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FRESH AND HARDENED PROPERTIES OF LIGHTWEIGHT CONCRETE MADE WITH PUMICE AS COARSE AGGREGATE

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ABSTRACT: The purpose of this research is to utilize pumice waste as one of the constituent materials of lightweight concrete. Indonesia, as an archipelagic country, has produced coral pumice waste scattered throughout the country. It is expected that by utilizing pumice waste, lightweight and environmentally friendly concrete may be produced. The tests carried out consisted of three series to examine the effect on the composition of light aggregate (series 1), the effect of light aggregate size (series 2), and the effect of the water to binder ratio (series 3). The composition of light aggregate as a substitute for coarse aggregate by 25%, 50%, 75%, and 100%, with a maximum aggregate size of 20 mm and water to binder ratio of 0.50. In the second series, the maximum size of lightweight aggregate is 9.5 mm, 16 mm, 20 mm, and 25 mm, using 100% lightweight aggregate with water to binder ratio of 0.50. In the third series, the water to binder ratio is varied 0.46, 0.48, and 0.50. A slump test was conducted to check the workability of fresh concrete, while the hardened properties test consisted of compressive strength and mass density. The results of the tests show that using a larger amount of lightweight aggregate reduces compressive strength. The variation of the maximum size of lightweight aggregate shows a pattern that the larger the aggregate size produces lower the compressive strength. The decrease in compressive strength also occurs in concrete with high water to binder ratio.

Keywords: Lightweight concrete, Pumice, Compressive strength, Mass density

1. INTRODUCTION

The construction industry is currently one of the biggest consumers in concrete production. Concrete remains the most popular construction material due to its many advantages, including durability, excellent resilience to various environmental conditions, and constituent materials widely available in many countries. The general ingredients of concrete consist of cement, water, fine aggregate, coarse aggregate, and superplasticizer. Several researchers predict that cement production will continue to increase until 2050, especially in developing countries such as India and China. It also concludes that concrete will continue to be a major consumption in the construction industry [1-4].

However, concrete also has several weaknesses, including low tensile strength and high mass density. The mass density of normal concrete is between 2300 – 2400 kg/m^3. The high mass of concrete is one of the issues that must be addressed in various structural scenarios, particularly for construction in earthquake-prone areas. The high mass density of concrete results in a high structural mass as well. If an earthquake occurs in a structure with a high mass density, the chance of damage due to gravity loads from the own concrete weight will be higher. Therefore, producing lightweight concrete is one of the right solutions in overcoming structural problems with high mass density.

Concrete is included in the lightweight category if the mass density produced is not more than 2200 kg/m^3. Currently, lightweight concrete applications have been carried out for both structural and non-structural components, such as the use of lightweight concrete blocks [5-7], precast slab floor [8-10], and the precast lightweight concrete beam [11-13]. The lightweight concrete mixing process has been carried out in various ways, either by replacing cement with other pozzolanic materials or by changing the type of aggregate, both fine aggregate and coarse aggregate. The replacement of aggregates and cement has been widely carried out both with organic and inorganic materials. In addition, the use of various types of waste has also been found in the effort to produce lightweight concrete.

Several studies have been found in the manufacture of lightweight concrete, including corn cob and clay as coarse aggregate [14-16], fiber as lightweight materials [17-19], Palm Oil Waste (Shell and Clinker) [20-22], Plastic waste as coarse aggregate [23-25], and Styrofoam waste [26-28]. In addition, another material that is often used for the manufacture of lightweight concrete is to use pumice as a substitute for coarse aggregate. The pumice comes from various resources. Several studies have found in the manufacture of lightweight concrete using pumice, including volcanic pumice [29-31], Basaltic pumice [32-34], and Breccia pumice [35-37]. In this study, pumice was used from coral waste that was no longer used. There are not many studies that discuss the utilization of coral pumice as a coarse aggregate replacement for the manufacture of lightweight concrete.

This study aims to utilize coral waste that is no longer used as a construction material. The light characteristics of coral pumice can be used as aggregate for the manufacture of lightweight concrete. This research was conducted in Indonesia by utilizing coral pumice waste from Lombok Island. Because Indonesia is an archipelagic country with many corals, the utilization of coral remains is ideal, especially for construction in coastal areas. This research was conducted to examine the concrete properties using coral pumice as a constituent material. The slump test is carried out to check the concrete workability level at the fresh state. Meanwhile, the hardened properties are tested for compressive strength and mass density. Fresh and hardened properties tests were carried out with variations consisting of the percentage of coral pumice as a substitute for coarse aggregate, the maximum size of coral pumice, and different water to binder ratios.

2. EXPERIMENTAL PROGRAM

2.1 Raw Materials

The concrete constituent materials used in this study consisted of Portland pozzolan cement, fine aggregate, water, and coarse aggregate. Portland pozzolans cement used in this study refers to ASTM C595 [38] with a specific gravity of 3.15. Examination of fine aggregate is carried out to determine the mechanical and physical properties before being used as a concrete constituent material. Fine aggregate from the eruption of a volcano located in Yogyakarta, Indonesia. Water content, specific gravity, water absorption, unit weight, mud content, and grain grading are all tests for fine aggregate properties. The results of the fine aggregate test can be seen in Table 1, where the water content obtained is 2.53%, the specific gravity is 2.66, the water absorption is 10.11%, the unit weight of the fine aggregate is 1.43 g/cm^3, while the mud content in the fine aggregate is 4.73%. Particle size gradation of fine aggregate can be seen in Figure 1.

The coarse aggregate used in this study consisted of two types, namely normal aggregate and light aggregate (coral pumice). Table 2 shows the results of coarse aggregate properties. The tests consisted of water content, specific gravity, water absorption, mass density, roughness, and mud content. Based on the test results, it can be seen that there are some significant differences between the properties of normal aggregates and lightweight aggregates. The results of the water content test show that the lightweight aggregate contains high water, and the water absorption rate is also higher than the normal aggregate. In addition, the roughness content of the light aggregate is also higher than the normal aggregate. Based on the aggregate properties test, it can be seen that lightweight aggregate from coral pumice also has weaknesses that might cause the concrete performance to decrease.

In terms of light aggregate, it can be seen that the specific gravity produced is smaller than normal aggregate. This indicates that lightweight aggregate will be able to produce lighter concrete than normal concrete. This is supported by the results of the mass density test. The mass density test shows that pumice aggregate has a lower mass density than normal aggregate. Aggregate is one of the most important components of concrete, the produced lightweight concrete when the coarse aggregate used is probably light.

Table 1 Properties of fine aggregate

Properties	Results
Water Content (%)	2.53
Specific Gravity	2.66
Water Absorption (%)	10.11
Mass Density (g/cm^3)	1.43
Mud Content (%)	4.73

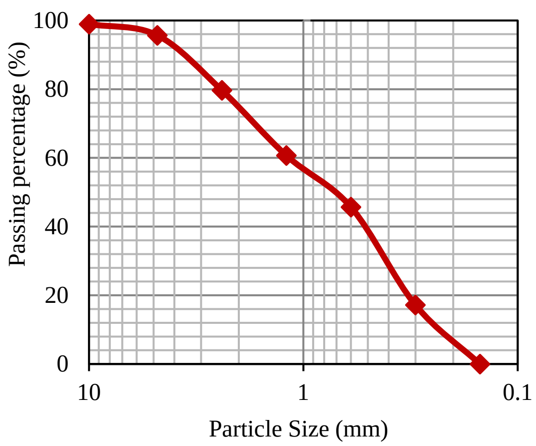

Fig.1 Size distribution of fine aggregates

Table 2 Properties of coarse aggregates

Properties	Normal Aggregate	Pumice
Water Content (%)	1.45	15.03
Specific Gravity	2.68	1.55
Water Absorption (%)	1.45	11.54
Mass Density (g/cm^3)	1.55	0.62
Roughness (%)	23.54	36.51
Mud Content (%)	0.67	0.93

2.2 Mix Proportion

The investigation on the effectiveness of light aggregates in this study consisted of three main series. Variations made consist of the effect of substitution of light aggregate on coarse aggregate, the effect of the maximum size of light aggregate, and the effect of the water to binder ratio. The mix proportion series 1 consists of replacing aggregates with normal aggregates of 25% (S1-25), 50% (S1-50), 75% (S1-75), and 100% (S1-100). The maximum size of aggregate used in series 1 is 20 mm with water to binder ratio of 0.50. Table 3 shows the material mix proportion for series 1.

Series 2 in this study aims to determine the size effect of the coarse aggregate. The size of the coarse aggregate used has an impact on the compressive strength of concrete, particularly when specific aggregates are used as a substitute for normal aggregates. This series is composed out of 100% lightweight aggregate with aggregate sizes varying from 9.5 mm (S2-9.5), 16 mm (S2-16), 20 mm (S2-20), and 25 mm (S2-25) (S2-25). This series 2 also uses water to binder ratio of 0.50. Table 4 shows the mix proportion for series 2. Meanwhile, this research also considers investigating the effect of the water to binder ratio. The investigation to determine the effect of the water to binder ratio consisted of three variations, namely 0.46 (S3-0.46), 0.48 (S43-0.48), and 0.50 (S3-0.50). Table 5 shows the results of the mix proportion for series 3.

2.3 Test Method

The tests in this study were divided into two categories: fresh properties and hardened properties. Inspection of fresh properties is carried out using the slump test, which aims to determine the level of workability of fresh concrete. Meanwhile, hardened properties are carried out through mass density and compressive strength. A compressive strength test was carried out according to the ASTM C39 standard [39] with a cylindrical specimen height of 300 mm and a diameter of 150 mm. The compressive strength test was carried out on the concrete, aged 3, 7, 14, and 28 days with water curing. While the mass density test was only carried out on concrete with an age of 28 days.

Table 3 Mix proportion for series 1 in 1 m^3

Materials	S1-25	S1-50	S1-75	S1-100
Cement (kg/m^3)	409.70	409.70	409.70	409.70
Water (kg/m^3)	204.85	204.85	204.85	204.85
Coarse Aggregate (Normal) (kg/m^3)	607.19	404.79	202.39	-
Coarse Aggregate (Pumice) (kg/m^3)	202.39	404.79	607.19	809.59
Fine Aggregate (kg/m^3)	475.34	475.34	475.34	475.34
Coarse Aggregate Size (mm)	20	20	20	20
Water to Binder Ratio	0.50	0.50	0.50	0.50

Table 4 Mix proportion for series 2 in 1 m^3

Materials	S2-9.5	S2-16	S2-20	S2-25
Cement (kg/m^3)	409.70	409.70	409.70	409.70
Water (kg/m^3)	204.85	204.85	204.85	204.85
Coarse Aggregate (Pumice) (kg/m^3)	809.59	809.59	809.59	809.59
Fine Aggregate (kg/m^3)	475.34	475.34	475.34	475.34
Coarse Aggregate Size (mm)	9.5	16	20	25
Water to Binder Ratio	0.50	0.50	0.50	0.50

Table 5 Mix proportion for series 3 in 1 m^3

Materials	S3-0.46	S3-0.48	S3-0.50
Cement (kg/m^3)	409.70	409.70	409.70
Water (kg/m^3)	188.46	196.66	204.85
Coarse Aggregate (Normal) (kg/m^3)	-	-	-
Coarse Aggregate (Pumice) (kg/m^3)	809.59	809.59	809.59
Fine Aggregate (kg/m^3)	475.34	475.34	475.34
Coarse Aggregate Size (mm)	20	20	20
Water to Binder Ratio	0.46	0.48	0.50

3. RESULTS AND DISCUSSION

3.1 Effect of Coral Pumice as Coarse Aggregate Replacement

An investigation of the effect of lightweight aggregate composition on compressive strength was carried out in this study. Figure 2 shows the slump results on fresh concrete with variations of light aggregate as a substitute for coarse aggregate. A 25% replacement of light aggregate with coarse aggregate results in a slump of 190 mm, whereas a 50% replacement of coarse aggregate with light aggregate results in a slump of 180 mm. The 75% variation of light aggregate produces a slump value of 150 mm, and at the use of 100% light aggregate, it produces a slump value of 135 mm. Based on the inspection results, it can be concluded that the addition of the amount of pumice used results in a lower slump so that the workability of fresh concrete also decreases. This is due to the higher water absorption rate in pumice compared to normal aggregates. When the mixing process is carried out, the pumice aggregate can absorb water so that the workability of the concrete is also reduced.

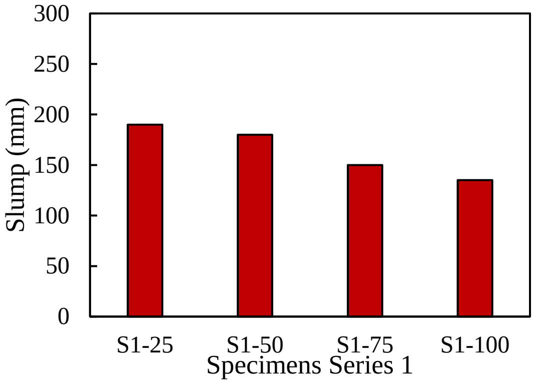

Fig.2 Slump results for lightweight concrete with different amounts of pumice aggregate

Figure 3 shows the compressive strength results at the age of 3, 7, 14, and 28 days of concrete with variations of pumice as a substitute for coarse aggregate. Based on the variation of concrete ages, the compressive strength has increased for all specimens with increasing age of the concrete. The increase in compressive strength occurs due to the hydration process, and the level of hardening increases. Meanwhile, the test results show that the compressive strength has decreased as light aggregate composition increases as a substitute for coarse aggregate. The decrease in compressive strength is due to the increasing composition of lightweight aggregates. Aggregate roughness in Table 2 shows pumice has higher than normal aggregates. So that it can be concluded that lightweight aggregates are more brittle in resisting the compressive forces of normal aggregates

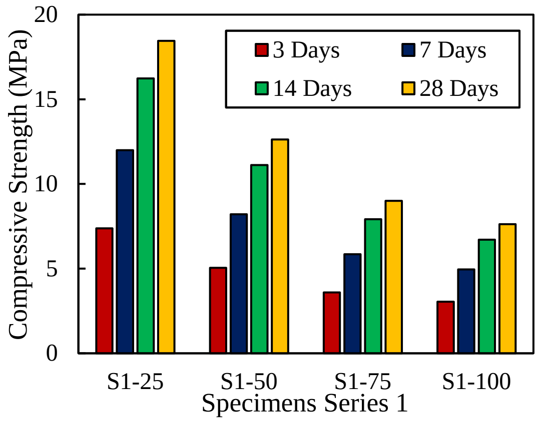

Fig.3 Compressive strength for lightweight concrete with different amounts of pumice aggregate

Figure 4 shows the mass density of concrete with variations in lightweight aggregate in concrete for 28 days. The test results show that as the amount of lightweight aggregate used increases, the mass density decreases. The decrease in the mass density of concrete occurs because the mass density of lightweight aggregate is lower than the normal aggregate. This test discovered that the concrete could no longer be classified as lightweight by replacing 25% of the coarse aggregate with lightweight aggregate. Lightweight concrete is defined with a coarse aggregate replacement of 50% to 100%. In general, it can be concluded that the use of lightweight aggregates in large quantities will cause the workability of fresh concrete and the compressive strength of concrete to decrease. However, the mass density of concrete decreases, causing the concrete to become lighter.

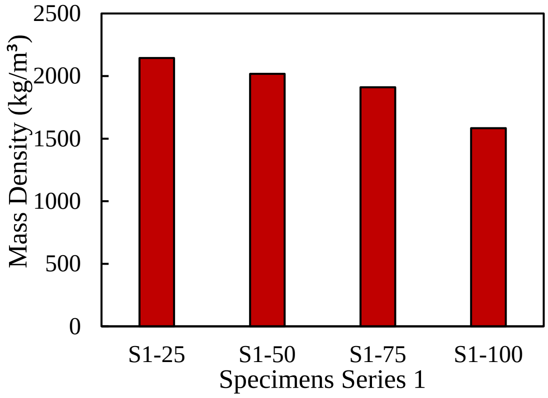

Fig.4 Mass density for lightweight concrete with different amounts of pumice aggregate

3.2 Effect of Size of Coral Pumice

The effect of maximum size of coarse aggregate on the fresh and hardened properties of concrete was also examined in this study. Figure 5 shows the results of testing fresh properties to determine the workability of concrete. The test results show that the resulting slump decreases as the maximum size of coarse aggregate increases. The decrease in workability is due to the increase in aggregate size, the ability of coarse aggregate to absorb water also increases because the aggregate surface will be wider.

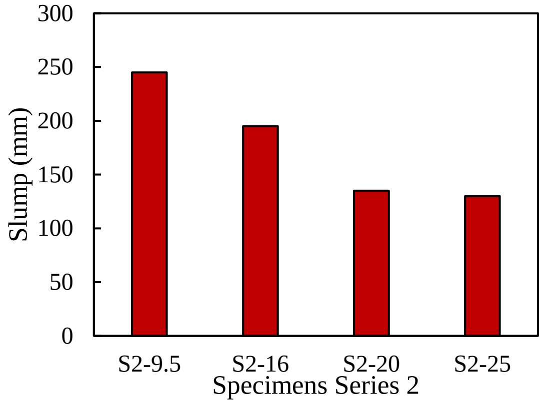

Fig.5 Slump results for lightweight concrete with different sizes of lightweight aggregate

The results of the compressive strength of concrete with variations in the maximum size of coarse aggregate can be seen in Figure 6. The test results show that as the size of the coarse aggregate increases, the compressive strength produced decreases. The larger size of the coarse aggregate causes the area of the aggregate in contact with the paste to be high. The surface of the pumice aggregate, which is smoother than normal aggregate will reduce the bonding between the paste and the aggregate. So, with a large aggregate size, the compressive strength will be lower compared to specimens with a smaller maximum size of coarse aggregate.

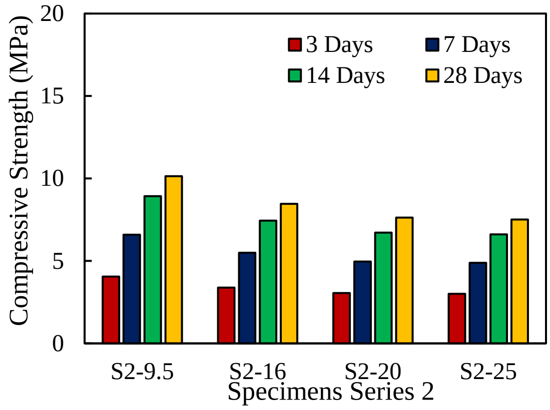

Fig.6 Compressive strength with different sizes of lightweight aggregate

Figure 7 shows the mass density of concrete at the age of 28 days with variations in the size of coarse aggregate. The investigation results show that with different aggregate sizes, the resulting mass density is almost the same. An insignificant difference in mass density due to the amount of aggregate used is the same even though the size is different.

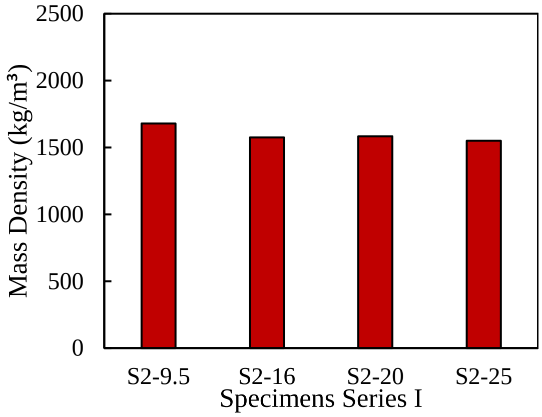

Fig.7 Mass density for lightweight concrete with different sizes of lightweight aggregate

3.3 Effect of Water to Binder Ratio

This study also carried out the effect of the water to binder ratio on the fresh and hardened properties of lightweight concrete. Figure 8 shows the results of the slump test with variations of water to binder ratio. The test results show that as the water to binder ratio increases, the slump value also increases. The increase in the slump value is caused by the increase in the amount of water used so that the fluidity level becomes high. The water to binder ratio of 0.46 produces a slump value of 90 mm, while the water to binder ratio of 0.48 produces a slump value of 110 mm, and using a water to binder ratio of 0.50 produces a slump value of 135 mm.

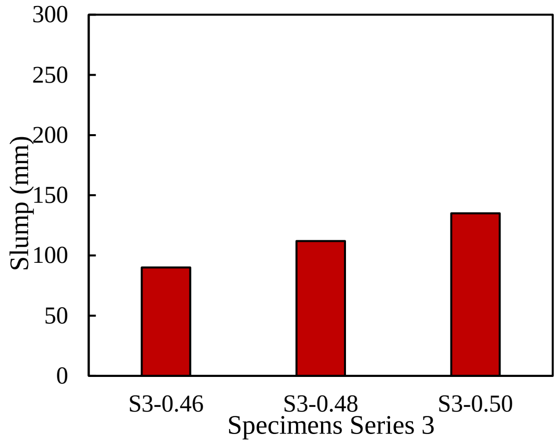

Fig.8 Slump results for lightweight concrete with different water to binder ratio

The results of the compressive strength of concrete with variations in the Water to binder ratio are shown in Figure 9. The test results show that as the water to binder ratio increases, the compressive strength produced decreases. The decreased compressive strength is due to the increased amount of water used when the water to binder ratio is high.

Water that is not used by cement to react will evaporate during the hydration process. When the water has evaporated, it will leave pores which cause the compressive strength of the concrete to decrease. Therefore, the use of high water to binder ratio causes decreases in compressive strength of concrete, both at the initial age and in concrete with the age of 28 days.

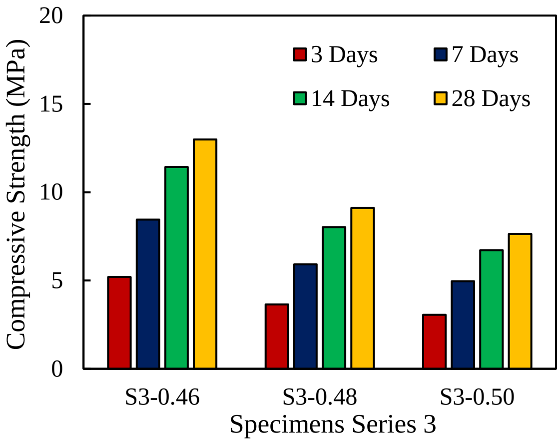

Fig.9 Compressive strength for lightweight concrete with different water to binder ratio

Figure 10 shows the mass density with variations of water to binder ratio in 28-day old concrete. The test results show that as the water to binder ratio increases, the mass density produced decreases. However, the reduction in mass density that occurs is not very significant between each variation. The reduction in mass density can be caused by increasing the number of pores in concrete with high water to binder ratio. The resulting pores cause the weight of the concrete to be reduced

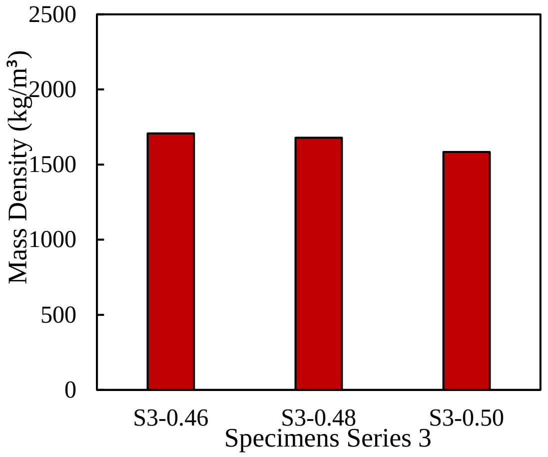

Fig.10 Mass density for lightweight concrete with different water to binder ratio

4. CONCLUSION

Based on the results and discussions that have been carried out, it can be concluded that:

a. The addition of lightweight aggregate as a substitute for coarse aggregate causes workability, compressive strength, and mass density to decrease. The use of coral pumice aggregates of 50% to 100% can be categorized as lightweight concrete.
b. The maximum size of lightweight aggregate greatly affects concrete workability and compressive strength but does not affect the mass density.
c. High water to binder ratio results in a higher level of workability of the resulting concrete. However, the compressive strength of the concrete is reduced.
d. This lightweight aggregate utilization is not for structural components but can be used for non-structural components to help reduce the load received by the structure.

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