Analysis of The Mechanical Properties of Concrete Beams That Use Pumice as a Partial Substitution of Concrete Mixtures

Abdul Gaus 1*), Imran 1), Chairul Anwar 1)
Department of Civil Engineering, Faculty of Engineering Universitas Khairun, Indonesia, kp. 97718
*Corresponding author: Gaussmuhammad@Gmail.com

Abstract. One of the most common inhibiting factors in the archipelago is the lack of availability of material resources and human resources. One of the options is the use of lightweight concrete precast using materials around the islands. The local material which is widely distributed in North Maluku is pumice but it has not been used maximally because so far it has only been used as pile material. This study aims to analyze the effect of partial substitution of pumice on fine aggregate in a concrete mixture. This research was carried out experimentally in a laboratory using UTM and divided into 2 stages. Stage 1, designing and analyzing concrete mix using pumice compared without using pumice, Phase 2 testing using concrete beam dimensions of 600x150x100 mm with an inter load of 150 mm. Beam test results show that the limited use of pumice in a concrete mixture does not greatly affect the strength of normal concrete beams, as indicated by the deflection value and strength of concrete blocks that are almost as large.

Keywords: Lightweight Concrete, Precast Concrete, Pumice

1. Introduction
The use of lightweight concrete in pavement construction and highway drainage can be considered as one of the solutions in the construction process of the islands. Some advantages of using lightweight concrete using sand include: first, the selection of pumice as a partial substitution of fine aggregates in a concrete mixture can significantly reduce the weight of the concrete. Secondly, the application of lightweight concrete in island areas can reduce barriers to concrete use in island areas such as the lack of equipment and skilled personnel. Finally, the use of lightweight concrete minimizes material transportation costs. The weight of the fine portion of pumice stone is between 500-900 kg/m³ so that it is suitable for use in lightweight concrete mixes. In addition, pumice is also able to absorb the water on the surface. Pumice deposits are quite large and spread in the North Maluku region.

Concrete is a mixture of several materials, the main ingredient consists of a mixture of cement, fine aggregates, coarse aggregates, water with or without other added ingredients with certain comparisons. Because concrete is a composite, the quality of concrete depends on the quality of each forming material [1].

The use of munice as a basic material for cement bricks has a positive impact by reducing the weight of cement bricks [2], as well as the weight of the mortar content becomes smaller [3] and the diffusivity value of concrete mortar becomes smaller if the mortar uses pumice [4]. Based on porosity, concrete using pumice in certain compositions still meets Indonesian national standards [5] and the resulting concrete mix is included in the lightweight concrete category [6].

Lightweight concrete or called Autoclaved Aereted Concrete (AAC) is concrete that has a lighter weight than general concrete. Normal concrete generally has its own weight reaching 2400 kg/m³. To
reduce the dead load on a concrete structure, a type of lightweight concrete is used. According to the Indonesian National Standard SNI 2847-2002, concrete can be classified as lightweight concrete if it weighs less than 1900 kg/m$^3$. In making lightweight concrete, of course material that has a light density is also needed. The combination of the very right mixture in accordance with the dose will produce lightweight concrete with the best quality as well, the strength of lightweight concrete greatly affects its ability to withstand loads both dead load due to structural loads and specific gravity of the lightweight concrete itself. In light concrete, what is done is the need for an aggregate combination to obtain a lower specific gravity than the normal density of concrete, because in lightweight concrete it is very effective to use in construction [7,8,11].

2. Materials lightweight concrete material using pumice
Portland cement is a type of cement that is gray to slightly brownish, which is commonly found in Indonesia, which functions as a filler of cavities in granules, adhesives between aggregates to become a solid and sturdy unit. The portland cement oxide composition is shown in Table 1 [1,8].

| Oxides                  | percentage (%) |
|-------------------------|----------------|
| Lime (CaO)              | 60 – 65        |
| Cilika (SiO2)           | 17 – 25        |
| Alumina (Al2O3)         | 3 – 8          |
| Iron (Fe2O3)            | 0,5 – 6        |
| Magnesium (MgO)         | 0,5 – 4        |
| Sulfur (SO3)            | 1 – 2          |
| Soda/Potash (Na2O+K2O)  | 0,5 – 1        |

The aggregate is divided into two groups of coarse aggregates and fine aggregates, coarse aggregates are natural sources that serve as fillers in concrete mixtures. Coarse aggregate has a very important role in concrete mixtures, the important physical properties are aggregate energy, because these properties can affect water absorption which has an impact on shrinkage and resistance to the effects of freezing in winter, affecting porosity and bonding with cement. The proportion of coarse aggregates in concrete mixes is around 60% - 80% of the volume of mortar or concrete (ASTM C 33-74a) [10,11]. In this study coarse aggregates are used in rocks whose grain size is between 5 mm to 40 mm with aggregate gradation seen in Table 2 [7,8].

| Sieve analysis (mm) | Pass percentage (%) |
|---------------------|---------------------|
| 25                  | 100                 |
| 19                  | 90 – 100            |
| 9,5                 | 20 – 55             |
| 4,75                | 0 – 10              |
| 2,36                | 0 – 5               |

The fine aggregate in the concrete mixture can be in the form of natural sand as a result of natural disintegration of the rocks or can also be in the form of artificial sand produced from rock breakers with a size of 0.15 mm - 5 mm. Fine aggregates play a role in determining Workability, Strength, and Durability of concrete (SK SNI T-15-1991-03) [9,10]. The fine aggregates used in this study are defined as rocks with the largest grain size of 5 mm, aggregate gradations are shown in Table 3 [7,8].

Water serves to wet the surface and lubricate aggregate grains so that it can be easily worked and compacted. Water is very necessary in the manufacture of concrete so that a chemical reaction occurs with cement which causes binding and hardening takes place. To react with cement, the water needed
is about 25% - 30% of the weight of the cement, but in reality the value of the cement water factor used can be more than 0.35. The excess water is used as a lubricant between cement with fine aggregate, so that the mixture mixes are easily done [1].

Table 3. Fine Aggregate Gradation

| Sieve analysis (mm) | Pass percentage Lolos (%) |
|---------------------|---------------------------|
| 4,75                | 95 – 100                  |
| 2,36 (No. 8)        | 80 – 100                  |
| 1,18 (No. 16)       | 50 – 85                   |
| 0,6 (No. 30)        | 25 – 60                   |
| 0,3 (No. 50)        | 10 – 30                   |
| 0,15 (No. 100)      | 2 – 10                    |

Lightweight concrete is concrete containing light aggregate and has a unit weight of not more than 1900 kg/m³ (SNI-2847-2002) or concrete containing light aggregate and equilibrium density as determined by ASTM C567, between 1140 and 1840 kg/cm³ (SNI-2847-2013). Lightweight concrete basically has the same mixture as normal concrete in general, but coarse aggregates that occupy 60% of all components are reduced in density. The use of lightweight concrete is also adjusted to its density and strength according to Table 4 [10].

Table 4. Classification of lightweight concrete density

| No | Category   | Concrete content weight (Kg/m³) | Typical concrete compressive strength | Typical application |
|----|------------|---------------------------------|--------------------------------------|---------------------|
| 1  | Non structure | 300 – 1100          | < 7 MPa                        | Insulating material |
| 2  | Non structure | 1100 – 1600         | 7 – 14 MPa                      | Unit masonry        |
| 3  | Structure   | 1450 – 1900         | 17 – 35 Mpa                     | Structural          |

3. Research Methods

3.1. Compressive strength
Concrete compressive strength serves to identify the quality of a concrete structure. Concrete quality is directly proportional to the level of structural strength, several factors that influence the compressive strength of concrete are cement water factor and density, age of concrete, type of cement, amount of cement, and aggregate properties. Concrete compressive strength can be calculated using Equation (1) [11,12].

\[
f'c = \frac{P}{A} = \frac{P}{\pi D^2} \tag{1}
\]

Where:

\(f'c\) = concrete compressive strength obtained from the test object (MPa)

\(P\) = test specimen load (N)

\(A\) = cross-sectional area (mm²)

\(D\) = diameter of cylindrical specimen (mm)

3.2. Flexural Strength Testing
Flexural strength is the ability of the test object to hold the force in a perpendicular direction until the specimen is broken. This test is guided by SNI 03-4431-2011 standard about the method of normal concrete flexural strength with two loading points, and SNI 03-2493-1991 standard regarding the manufacture and maintenance of concrete test objects in the Laboratory. The panel flexural loading scheme can be described using Figure 1.
The maximum load in the flexural strength assumes that the moment to break the concrete beam is the moment due to the maximum load UTM added to the weight of the specimen itself and the gravity of the specimen [13].

![Figure 1](image1.png)

**Figure 1.** Loading the flexural strength of a concrete beam

### 4. Results and Discussion

#### 4.1. Mechanical Properties of Reinforced Concrete Beams

![Figure 2](image2.png)

**Figure 2.** Relationship between deflection and the load on the beam using pumice BPU1

Figure 2 shows the curve of the relationship between deflection and the load on the beam without pumice, the curve can be divided into two parts, the first part of the curve is straight or linear with a fairly large slope. This curve shows a linear relationship between the load and the crack width value arising from the concrete beam. The second part of the curve shows the relationship of deflection and load in the form of linear with a smaller slope. The first beam cracked at a load of 14.65 kN with a deflection of 0.28 mm. The maximum load that can be carried by concrete blocks is 56.75 kN with a maximum deflection of 1.09 mm.

Figure 3 shows the curve of the relationship between the magnitude of the load with the deflection value that occurs in concrete blocks using pumice, the first crack arises when the load is 14.68 kN with a deflection value of 0.29 mm, the deflection size increases with the amount of load acting on the beam, the increase is proportional to the whole up to a load of 42 kN. Maximum bahan that can be carried by the beam is 56.77 kN with a maximum deflection of 1.10 mm.

Stiffness of concrete beams using low pumice compared to concrete blocks without pumice, but the difference in the value of the stiffness of the two is not very significant. Although concrete blocks
using pumice have lower strengths, they are still suitable for use in the construction of drainage channels that do not require high strength concrete.

**Figure 3.** Relationship between deflection and the load on the beam using pumice BPA1

4.2. Crack Pattern

Figure 4 and 5 shows a visualization of crack patterns during testing, flexural and sliding crack patterns, flexural crack patterns starting from the bottom of the beam, after which it spreads upward along with the increase in load. Sliding crack pattern occurs on the side of the beam that spreads up diagonally with increasing length as the load increases.

**Figure 4.** Cracked pattern of concrete beams without pumice

**Figure 5.** Cracked patterns of concrete beams using pumice

Cracking on a concrete beam without using pumice first arises when the load is 14.65 kN, the increasing load has an impact on cracks that continue to spread from the underside of the beam to the top side of the beam in addition to the emergence of new cracks on the beam that occur randomly, until the beam loss of strength at a load of 56.75 kN.

Concrete beams using pumice also experienced the same crack pattern, the first crack occurred in a deflection of 0.29 mm, almost the same as the deflection of a BPI concrete beam. Cracks spread from the underside of the beam radiating to the upper side of the beam.

The crack pattern on the concrete beam shows cracks occur in the middle span region or in the field area and the direction of the crack occurs almost perpendicular to the axis of the beam indicating flexural cracking. This type of cracking occurs due to the failure of the beam in holding the bending load in the field due to this area arises the greatest bending moment [14].
5. Conclusion

Based on the results and discussion of the research that has been done, it can be concluded that the use of pumice as a material for partial substitution of fine aggregate in a concrete mixture does not greatly affect the value of deflection on the concrete beam.

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