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Pervious low-calcium fly ash geopolymer concrete using gap-graded limestone coarse aggregates in ambient curing

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Abstract. This paper describes the research of pervious geopolymer concrete using limestone from Timor Island in Indonesia as coarse aggregate. No sand was used to make this pervious geopolymer concrete. Two types of crushed limestone aggregates used were coral limestone (organic limestone) and limestone (calcilutite). Abrasion losses of the aggregates using Los Angeles Machine test were 18.9% for limestone (calcilutite) and 34.98% for coral limestone. Those aggregates had many characteristics such as 10-20 mm of diameter length, angular shapes and apparent specific density 2.74-2.75. The mass ratios of aggregate to geopolymer paste were varied from 2.86 to 6.91. To make the geopolymer paste, it was used Class F or Low-Calcium Fly Ash from Bolok-Kupang Coal Fired Power Plant as a rich silica-alumina of precursor material. Meanwhile, the mass ratio of natrium silicate solution to natrium hydroxide solution 10 M was 1.0 and the mass ratio of fly ash to alkaline solution was 2.0. Ambient curing was applied to all specimens. Mechanical characteristics obtained at the age of 28 days of hardened pervious geopolymer concrete were: (1) compression strength, (2) splitting tensile strength, and (3) abrasion losses using Los Angeles Machine Test. Besides, density of hardened specimens were also obtained. In addition, the comparisons of mechanical properties of pervious geopolymer concretes using coral limestone and limestone (calcilutite) as coarse aggregate were also conducted. According to the results of this research, it is feasible to make pervious geopolymer concrete using Timor limestone as coarse aggregate due to its mechanical characteristics.

1. Introduction

Geopolymer concrete is a relatively new concrete. This is the most promising concrete to replace the conventional or Portland Cement based concrete. The difference between geopolymer concrete and portland cement based concrete is the paste i.e geopolymer paste and cement paste. Meanwhile, all types of aggregates as a filler in cement based concrete can be used to make geopolymer concrete. Comprehensive researches and applications of geopolymer paste, mortar or concrete have been available in three well-known text books about geopolymer [1-3]. The dominant geopolymer paste used was fly ash based geopolymer paste. The reason was that fly ash was an abundant waste material so that usaged of it was a solve of environmental problem. Many types of fly ash in Indonesia have been used to make the durable geopolymer paste, mortar or concrete [4], [5], [6]. From previous
results, Indonesian fly ash based geopolymer material is comparable to cement based material according to its mechanical characteristics.

Most application of geopolymer concrete is well known except pervious geopolymer concrete. In the last seven years, very few papers or reports of researches were available according to pervious geopolymer concrete. The most cited paper of it was the work of Khon Kaen University of Thailand [7]. They used limestone as coarse aggregate. Their pervious geopolymer concretes were made of Class C fly ash or lignite fly ash with CaO 19.4% and dry curing 60OC. It was contrast to papers or research report of pervious cement-based concrete by [8]. In Indonesia, pervious cement-based concrete are also well known and applied material. Then, locally available materials can actually be used to produce High Performance Concrete [9,10].

ACI 522R-10 has recommended the range of composition per m3 of pervious cement-based concrete to be applied as road pavement i.e cement (270-415 kg), coarse aggregate (1190-1480 kg), and mass ratio of water to cement (0.27-0.34). Meanwhile, in Indonesia, the volume ratio of aggregate to paste is preferred and the range of it is 2:1 – 12:1 with range of compressive strength 2 MPa – 35 MPa [9],[11].

Therefore, this study focused on pervious geopolymer concrete using Class F or Low-Calcium fly ash with ambient curing. Coarse aggregates used were crushed coral limestone and crushed limestone (calcilutite) from Timor Island Nusa Tenggara Timur Province-Indonesia. The mass ratios of aggregate to geopolymer paste were varied from 2.86 to 6.91. To make the geopolymer paste, it was used Class F Fly Ash from Bolok-Kupang Coal Fired Power Plant as a rich silica-alumina of precursor material. Meanwhile, the mass ratio of natrium silicate solution to natrium hydroxide solution 10 M was 1.0 and the mass ratio of fly ash to alkaline solution was 2.0. The physical and mechanical characteristics of the pervious geopolymer concrete were obtained.

2. Experimental programme
This subsection will present raw material used, sample made, and testing conducted. There was no treatment to lime stone aggregates and fly ash as raw materials. Testing conducted were: (1) the characteristics of aggregates including specific gravity and abrasion losses of aggregates in The Los Angeles Machine, (2) compression and splitting tensile strength, (3) Abrasion Losses of concrete samples in The Los Angeles Machine.

2.1. Materials
Two types of crushed limestone aggregates used were coral limestone (organic limestone) and limestone (calcilutite). The aggregates were crushed by hand with diameter 10-20 mm and angular shapes as shown in Figure 1.

![Figure 1. The gap-graded limestone coarse aggregates](image-url)
The characteristics of coarse aggregates are given in Table 1. Apparent specific gravity of the coral limestone (organic limestone) and limestone (calcilutite) are almost the same. Meanwhile, there is a significant difference of abrasion losses between the coral limestone and limestone (calcilutite). The coral limestone has a higher value of abrasion losses so that this aggregate has weaker abrasion strength.

The gap-graded limestone coarse aggregates used is given in Figure 2. This gradation was not comply to any standard of gradation of coarse aggregate in Indonesian Standard (SNI). The size of coarse aggregate used was dominantly in the range 12.7 – 15.8 mm.

The mixture composition of geopolymer paste was fly ash and alkaline activator solution with certain mass ratios. Alkaline activator solution was a mixture of 10 M sodium hydroxide solution and natrium silicate with mass ratio = 1:1. Class F or Low-Calcium fly ash from Power Plant Bolok Kupang was used as a precursor material to make geopolymer. This fly ash had CaO 8.48%, SiO2 43.18 % and Al2O3 17.78 %. More detail oxide compositions and XRD (X-Ray Diffraction) of fly ash can be referred in Simatupang et al [6].

### Table 1. Characteristics of coarse aggregates

| Characteristics                        | Coral Limestone | Limestone (Calcilutite) |
|----------------------------------------|-----------------|-------------------------|
| Dry Specific Gravity                   | 2.57            | 2.68                    |
| SSD Specific Gravity                   | 2.62            | 2.70                    |
| Apparent Specific Gravity              | 2.74            | 2.75                    |
| Absorption                             | 1.74            | 0.75                    |
| Abrasion Losses by Los Angeles Machine Test | 34.98          | 18.90                   |

![Figure 2. The gap-graded limestone coarse aggregates.](image1)

2.2. *Mixture compositions, mixing, and casting*

Sample used were cylindric concrete with diameter 10 cm and 20 cm length. After fresh pervious concrete casted, the samples were cured in ambient curing. Composition of pervious geopolymer concrete for each m3 used in this paper is given in Table 2. Every mixture was prepared i.e 3 samples
for compression testing, 3 samples for splitting tensile strength, 2 samples for abrasion losses. Results presented in this paper are the mean of those samples.

The mixing and casting of pervious geopolymer concrete is shown in Figure 3. To make geopolymer paste, it was mixed fly ash and alkali activator solution by using Paint Mixer with 1800 rpm for 2-3 minutes. After, geopolymer paste was ready, it was poured in concrete mixer with coarse aggregate. Concrete mixer run for 5 minutes. Fresh geopolymer concrete was casted in plastic formwork with 3 layers. Each layer was compacted by steel rod. Then, samples were cured with ambient curing. After 28 days, the formworks were released.

Table 2. Composition of pervious geopolymer concrete (per m$^3$).

| Mixture | FA$^a$ (kg) | NS$^b$ (kg) | NH$^c$ (10 M) (kg) | Aggregate (kg) | Type of Aggregate | Mass ratio of Aggregate/Geopolymer Paste |
|---------|-------------|-------------|-------------------|----------------|-------------------|----------------------------------------|
| A1      | 360         | 90          | 90                | 1548           | Coral limestone   | 2.86                                   |
| A2      | 180         | 45          | 45                | 1548           | Coral limestone   | 5.73                                   |
| B1      | 360         | 90          | 90                | 1865           | Limestone (Calcilutite) | 3.45                             |
| B2      | 180         | 45          | 45                | 1865           | Limestone (Calcilutite) | 6.91                             |

$^a$Fly Ash

$^b$Natrium Silicate

$^c$Natrium Hydroxide

Figure 3. Mixing and casting pervious geopolymer concrete
2.3. Testing

2.3.1. Compression and splitting tensile strength. The compressive strength was tested at the age of 28 days using ASTM C 39/C 39M-01 standard or SNI 03-1974-1990 (Indonesian standard). Meanwhile, the splitting tensile strength was tested at the age of 28 days using ASTM C 496-96 standard or SNI-03-2847-2002 (Indonesian standard). The reported values of strength were the average of three samples. Compression testing samples were capped at top and bottom side with a gypsum capping compound. The compression and splitting tensile strength testing is shown in Figure 4.

![Figure 4. The testing of compression and splitting tensile strength of pervious geopolymer concrete.](image)

2.3.2. Abrasion Losses in The Los Angeles Machine. The abrasion losses and impact testing of aggregates was tested using ASTM C 131-01 standard or SNI 2417-2008 (Indonesian standard). The abrasion losses was calculated using Eq. (1).

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N = (a - b)/a
\]

Where N is the abrasion and impact value, a is mass of original sample (gram) and b is mass of sample retained in No.12 (gram). The reported values of strength were the average of two samples. Mass of each sample was 5000 gram and comply to gradation B (in Indonesian standard). Steel ball bearing used was 11 balls with total mass 4584±25 gram. The Los Angeles machine rotated at 30 to 33 r/min for 500 revolutions.

In addition, the abrasion and impact testing with similar procedure was also applied to pervious geopolymer concrete. The origin samples of abrasion and impact testing of pervious geopolymer concrete were from the broken splitting tensile samples.

3. Results and discussion

3.1. Compressive strength

The results of testing are summarized in Table 3. The compressive strength of samples A2 and B2 (higher ratio of aggregate to geopolymer pastes) were higher than the strength of samples A1 and B1 (lower ratio of aggregate to geopolymer pastes). It means excessive geopolymer paste that trapped at the bottom of samples gives negative effect as shown in Figure 5. This is very different manner with pervious cement-based concrete that the higher ratio volume of aggregate to cement paste the higher compressive strength of pervious cement-based concrete [9],[11]. An important consideration to make pervious geopolymer concrete is the different cohesive and rheology characteristics between geopolymer paste and cement paste.

The results of this research compared to Tho-in et al [7] are shown in Figure 6. The compressive strength of pervious geopolymer concretes in this research are lower than the concretes strength of...
Tho-in et al [7]. There is no good relationship between the results of this research and the results of Tho-in et al [7]. This result indicates that the compressive strength of the geopolymer paste in this research was not optimally contributed.

| Mixture | Density (kg/m$^3$) | Compressive Strength (MPa) | Tension strength (MPa) | Abrasion Losses (%) |
|---------|---------------------|-----------------------------|------------------------|---------------------|
| A1      | 1777                | 1.66                        | 0.35                   | 36.60               |
| A2      | 1645                | 2.55                        | 0.48                   | 35.14               |
| B1      | 1925                | 1.95                        | 0.42                   | 23.06               |
| B2      | 1748                | 3.01                        | 0.61                   | 22.50               |

Figure 5. The excessive geopolymer paste were trapped at the bottom of samples.

Figure 6. Relationship between compressive strength and density of pervious geopolymer concrete.
3.2. **Splitting tensile strength.**
The splitting tensile strength of samples A2 and B2 (higher ratio of aggregate to geopolymer paste) were higher than the strength of samples A1 and B1 (lower ratio of aggregate to geopolymer paste). The splitting tensile strength tends to have the same trend with the compressive strength. Figure 7 shows good linear relationship between compressive strength and splitting tensile strength of pervious geopolymer concrete with R²=0.86.

![Figure 7. Relationship between compressive strength and splitting tensile strength of pervious geopolymer concrete.](image)

3.3. **Abrasion losses of samples.**
The abrasion and impact strength of aggregate and pervious geopolymer concrete is shown in Figure 8. The abrasion and impact strength of pervious geopolymer concrete is lower than its aggregate regardless the type of aggregate. It is indicated with higher abrasion and impact value of pervious geopolymer concrete compared to the aggregate. There is a significant abrasion and impact strength of pervious geopolymer concrete according to their aggregate. It depends closely to the abrasion and impact strength of aggregate.

![Figure 8. Abrasion and impact values of aggregate and pervious geopolymer concrete.](image)
4. Conclusions
It has been shown mechanical characteristics of pervious geopolymer concrete using two types of Timor limestone as coarse aggregate. The pervious geopolymer concrete using crushed coral limestone aggregate is comparable to pervious geopolymer concrete using crushed limestone (calcilitite) according to its compression strength and splitting tensile strength. The abrasion and impact strength of pervious geopolymer concrete closely depends on the strength of its aggregate.

An important consideration to make pervious geopolymer concrete is cohesive and rheology characteristic of geopolymer paste. Furthermore, the excessive geopolymer paste must be limited to make reliable pervious geopolymer concrete. It is recommended that the strength of this pervious geopolymer concrete need to be increased by using different curing method, continuous grading of coarse aggregate and finding the optimal compositions of the pervious geopolymer concrete.

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