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The Effect of Adding Perlite to Unfired and Fired Geopolymer Concrete Made from Fly Ash on Pore Distribution and Compressive Strength

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ABSTRACT

This study focuses on the importance of sustainability and environmental protection in building construction. Materials used should safe and free of toxins, while also adhering to circular construction principles. This study seek materials with appropriate structure and composition, unifying features, insulation, and environmentally friendly properties. In this study, five compositions of fly ash and perlite-based concrete geopolymer have been burned for 900°C for 2 hours. The distribution of pore decreases for both unburned and burned concrete geopolymer is observed. One of the strength of concrete geopolymer indicator is compressive strength. Both of the results of compressive strength and the pore distribution are conducted through experimental study. Bet method has been used to measure pore volume of it. UTM machine has been used to calculate compressive strength. It is found that the addition of perlite to fly ash-based geopolymer concrete will increase the pore distribution value of unburned geopolymer concrete. On the other hand, the summation of perlite to fly ash-based geopolymer concrete will decrease the pore distribution value of burned geopolymer concrete. The highest compressive strength value are in 25% perlite addition. This work advances knowledge of the relationship between fly ash and perlite geopolymer concrete's pore distribution and compressive strength under both unfired and fired situations, which can serve as a foundation for material selection in passive fire protection design.

Keywords: geopolymer, compressive strength, pore distribution, passive fire protection.

INTRODUCTION

Growing and bettering the world now without endangering the future is known as sustainable development. It's about making wise decisions that improve people's lives both now and in the future. It strikes a balance between three fundamental pillars: environmental preservation, social inclusion, and economic prosperity. Sustainable development pushes us to consider the whole picture rather than just profit or quick advancement. It helps guarantee that everyone has an equal opportunity to live safely, work, and prosper, as well as the preservation of our natural resources, such as clean water, air, and forests. A strategic road plan for sustained global prosperity is provided by sustainable development. This is why it's important: protects natural resources, fights climate change, and promotes economic stability enhances quality of life, advances social justice, and fosters innovation and responsible production.

Fire safety is one area where the significance of sustainability has implications. The minimum level of fire safety strives to reduce the likelihood of death and harm to building inhabitants, firefighters, and anyone in close vicinity to the building.Levels of safety can be raised to preserve the building's contents, superstructure, heritage, business continuity, corporate limits of the tenants or owner, and environmental impact.

In order to tackle damage in cause of fire, there are three types of fire defense. Fire defense is comprised of fire management, passive fire protection, and active fire protection [1-2]. This paper presents passive fire protection. It is a build in fire protection in building. One of material used for passive fire protection is geopolymer. Geopolymer is a synthetic aluminasilicate material.It is made from alkali aluminosilicate with alkali hydroxide/ alkali silicate [3-6]. Geopolymers have long been recognized as materials with high resistance to aggresive environments such as high temperatures, variable temperature cycles, moisture, and chemical agents with varying pH levels [7-10]. It consists of basic materials and alkaline solution. For making geopolymer concrete, aggregates are added. Impact of using aggregates in concrete has been studied [11]. Lightweight aggregates have been used in geopolymer [12-14].

One type of lightweight aggregates is perlite. The acid volcanic rhyolite glass that makes up perlite is a metamorphic eruptive rock that contains 2-5% water trapped in the weathered and hardened lava [15]. Chemically speaking, perlite is a hydrous sodium potassium aluminum silicate that primarily consists of silica SiO_2 (65-75%) and aluminium oxide Al_2O_3 (10-18%), along with sodium and potassium oxide K_2O+Na_2O (6-9%), magnesium and calcium oxides MgO +CaO (2-6%), and iron oxide Fe_2O_3 (1-5%) [16-17]. The source of origin affects the material’s chemical makeup. Its grains inflate and the bound water suddenly evaporates, creating a lot of bubbles, when heated quickly to a temperature over 850-870°C. The perlite undergoes an irreversible structural change after heating, the closed air is contained empty, glazed, irregularly shaped bubbles. Because of its exceptional porosity, which aids in water absorption and dissolved nutrients that are then gradually released in dry and warm weather, it is used a a cultivation basis for flowers and vegetables in horticulture [18-21].

Studies regarding mechanical properties of perlite have been done [19-25]. In research [19], the yield strength and elasticity modulus of burned material diminish. It is necessary to have fire surveillance. Geopolymer is one of the sustainable materials. Fly ash and perlite-based concrete geopolymer were burned at 900°C for two hours in this investigation. Surface Area Analyzer test equipment comes next. For burned concrete geopolymer, the pore size varies. In the meantime, compressive strength is a concrete geopolymer indication of strength. Experimental research is used to determine the pore size and compressive strength outcomes. Its pore size has been measured using the BET method. Compressive strength has been calculated using a UTM machine. According to the results of the Surface Area Analyzer Test, adding perlite to fly ash-based geopolymer concrete will reduce the values of surface area, pore volume, and pore distribution in burned geopolymer concrete. However, adding perlite to fly ash-based geopolymer concrete will increase the value of pore distribution and decrease the values of surface area and pore volume in unburned geopolymer concrete.

In this investigation [20], the alkali activation of raw perlite and regular sand is used to create cementless pastes and cementless mortars. Cementless paste and mortar were made using perlite and alkali activators (NaOH and Na_2SiO_3) as binding agents. Additionally, hydrogen peroxide (H_2O_2) was used as a blowing agent to create aerated lightweight pastes and mortars. As a result, the sample's aeration mechanism was investigated, and variations in the values of apparent density, compressive strength, and flexural strength were ascertained. The thermal conductivity characteristics of aerated paste and mortars were examined concurrently. The thermal conductivity, apparent density, compressive strength, and flexural strength of geopolymers in different water/ perlite and H_2O_2/ perlite ratios were compared. The results of the experiment showed that lightweight pastes and mortars with a reduced density and thermal conductivity coefficient may be produced without a substansial loss of ultimate strength by adiing 0.25% H_2O_2 (by mass of perlite) to the mixtures. The proposed aerated geopolymer based on perlite is a sustainable and energy-efficient building solution. The findings indicate that for both paste and mortars, H_2O_2/ Perlite percentage is above 0.5% and water/perlite percentage is above 45% sdhould be avoided.

The mechanical and microstructural characteristics of geopolymer mortars were examined in the study [21] both before and after exposure to high temperatures. Class F fly ash (FA) and finely ground raw perlite (RP) were used to create the mortars. A 10 M NaOH solution was used to alkali-activate RP-FA mixes. Geopolymer mortars were synthesized at 90°C for 4, 8, and 24 hours using various RP/FA mass ratios (100/0; 75/25; 50/50; 25/75; 0/100). After curing for seven, twenty-eight, and ninety days, a number of investigations pertaining to the hardened qualities were carried out. The geopolymer mortars were heated to high temperatures of 400°C, 600°C, and 800°C, respectively, after curing. The effects of high temperatures on the properties of geopolymers were assessed in terms of mass loss, strength loss, and microstructire changes following exposure to high temperatures. The geopolymer mortars produced with an RP/ FA mass ratio of 25/75 showed the greatest outcomes. Following exposure to 800°C, the mortars' flexural and compressive strength values were greater than those following exposure to 600°C. After the mortars were heated to 800°C, new crystalline phases were found in them.

Expandable perlite (EP) and pure perlite (PP) blocks' fundamental mechanical and physical properties are experimentally determined in study [22]. The purpose of the study [22] was to ascertain the EP and PP sample preparation process, inncluding the mixing process, the displacement speed during compaction, and the maximum loading force during compaction. It was found that 15 mm per minute, or the same pace as during the compressive strength testing, is the proper compaction speed to create the samples. For dry density class 650, a maximum compaction force of 10,000 N during sample preparation at a displacement speed of 15 mm per minute ensures a compressive strength greater than 3 MPa, and the process of producing the samples in a single layer, i.e., solid samples.

Study [23] seeks to create a lightweight aggregate geopolymer concrete (LWAGC) that has high density, strong compressive strength, and good thermal insulation capabilities. The dry density of LWAGC was changed by adding expanded perlite (EP). The differences in the physical and mechanical characteristics of LWAGC based on varying EP content were examined, covering aspects like dry density, P-wave velocity, maximum compression strength, and elastic modulus. A quick way to measure was developed using infrared thermal imaging technology, which helps simulate how indoor temperatures of buildings change when the outside temperature is very high. The thermal insulation effectiveness of the LWAGC was further tested with varying levels of EP content. The results indicate that when the amount of EP in LWAGC goes up, there is a matching drop in P-wave velocity, dry density, ultimate compressive strength, and elastic modulus. The lowest dry density of LWAGC is 1209 kg/m^3, while the ultimate compressive strength remains higher than 25.0 MPa, making it suitable for use as LC25 building material in load-bearing structures. The findings also indicate that adding EP can enhance the thermal insulation performance of LWAGC. The LWAGC containing 50% EP has the best ability to reduce temperature and can keep the indoor temperature below 35°C even when the outside temperature is very high, making it a promising material for use in structural parts and insulation of tall buildings.

The study [24] looks at how both expanded perlite and raw perlite are used in cement-based materials, with a focus on how they affect thermal insulation, fire resistance, long-term durability, and the mechanical properties of the materials. It also looks into how where the perlite comes from geographically influences its chemical and physical characteristics. The paper also deals with the difficulties that come with using higher amounts of perlite in cement-based materials, like the rise in porosity and the decrease in strength. The ability of perlite to be used in new and different ways is also talked about. The paper points out important areas where research is lacking and suggests ways to enhance the durability and use of perlite-based applications.

Based on the studies have been done, there is no study regarding correlation between pore distribution and compressive strength of Fly ash perlite-based geopolymer concrete. The goal of this study is to present the connection between pore distribution of fly ash and perlite geopolymer with compression strength test result. The goal of this study is as a basis for choosing materials in the design of passive fire protection.

MATERIALS

Fly ash and perlite are basic material in this research. Fly ash used is class f fly ash. Fly ash from Power Plant Pelabuhan Ratu Sukabumi. It has Ca 7.56%, which is less than 10%. Whilst,

TABLE 1. Chemical Composition of Fly Ash Pelabuhan Ratu Sukabumi and Perlite Sumatera Barat.

	Fly Ash (%)	Perlite (%)
SiO_2	52.15	73.84
Al_2O_3	27.87	12.58
CaO	7.56	1.15
Fe_2O_3	7.87	1.11
MgO	1.30	<0.001
MnO	0.158	0.055
Na_2O	1.23	3.24
K_2O	0.672	4.97
TiO_2	0.845	0.088
P_2O_5	0.193	0.051
SO_3	0.611	0.011
SrO	0.0979	0.010
ZnO	0.0095	0.003
ZrO_2	0.0364	0.019
Rb_2O	0.0028	0.025
Cr_2O_3	0.0034	0.015
Y_2O_3	0.0081	0.004
Rest	0.82 LOI	2.70

perlite gets from Sumatera Barat. TABLE 1 presents the chemical compositition of fly ash and perlite in this research.

The alkaline liquid of geopolymer in this study are Natrium Silicate (Na_2SiO_3) and Natrium Hydroxide (NaOH). Bulk grade natrium silicate (NS) (37,6% SiO_2, 16,2% Na_2O, and 33,9% H_2O by weight). Natrium hydroxide pellets (98%wt) and natrium hydroxide solution (NH) with 6 M. Meanwhile, limestone with maximum size of 10 mm and specific gravity 2.57 used as a coarse aggregate. White sand from Bangka island with specific gravity of 2,56 and fineness modulus 2.9 is used as a fine aggregate.

METHOD

This study uses an experimental method. Composition of geopolymer concrete in this study, can be seen in TABLE 2. NaOH solution was made 24 hours before. Combining the NaOH solution and Na_2SiO_3 can be set a few hours before concrete blending. Fine and coarse aggregate were set under Saturated Surface Dry (SSD) condition. SSD is defined as the situation of an aggregate in which the outlying of the particles are dry (i.e., surface suction would no longer take place), but the inter-particle voids are saturated with water. In SSD condition, aggregates will not affect the free water content of a composite material.

TABLE 2. Percentage of geopolymer concrete mix design.

	6M NaOH
Coarse Aggregate	55 %
Fine Aggregate	4,7 %
Fly Ash	13,80 %
Perlite	4,5 %
Na_2SiO_3	11,67 %
NaOH	3,88 %
Water	6,45 %

The blending process begins by mixing fly ash, perlite, and the alkaline solution for 5-10 minutes. Coarse and fine aggregate were casted into the mixer which consists of fly ash, perlite, and alkaline solution paste. Process of blending takes place around 10-15 minutes until analogous fresh concrete is formed. In the matter to obtain mechanical properties of fly ash geopolymer concrete, cylinder concrete specimens with the dimension 150/300 mm are used. Variations in the mix design of perlite and fly ash used in making geopolymer concrete using variations with percentages of 0% : 100%, 25% : 75%, 50% : 50%, 75% : 25%, and 0% : 100%.

Specimens was cured by water curing. Water curing is in 28 days. After 28 days, the water curing specimens are then put in the furnace. FIGURE 1 shows the furnace. Fire rate in the furnace can be seen in FIGURE 2. Geopolymer specimens burned at 900°C for two hours [13].

FIGURE 1. Furnace used to expose fly ash–perlite geopolymer concrete specimens to a temperature of 900°C for 2 h after 28 days of water curing.

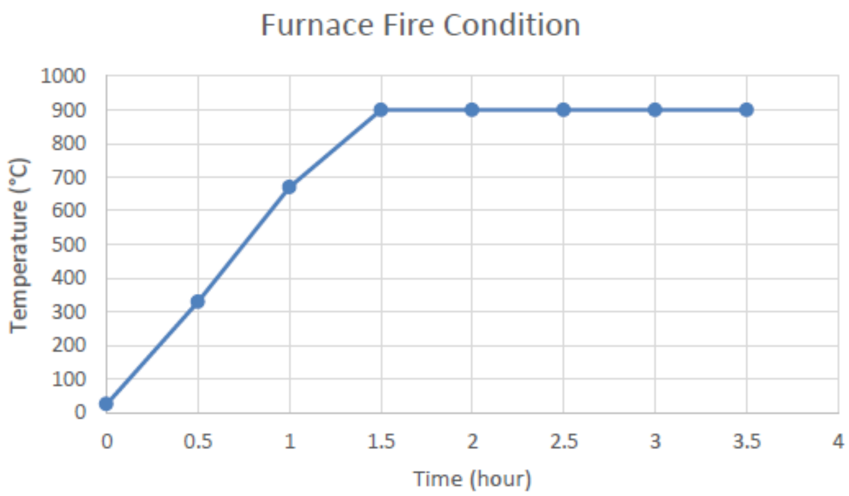

FIGURE 2. Furnace firing condition and temperatire profile used for thermal exposure of fly ash-perlite geopolymer concrete specimens at 900°C for 2 hours

RESULT AND DISCUSSION

Material burned will have different pore distribution than that of unburned material. Water in the pore of burned material will disappear. This is the same situation with the distribution of pore of fly ash and perlite geopolymer. Variations in the mix design of perlite and fly ash used in making geopolymer concrete using variations with percentages of 0% : 100%, 25% : 75%, 50% : 50%, 75% : 25%, and 100% : 0%. The aim is to find the optimal content in the mix design.

FIGURE 3 is a graph of the results of the SAA pore distribution test. Samples in variation 1 with a composition of 100% fly ash: 0% unburned perlite showed a pore distribution size of 14.30405 nm. Samples in variation 2 with a composition of 75% fly ash: 25% unburned perlite showed a decrease in the pore distribution size of 13.66385 nm. Samples in variation 3 with a composition of 50% fly ash: 50% unburned perlite showed an increase in the pore distribution of 15.88945 nm. Samples in variation 4 with a composition of 25% fly ash: 75% unburned perlite showed the most significant decrease in the pore distribution size of 13.82408 nm. The pore distribution size then experienced the most significant increase and also the largest size compared to other samples, namely 27.45661 nm in sample variation 5 with a composition of 0% fly ash: 100% unburned perlite. The addition of perlite to fly ash-based geopolymer concrete will increase the pore distribution size as seen in FIGURE 3. The trendline analysis shows an increase from sample 1 to sample 5.

On the other side, samples in variation 1 with a composition of 100% fly ash: 0% burnt perlite showed the largest pore distribution size compared to the others, which was 28.70213 nm. Samples in variation 2 with a composition of 75% fly ash: 25% burnt perlite showed a decrease in pore distribution size of 13.61849 nm. Samples in variation 3 with a composition of 50% fly ash: 50% burnt perlite showed an increase in pore distribution size of 21.45030. Samples in variation 4 with a composition of 25% fly ash: 75% burnt perlite again showed a decrease in pore distribution size of 11.19582 nm. The pore distribution size then increased in sample

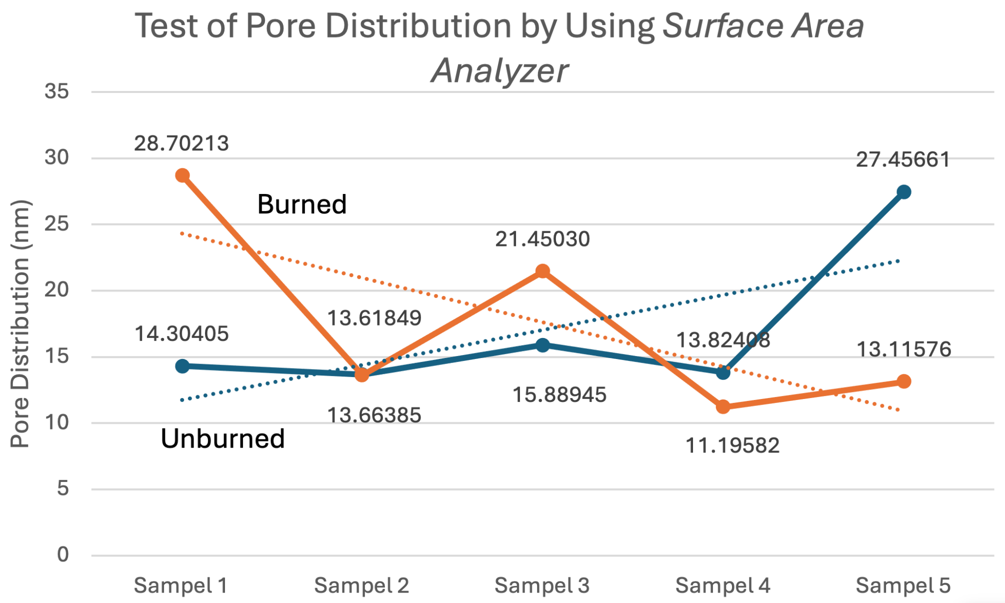

FIGURE 3. Test of Pore Distribution by Using Surface Area Analyzer.

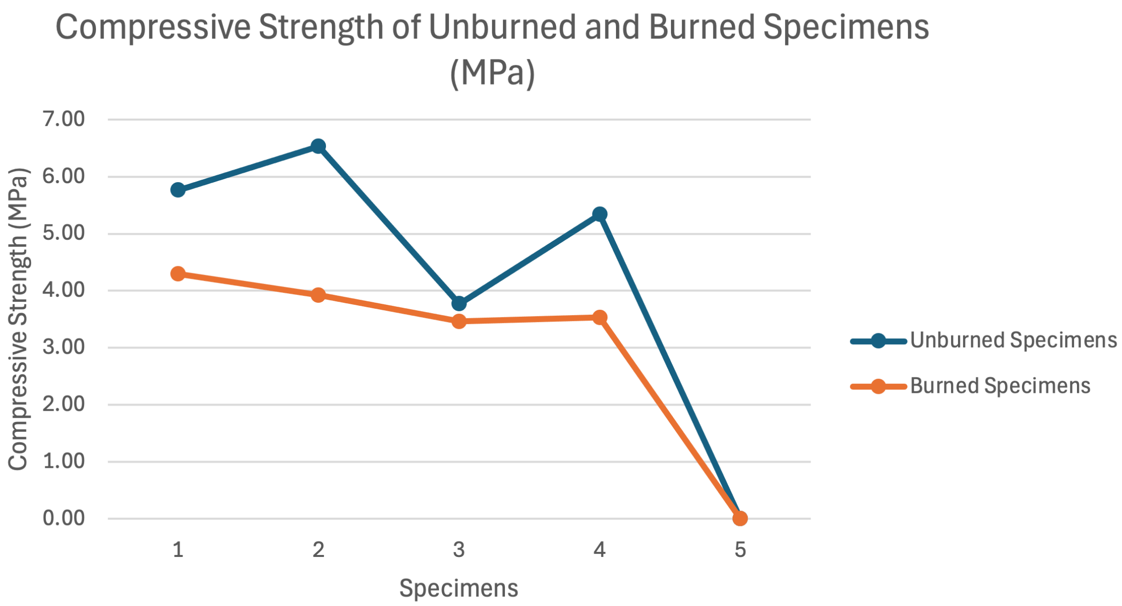

FIGURE 4. Compressive strength VS variations in the mix design of perlite and fly ash in geopolymer.

variation 5 with a composition of 0% fly ash: 100% burnt perlite of 13.11576 nm. The combustion of geopolymer concrete burned at a temperature of 900 °C for a period of 2 hours will cause changes in the characterization of the pore distribution size. The combustion of geopolymer concrete burned at a temperature of 900 °C for a period of 2 hours experienced a decrease in the pore distribution size as can be seen in FIGURE 3 trendline analysis shows a decrease from sample 1 to sample 5.

The results of the surface area analyzer test show that the addition of unburned perlite to fly ash-based geopolymer concrete will experience an increase in pore distribution compared to the burnt perlite to fly ash-based geopolymer concrete, as shown in FIGURE 3. For compressive strength value, the characteristics of the addition of perlite variations of 0%, 25%, 50%, 75% and 100% to fly ash-based geopolymer concrete show that the highest compressive strength value for unburned and burned geopolymer concrete at 25% perlite addition. The reason of this situation is described, respectively. Perlite's granules inflate when heated quickly to a temperature above 850-870°C, and the bound water suddenly evaporates, creating many bubbles. The perlite undergoes an irreversible structural change after heating. The closed air is contained within empty, glazed, irregularly shaped bubbles. This process is called as swelling. Perlite bubbles fulfilled pore and it decrease the pore distribution after perlite is burnt. Meanwhile perlite addition replaced sand. It makes fly ash as a basic material of geopolymer concrete. From this study it can be shown that 75% fly ash and 25% perlite have the highest compressive strength value.

CONCLUSION

The addition of perlite to fly ash-based geopolymer concrete improves the pore dispersion of unburned geopolymer concrete. On the other hand, the addition of perlite reduces the pore distribution value of burned geopolymer concrete. The inclusion of perlite increases the compressive strength of unburnt specimens. Meanwhile, the addition of perlite reduces the burned material. When heated rapidly to temperatures exceeding 850-870°C, perlite granules inflate and the bound water evaporates, resulting in a large number of bubbles. Perlite exhibits an irreversible structural change after heating. The closed air is held within empty, glazed, irregularly shaped bubbles. This process is referred to as swelling. Perlite bubbles filled the pores and reduced the pore dispersion when the perlite was burned. Meanwhile, perlite replaced sand. It uses fly ash as a base ingredient for geopolymer concrete.The highest compressive strength was achieved with 25% perlite added. Future research should look into the relationship between pore distribution, total pore volume, thermal characteristics, and compressive strength, using additional specimen variations and repeated tests.

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