continuous monotone load at a consistent pace to produce compressive stress on the specimen. In the compressive strength test, the test item, which is shaped like a cylinder, is in a standing or upright posture when loaded. The test object will eventually collapse or be destroyed due to the compressive stress that it is being subjected to. In the geopolymer cylindrical concrete compressive strength test, which employs the LVDT as a measuring instrument for horizontal displacement due to the applied load, Figure 7 depicts the location of the test object.

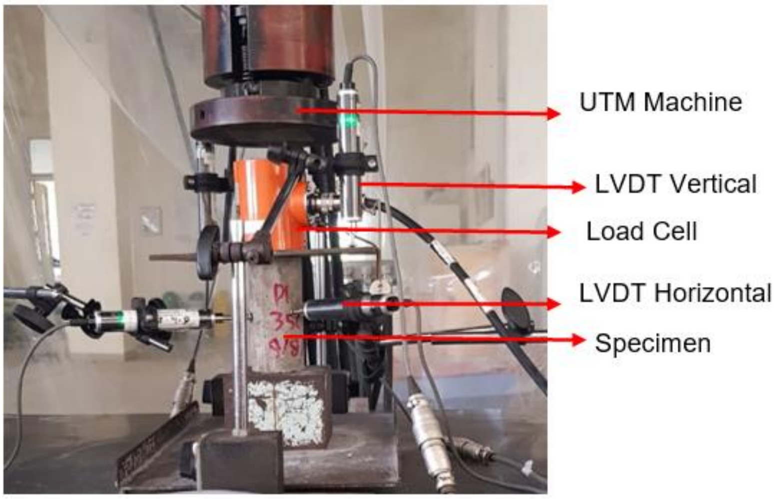


Figure 7. Test of compressive strength

4. Results and Discussion

4.1. Flowability

The outcomes of flow tests on geopolymer mortar mixtures with molarity concentrations of 12 M are depicted in Figure 8 and demonstrate how geopolymer mortar behaves under fresh conditions. Fresh geopolymer mortar had the same flow at each molarity concentration, or 112.50 mm, and had a specific gravity of 1901.3 kg/m^3 at that time. The geopolymer mortar combination has the ability to bond laterite soil, allowing new geopolymer mortar to flow and disseminate evenly without clumping or building up in the center of the circle. Saleh et al. [36] investigated the use of rice husk ash as a cementitious material in geopolymer mortar and found that using more replacement agricultural waste resulted in a smaller flow diameter. Additionally, according to Chen et al. [37], the effect of increased SiO_2/Al_2O_3 and CaO could shorten the setting time. Each geopolymer mortar component that accelerated setting time in our experiment has demonstrated it.

Figure 8. Flowability of fresh mortar geopolymer

A criterion that can only be utilized as a guideline for the flow value in this study's diameter is the specific gravity aligned for each geopolymer material employed in it, specifically rice straw ash, fly ash, and laterite soil. Additionally, the geopolymer material's specific gravity ranges from 2.36 to 2.65. But additional investigation is needed into the flowability of geopolymer effect indicators based on the physical and chemical characteristics of the bonds created during the geopolymerization process or the geopolymerization itself.

4.2. Compressive Stress

With a concentration of 12 M curing water, sulfuric salt (Na_2SO_4), and sulfuric acid (H_2SO_4), the compressive strength test results of straw ash geopolymer mortar at ages 3, 7, and 28 are summarized in Table 8. As can be seen, stress values were 1.287 N/mm^2, 1.475 N/mm^2, and 3.209 N/mm^2 for curing water aged 3, 7, and 28 days, respectively. Na_2SO_4 immersion curing of sulfate salts was 1.444, 1.538, and 2.214 N/mm^2, respectively. In the immersion curing of sulfuric acid (H_2SO_4), they were, in order, 1.346 N/mm^2, 1.354 N/mm^2, and 1.785 N/mm^2. Comparatively to specimens treated in water, the compressive strength of the specimens immersed in sulfuric acid and sulfuric salt decreased. When specimens were exposed to sulfuric acid for curing, the compressive strength decreased by 25.11%, 27.10%, and 84.64% at the ages of 3, 7, and 28 days, compared to 16.62%, 11.89%, and 48.87% for specimens exposed to sulfate-salt for curing. The compressive strength of geopolymer mortar is depicted in Figure 9.

Table 8. Compressive strength of geopolymer mortar water, Na_2SO_4 and H_2SO_4 curing

Curing	Age (Days)	Compressive stress (N/mm^2)
Water	3	1.287
	7	1.475
	28	3.209
Sulfuric Salt (Na_2SO_4)	3	1.444
	7	1.538
	28	2.214
Sulfuric Acid (H_2SO_4)	3	1.346
	7	1.354
	28	1.785

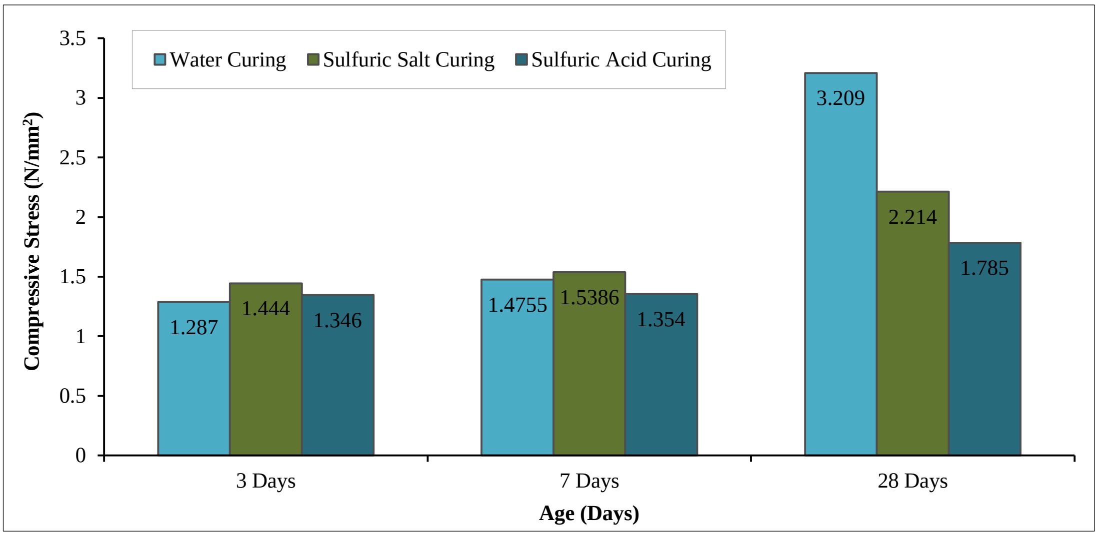


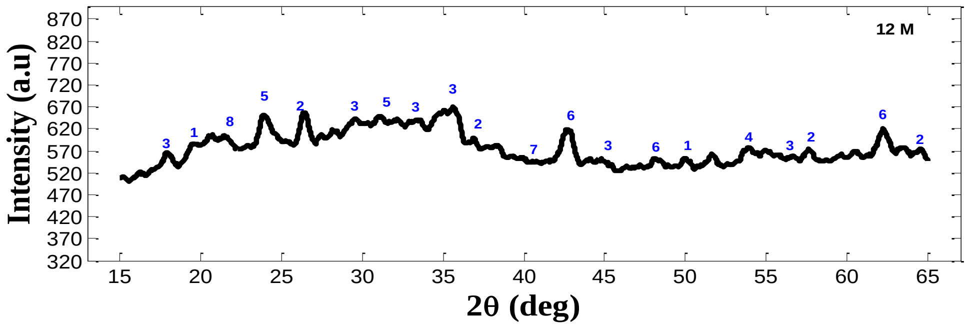
Figure 9. Compressive strength of geopolymer mortar water, Na_2SO_4 and H_2SO_4 curing

It is clear that the specimen that underwent water curing had a higher compressive strength value than the specimens that underwent sulfuric salt and sulfuric acid curing. This is because, in contrast to the sulfuric salt and sulfuric acid-cured specimens, the polymerization reaction on the specimen that has been water-cured occurs flawlessly. The blend of the geopolymer components (rice straw ash, fly ash, and lateritic soil) as a result of the ideal polymerization reaction impacts the test object's hardness and density. The reaction of sulfate ions with the geopolymer mortar binder, which lowers the bonding strength between the binder (alkaline activator) and geopolymer materials, results in the decrease in compressive strength produced by salt and sulfuric acid immersion (rice straw ash, fly ash, and laterite soil).

Concrete can undergo extensive microstructural reconfiguration as a result of exposure to mild sulfate solutions. Sulfate ions enter the material by a variety of processes, including the dissolution of calcium hydroxide and C-S-H decalcification as well as the precipitation of sulfate-bearing phases like ettringite and eventually gypsum. This will be significant since the chemical composition discovered through testing with the XRD equipment will ultimately influence the geopolymerization process. This is what results in the production of the geopolymer in this study without the usage of oven heat.

4.3. Chemical Compositions, Geopolymerization Process and Physical Appearance of the Test Object

Figure 10 depicts the correlation between the phase angle and the intensity of the geopolymer mortar test object's XRD data after air curing with a NaOH concentration of 12 M. Fe_3O_4, which is 31.88%, $CaCO_3$, which is 16.16%, MgO, which is 10.83%, Fe_2O_3, which is 11.53%, SiO_2, which is 10.13%, CaO, which is 5.07%, KOH, which is 4.37%, and P_2O_5, which is 5.07%, are the major components in the geopolymer mortar test specimens, as can be seen. According to the results of the compressive strength test, the test object's strength is supported by the presence of crystallization that can be seen under a microscope in both the XRD and SEM test results. This is due to the fact that crystallization has a significant impact on the test object's hardness.



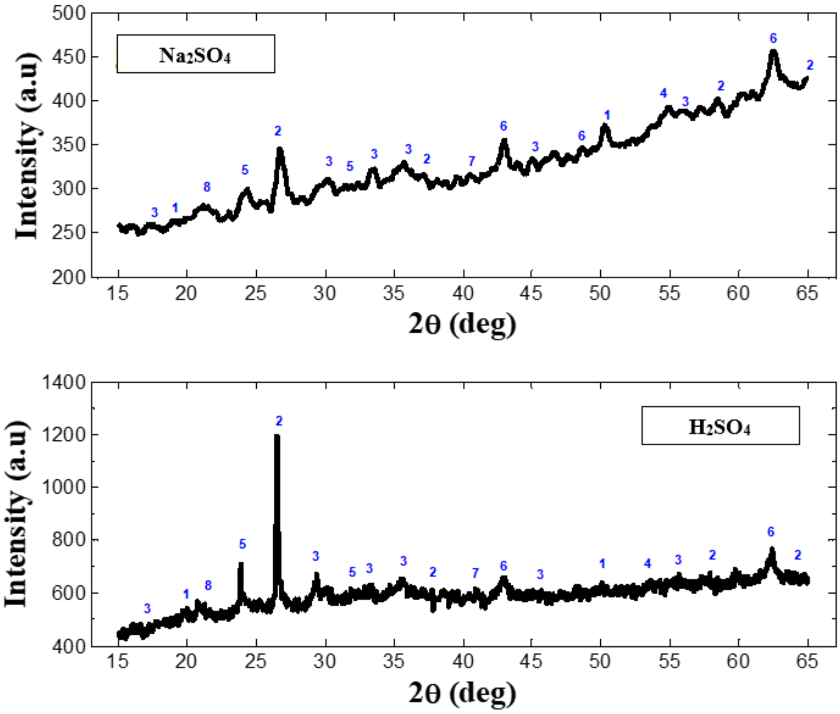
No	Formula	12 M
1	SiO_2	10.13
2	$CaCO_3$	16.16
3	Fe_3O_4	31.88
4	CaO	5.07
5	Fe_2O_3	11.53
6	MgO	10.83
7	KOH	4.37
8	P_2O_5	5.07

Figure 10. Correlation between phase angle and intensity of the geopolymer mortar water curing

Based on the findings of the compressive strength test of the geopolymer mortar test object, the presence of microscopic crystallization also supports the object's strength. This is because crystallization significantly affects hardness. Silica oxide compounds have a significant impact on a material's degree of crystallinity. Calcium silicate cement is created when fine pozzolanic elements such as straw ash interact. Fly ash's primary component, silica, interacts with straw ash to produce a gel known as $[Ca(Si)_3]$. When straw ash, water, and fly ash are combined, the fly ash's pozzolanic characteristics cause a reaction that results in hydrated calcium silicate (C-S-H). Geopolymer mortar undergoes crystallization with regular atomic structures. The materials that make up the geopolymer mortar, namely straw ash, fly ash, and laterite soil activated with NaOH, are able to blend well, harden, and have good density.

Under sulfate immersion circumstances, the geopolymer mortar's chemical properties (Na_2SO_4 and H_2SO_4) were tested using XRD to determine the chemical composition's properties (X-Ray Diffraction). Figure 10 depicts the correlation between the 2θ angle and the intensity of a geopolymer mortar specimen submerged in sulfuric acid and sulfate salt (H_2SO_4 and Na_2SO_4). Under sulfate immersion circumstances, the geopolymer mortar's chemical properties

(Na_2SO_4 and H_2SO_4) were tested using XRD to determine the chemical composition's properties (X-Ray Diffraction). Figure 11 depicts the correlation between the angle and the intensity of a geopolymer mortar specimen submerged in sulfuric acid and sulfate salt (Na_2SO_4) (H_2SO_4).



No	Formula	12 M	
		Na_2SO_4	H_2SO_4
1	SiO_2	8.92	9.02
2	$CaCO_3$	21.05	23.41
3	Fe_3O_4	27.53	23.64
4	CaO	5.44	4.70
5	Fe_2O_3	8.36	10.00
6	MgO	16.59	15.83
7	KOH	4.46	4.70
8	P_2O_5	3.83	4.39

Figure 11. Correlation between phase angle and intensity of the geopolymer mortar Na_2SO_4 and H_2SO_4 curing

Figures 12 to 14, respectively shows the physical appearance of the water curing test object, curing sulfuric acid and sulfate salt (H_2SO_4 and Na_2SO_4). The physical appearance shows the initial damage that occurred to the test object before the compressive strength test was carried out, especially on the specimen that was immersed in sulfuric acid and sulfate salt (H_2SO_4 and Na_2SO_4).

Figure 12. Physical appearance of specimen curing water

Figure 13. Physical appearance of specimen curing sulfuric acid (H_2SO_4)

Figure 14. Physical appearance of specimen curing sulfate salt (Na_2SO_4)

Likewise, 21.05% and 23.41%, respectively, of $CaCO_3$ molecules. The chemical SiO_2, which is in charge of the polymerization reaction in geopolymers, is present in concentrations of 8.92% and 9.02%, respectively, with intensities of 270 a. u. and 570 a. u. But the concentration and intensity that increased with the addition of sulfuric salts to sulfuric acid revealed distinct silica components, including crystalline silica in the specimens exposed to the sulfate salts and amorphous silica in the specimens exposed to sulfuric acid. This is caused by the presence of rice straw ash in this mortar mixture, which contributes to the heat; hence, without the curing of the oven temperature, the fly ash geopolymer mortar with this laterite soil material can still provide strength. This result also indicated that compressive strength increased without oven curing similar because the oxide content of rice straw ash, laterite soil, and fly ash (SiO_2) was able to bind well and produce amorphous silica.

Because they are sulfate pollutants brought on by chemical reactions in cement or concrete, sulfate salts are harmful. These salts, sodium and magnesium sulfates, are common in soils with an alkaline pH. These salts are more harmful than gypsum's (calcium sulfate) drawbacks because they are not only more soluble but also produce more sulfate in groundwater and interact with cement minerals, completely ruining the cement paste [2, 3, 26, 31, 35]. Sulfate salts from different bases can also destroy hardened cement. In order to harden cement, the sulfate salt combines with calcium hydroxide to produce calcium sulfate and with hydrated calcium aluminate to produce further insoluble calcium sulfoaluminate salts.

5. Conclusion

Fly ash reacts with straw ash, laterite soil, and alkaline solutions to generate alumina-silica binders in fly ash-based geopolymer binders without the need for cement. The aggregate is then joined together by the geopolymer binder to create mortar or concrete. According to various existing studies, geopolymer concrete or mortar needs to be baked for 24 hours at temperatures between 35 and 80°C to equal the strength of conventional existing concrete. This study was able to demonstrate that alkaline sodium hydroxide (NaOH)-bound fly ash, rice straw ash, and laterite soil geopolymers can solidify without the use of oven heat. This suggests that a proper polymerization reaction can occur. The creation of a sustainable breakthrough in geopolymer concrete and mortar technology that makes use of waste materials (straw ash), PLTU waste (fly ash), and laterite soil, all of which are plentiful in Indonesia. The results of this study can be used to support the use of waste materials (fly ash and laterite soil) and local materials (straw ash) as geopolymer mortar-forming materials. In addition, it can also support the development of eco-friendly (environmentally friendly)-based national infrastructure without the use of oven heat for the polymerization reaction to take place. However, this research can also be developed to increase the compressive strength of geopolymer mortar, which resembles that of conventional concrete in general.

6. Declarations

6.1. Author Contributions

Conceptualization, P.R.R., M.T., and M.; methodology, M.T., M., and D.S.M.; validation, D.S.M., M., and M.T.; formal analysis, P.R.R., M.T., D.S.M., and M.; investigation, P.R.R., D.S.M., and M.; resources, P.R.R., M.T., D.S.M., and M.; writing—original draft preparation, P.R.R., and M.T.; writing—review and editing, M., and M.T.; project administration, D.S.M. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

Data sharing is not applicable to this article.

6.3. Funding

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] Tumpu, M., & Mabui, D. S. (2022). Effect of hydrated lime ($Ca(OH)_2$) to compressive strength of geopolymer concrete. AIP Conference Proceedings. doi:10.1063/5.0086702.

[2] Mansyur, & Tumpu, M. (2022). Compressive strength of normal concrete using local fine aggregate from Binang River in Bombana district, Indonesia. AIP Conference Proceedings. doi:10.1063/5.0072888.

[3] Dabakuyo, I., Mutuku, R. N., & Onchiri, R. O. (2022). Mechanical Properties of Compressed Earth Block Stabilized with Sugarcane Molasses and Metakaolin-Based Geopolymer. Civil Engineering Journal, 8(4), 780-795. doi:10.28991/CEJ-2022-08-04-012.

[4] Rangan, P. R., Irmawaty, R., Amiruddin, A. A., & Bakri, B. (2020). Strength performance of sodium hydroxide-activated fly ash, rice straw ash, and laterite soil geopolymer mortar. IOP Conference Series: Earth and Environmental Science, 473(1), 012123. doi:10.1088/1755-1315/473/1/012123.

[5] Zhang, P., Zheng, Y., Wang, K., & Zhang, J. (2018). A review on properties of fresh and hardened geopolymer mortar. Composites Part B: Engineering, 152, 79-95. doi:10.1016/j.compositesb.2018.06.031.

[6] Mansyur, & Tumpu, M. (2022). Compressive strength of non-sand concrete with coarse aggregate in Kolaka district as yard pavement. AIP Conference Proceedings. doi:10.1063/5.0072889.

[7] Adnan, A., Parung, H., Tjaronge, M. W., & Djamaluddin, R. (2020). Bond between Steel Reinforcement Bars and Seawater Concrete. Civil Engineering Journal, 6, 61–68. doi:10.28991/cej-2020-sp(emce)-06.

[8] Jindal, B. B. (2019). Investigations on the properties of geopolymer mortar and concrete with mineral admixtures: A review. Construction and building materials, 227, 116644. doi:10.1016/j.conbuildmat.2019.08.025.

[9] Tumpu, M., Rangan, P. R., & Mansyur. (2023). Compressive Strength Characteristic of Concrete Using Mountain Sand. IOP Conference Series: Earth and Environmental Science, 1134(1), 012046. doi:10.1088/1755-1315/1134/1/012046.

[10] Benalia, S., Zeghichi, L., & Benghazi, Z. (2022). A Comparative Study of Metakaolin/Slag-Based Geopolymer Mortars Incorporating Natural and Recycled Sands. Civil Engineering Journal, 8(8), 1622-1638. doi:10.28991/CEJ-2022-08-08-07.

[11] Mohammed, A. H., Mubarak, H. M., Hussein, A. K., Abulghafour, T. Z., & Nassani, D. E. (2022). Punching Shear Characterization of Steel Fiber-Reinforced Concrete Flat Slabs. HighTech and Innovation Journal, 3(4), 483-490. doi:10.28991/HIJ-2022-03-04-08.

[12] Morsy, M. S., Alsayed, S. H., Al-Salloum, Y., & Almusallam, T. (2014). Effect of sodium silicate to sodium hydroxide ratios on strength and microstructure of fly ash geopolymer binder. Arabian journal for science and engineering, 39, 4333-4339. doi:10.1007/s13369-014-1093-8.

[13] Deja, J., Uliasz-Bochenczyk, A., & Mokrzycki, E. (2010). CO_2 emissions from Polish cement industry. International Journal of Greenhouse Gas Control, 4(4), 583–588. doi:10.1016/j.ijggc.2010.02.002.

[14] Pacheco-Torgal, F., Castro-Gomes, J., & Jalali, S. (2008). Alkali-activated binders: A review. Part 1. Historical background, terminology, reaction mechanisms and hydration products. Construction and Building Materials, 22(7), 1305–1314. doi:10.1016/j.conbuildmat.2007.10.015.

[15] Phummiphan, I., Horpibulsuk, S., Sukmak, P., Chinkulkijniwat, A., Arulrajah, A., & Shen, S. L. (2016). Stabilization of marginal lateritic soil using high calcium fly ash-based geopolymer. Road Materials and Pavement Design, 17(4), 877–891. doi:10.1080/14680629.2015.1132632.

[16] Park, Y., Abolmaali, A., Kim, Y. H., & Ghahremannejad, M. (2016). Compressive strength of fly ash-based geopolymer concrete with crumb rubber partially replacing sand. Construction and Building Materials, 118, 43–51. doi:10.1016/j.conbuildmat.2016.05.001.

[17] Rangan, P. R., Irmawaty, R., Tjaronge, M. W., Amiruddin, A. A., Bakri, B., & Tumpu, M. (2021). The effect of curing on compressive strength of geo-polymer mortar made rice straw ash, fly ash, and laterite soil. IOP Conference Series: Earth and Environmental Science, 921(1), 12009. doi:10.1088/1755-1315/921/1/012009.

[18] Maignien, R. (1966). Review of Research on Laterite. Natural Resource Research IV, UNESCO, Paris, France.

[19] Tang, C., Shi, B., Gao, W., Chen, F., & Cai, Y. (2007). Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotextiles and Geomembranes, 25(3), 194–202. doi:10.1016/j.geotexmem.2006.11.002.

[20] Kasthurba, A. K., Santhanam, M., & Mathews, M. S. (2007). Investigation of laterite stones for building purpose from Malabar region, Kerala state, SW India – Part 1: Field studies and profile characterisation. Construction and Building Materials, 21(1), 73–82. doi:10.1016/j.conbuildmat.2005.07.006.

[21] Cizer, Ö., Elsen, J., Feys, D., Heirman, G., Vandewalle, L., Van Gemert, D., ... & De Schutter, G. (2011). Microstructural changes in self-compacting concrete by sulphuric acid attack.13th International Congress on the Chemistry of Cement, 3-8 July, 2013, Madrid, Spain.

[22] Nugraha, P. D. A. (2007). Concrete Technology. Andi Publisher, Yogyakarta, Indonesia. (In Indonesian).

[23] Matalkah, F., Soroushian, P., Balchandra, A., & Peyvandi, A. (2017). Characterization of Alkali-Activated Nonwood Biomass Ash–Based Geopolymer Concrete. Journal of Materials in Civil Engineering, 29(4). doi:10.1061/(asce)mt.1943-5533.0001801.

[24] Detphan, S., & Chindaprasirt, P. (2009). Preparation of fly ash and rice husk ash geopolymer. International Journal of Minerals, Metallurgy and Materials, 16(6), 720–726. doi:10.1016/S1674-4799(10)60019-2.

[25] Roselló, J., Soriano, L., Santamarina, M. P., Akasaki, J. L., Monzó, J., & Payá, J. (2017). Rice straw ash: A potential pozzolanic supplementary material for cementing systems. Industrial Crops and Products, 103, 39–50. doi:10.1016/j.indcrop.2017.03.030.

[26] Kim, Y. Y., Lee, B.-J., Saraswathy, V., & Kwon, S.-J. (2014). Strength and Durability Performance of Alkali-Activated Rice Husk Ash Geopolymer Mortar. The Scientific World Journal, 2014, 1–10. doi:10.1155/2014/209584.

[27] Al-Akhras, N. M., Al-Akhras, K. M., & Attom, M. F. (2008). Thermal cycling of wheat straw ash concrete. Proceedings of the Institution of Civil Engineers - Construction Materials, 161(1), 9–15. doi:10.1680/coma.2008.161.1.9.

[28] Malasyi, S. (2014). Analysis of the Effect of Straw Ash on the Compressive Strength of Concrete. Teras Jurnal, 4, 2088–0561. (In Indonesian).

[29] ASTM C618-03. (2017). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use. ASTM International, Pennsylvania, United States. doi:10.1520/C0618-03.

[30] Temuujin, J., van Riessen, A., & Williams, R. (2009). Influence of calcium compounds on the mechanical properties of fly ash geopolymer pastes. Journal of Hazardous Materials, 167(1–3), 82–88. doi:10.1016/j.jhazmat.2008.12.121.

[31] Todingrara, Y. T., Tjaronge, M. W., Harianto, T., & Ramli, M. (2017). Performance of laterite soil stabilized with lime and cement as a road foundation. International Journal of Applied Engineering Research, 12(14), 4699-4707.

[32] Persson, B. (2001). A comparison between mechanical properties of self-compacting concrete and the corresponding properties of normal concrete. Cement and Concrete Research, 31(2), 193–198. doi:10.1016/S0008-8846(00)00497-X.

[33] Petrillo, A., Cioffi, R., Ferone, C., Colangelo, F., & Borrelli, C. (2016). Eco-sustainable Geopolymer Concrete Blocks Production Process. Agriculture and Agricultural Science Procedia, 8, 408–418. doi:10.1016/j.aaspro.2016.02.037.

[34] SNI 03-6825-2002. (2002.) Indonesian National Standard (SNI) Method of Testing the Compressive Strength of Portland Cement Mortar for Civil Works. National Standardization Council, Jakarta, Indonesia. (In Indonesian).

[35] SNI 1974-2011. (2004). Indonesian National Standard (SNI) Method of Testing the Compressive Strength of Concrete with Cylindrical Specimens. National Standardization Council, Jakarta, Indonesia. (In Indonesian).

[36] Saleh, F., Prayuda, H., Monika, F., & Pratama, M. M. A. (2019). Characteristics Comparison on Mechanical Properties of Mortars using Agriculture Waste as a Cement Replacement Materials. IOP Conference Series: Materials Science and Engineering, 650(1), 12039. doi:10.1088/1757-899X/650/1/012039.

[37] Chen, X., Sutrisno, A., & Struble, L. J. (2018). Effects of calcium on setting mechanism of metakaolin-based geopolymer. Journal of the American Ceramic Society, 101(2), 957–968. doi:10.1111/jace.15249.