© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Effect of Coarse Aggregate Treatment On Characteristics of Pumice and Scoria Lightweight Concretes

Hendro Suseno[1*]

[1]Department of Civil Engineering,
Brawijaya University, Jl. MT Haryono 167, Malang 65145, INDONESIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2023.15.01.031
Received 12 October 2022; Accepted 22 January 2023; Available online 31 March 2023

Abstract: This study presents an experimental investigation of lightweight concretes production using typical pumice and scoria from Kelud volcano, Indonesia as coarse aggregates. Three different treatments were evaluated to obtain an effective treatment method. Method A was a combination of preheating to the temperature of 100° C and soaking for 2 hours. Method B was a direct presoaking for 3 hours and Method C was a premixing with water in the concrete mixer for 10 minutes. These methods were based on the water content of lightweight coarse aggregates tested before. The results showed that Method A provided the highest water content compared to Methods B and C. Similarly, it also provided the most satisfying workability during concrete production. Moreover, all physical and mechanical characteristics of hardened concrete were not affected by the coarse aggregate treatment methods given. Therefore, Method A was considered an effective treatment method. Pumice and scoria lightweight concretes constituted the structural lightweight concrete with equilibrium densities in the range of 1724 kg/m^3 to 1837 kg/m^3. The density reduction was between 21% and 24% so that they can reduce the self-weight of structural element. However, the chord modulus of elasticity, the splitting tensile strength as well as the modulus of rupture was lower than the normal concrete and must be considered throughout in the structural lightweight concrete design.

Keywords: Coarse aggregate treatment, pumice, scoria, lightweight concrete

1. Introduction

Pumice and scoria lightweight concretes are categorized as a structural lightweight concrete [1] where the coarse aggregates consist of pumice and scoria which are natural resources. The structural lightweight concrete is a concrete with all lightweight aggregates or a combination of lightweight and normal aggregates that has a minimum compressive strength of 17 MPa at 28 days and a practical equilibrium density in the range of 1680 kg/m^3 to 1920 kg/m^3 [2]. The use of these lightweight coarse aggregates are particularly advantageous because their existences are abundant so that they are economically cheaper, especially in volcanic zones. By using both natural coarse aggregates as a substitute for artificial coarse aggregates, the structural lightweight concrete becomes energy saving and more environmentally friendly. So the high energy requirement for producing artificial coarse lightweight aggregates [3], can be removed as well as air pollution emitted can be also avoided. Indonesia, which is the volcanic zone and part of Pacific Ring of Fire, has huge and potential deposits of pumice and scoria. However, in contrast to Turkey, for example, both have not been explored optimally, especially for coarse aggregates of lightweight concrete so that they become more economical as the local construction materials [4].

One of the type of pumice and scoria is the eruptive deposit of Kelud volcano located in the southern East Java. These eruption products, namely Medium-K basaltic andesitic pumice and scoria, are typical vesicular rocks ejected simultaneously during each eruption period [5], [6]. Moreover, these are very abundant in the lava catchmaent areas,

Corresponding author: hendros@ub.ac.id

for exemple, the eruption in 2014 produced approximately the volume of tephra of 219 in million m^3 including typical pumice and scoria [7]. Today, these abundant natural sources have not been optimally explored as coarse aggregates of structural lightweight concrete. Although different in color, where pumice is pale white while scoria is black, the chemical composition, petrography and texture are not significantly different so these give unique characteristics that are different from those in general. Pumice is harder, denser and heavier whereas scoria is less hard and less dense but lighter, this may be due to the combination of andesite and basalt that exist in the solid mass. These volcanic rocks have a specific gravity greater than one so that they sink immediately in water. From the results of previous study [8], the average density of intact rock core specimens were 1.30 kg/m^3 for pumice and 1.53 kg/m^3 for scoria. Meanwhile, the average compressive strengths were 5.68 MPa for pumice and 6.23 MPa for scoria. In the coarse aggregate specimens, the physical characteristics fulfilled the requirements of lightweight coarse aggregate. However, their resistances to the degradation due to abrasion by LA machine were very high and exceeded the limits for coarse aggregate requirements for concrete. This may be due to the high porosity and dominant amorphous glass microstructure in the ground masses.

The production of pumice and scoria lightweight concretes are rather complicated and require a longer production time than normal concrete. Because the texture of pumice and scoria coarse agregates are thoroughly porous, so the absorption and absorption rate become very high [9]. They will absorb excessively water in the concrete mixtures and then the slump value is reduced significantly and the concrete mixtures become stiff and difficult to work. Therefore, the hardened lightweight concretes may be porous and their qualities also decrease eventually. One way to overcome this problem, several researchers prewetted both lightweight coarse aggregates prior to the concrete mixing. For example, pumice and scoria lightweight coarse aggregates were presoaked for 24 hours [9]-[13]. Scoria lightweight coarse aggregate was premixed with water and admixtures in the concrete mixer for 30 minutes [14], for 10 minutes [15], or for 3 to 4 minutes [16]. Pumice and scoria lightweight coarse aggregates were presoaked to surface saturated dry (SSD) conditions [17]-[19]. Also, pumice lightweight coarse aggregate was presoaked to vacuum saturated conditions [20], [21]. Another method was to shorten the presoaking time to 18 hours so that their productions become faster [4], [8]. Although, the above treatments were rather complicated and the production became longer, however the results can overcame the problems of workability and the requirement of structural lightweight concrete can be achieved.

The treatment of lightweight coarse aggregates can also be conducted by thermal quenching, i.e. preheating them and then soaking in water at room temperature for a certain time [2], [22]. This method produces very high water content in the lightweight coarse aggregate and is recommended for placing the concrete mixture by the pumping method [23]. The hot coarse lightweight aggregate may be able to absorb water faster due to the temperature difference with water around them. Similarly, their pores may expand thoroughly due to preheating, increase in volume and absorb more water so that the water content increases. Water absorption in the concrete mixture by the lightweight coarse aggregate, is significantly reduced then the slump value can be controlled precisely and the workability remains satisfactory. This practical treatment is very interesting to be investigated and has not been performed on pumice and scoria lightweight concretes, especially for typical pumice and scoria from Kelud volcano.

The use of characteristics of fresh and hardened concretes is generally for the requirement of structural concrete, structural design and quality control [24], [25]. The slump value is a physical characteristic of fresh concrete used for investigating the workability of concrete mixture, when it increases up to the required value then the fresh concrete be easy to mix. The density is a physical characteristic of hardened concrete used to determine the self-weight of death load. Meanwhile, the compressive strength, modulus of elasticity, splitting tensile strength and modulus of rupture are mechanical characteristics of hardened concrete used to determine their strength and stiffness [26]. The compressive strength is generally utilized as a common index of concrete strength because the test is most easily conducted in laboratory [27], while others are considered to be directly correlated with the compressive strength. The mechanical characteristics of pumice and scoria lightweight concretes are smaller than normal concrete this is due to the high porosity and the dominant amorphous glass microstructure in both lightweight coarse aggregates [28]. Generally, the failure mode of lightweight concrete due to external loads is also different from normal concrete, the lightweight coarse aggregate is relatively weak due to the presence of high pores and fail earlier than the transition zone and cement paste [2], [27].

The objective of this study is to investigate experimentally the effect of coarse aggregate treatments on characteristics lightweight concrete utilizing typical pumice and scoria from Kelud volcano, Indonesia. Three different treatment methods were evaluated to obtain an effective method that can shorten the production time of both lightweight concretes. The investigations of water content in these lightweight coarse aggregates are carried out first to determine the preheating temperature and soaking time. This study only investigates experimentally the macrostructural aspects which include the physical characteristics of coarse aggregates, fresh concrete as well as the physical and mechanical characteristics of hardened concrete. In addition, this study may be considered as one of the regional developments to increase the potential use of local construction materials to be more economical.

2. Materials and Method

2.1 Materials

The lightweight coarse aggregates used were Medium-K basaltic andesitic pumice and scoria and obtained from the eruption deposit of Putih river check dam on the southern slope of Kelud volcano. The maximum particle size of coarse aggregate (CA) was 19 mm with a gradation consisting of four fractions that fulfilled the existing requirements. The percentages of retained weight comprised 38 % in 12.5 mm sieve size, 32 % in 9.5 mm sieve size, 25 % in no. 4 (4.75 mm) sieve size and 5 % in no. 8 (2.36 mm) sieve size. The fineness modulus of this designing gradation was 6.65 which fulfilled Indonesian standard of SK SNI S-04-1989-F [29], i.e. between 6.00 and 7.10. A control with similar previous gradation was the commercial local crushed stone commonly used for normal concrete. Fig. 1 presents the photographs of pumice, scoria and the gradation of pumice and scoria coarse aggregates. The fine aggregate was lightweight river sand with maximum particle size was 4.75 mm. Its gradation provided a fineness modulus of 2.64 that fulfilled ASTM C33/33M-16 [30], i.e. between 2.30 and 3.10. The physical characteristic tests utilized the existing requirements where the oven dry density was 1446.23 kg/m^3, specific gravity was 2.48, and 24-hours absorption was 1.73 %. The binder included the Ordinary Portland Cement (OPC) and tap water. In order to reduce costs, lightweight concretes were not used in all kinds of admixture.

(a) (b) (c)

Fig. 1 - (a) Pumice; (b) scoria, and; (c) the gradation of pumice and scoria coarse aggregates

2.2 Testing Characteristic of Coarse Aggregates

The physical characteristics of typical pumice and scoria from Kelud volcano were very random, therefore it was necessary to test and control them whenever utilized in concrete mixtures. Moreover, these pumice and scoria were taken from different quarry, but they were still in the similar lava catchment area as in the previous studies. The testing of density, specific gravity and absorption of coarse aggregates were carried out according to ASTM C127-12 [31] for five specimens. Due to their high porosity, absorption investigations were also carried out at 96-hours and assumed as the maximum absorption [7]. The tests of resistance to the degradation due to abrasion by LA machine were conducted according to ASTM C535-16 [32] for five specimens. These five specimens represented the values of their physical characteristics expressed by their mean values and standard deviations. The mean characteristics of coarse aggregates are presented in Table 1.

Table 1 - Results of the characteristics of lightweight coarse aggregates

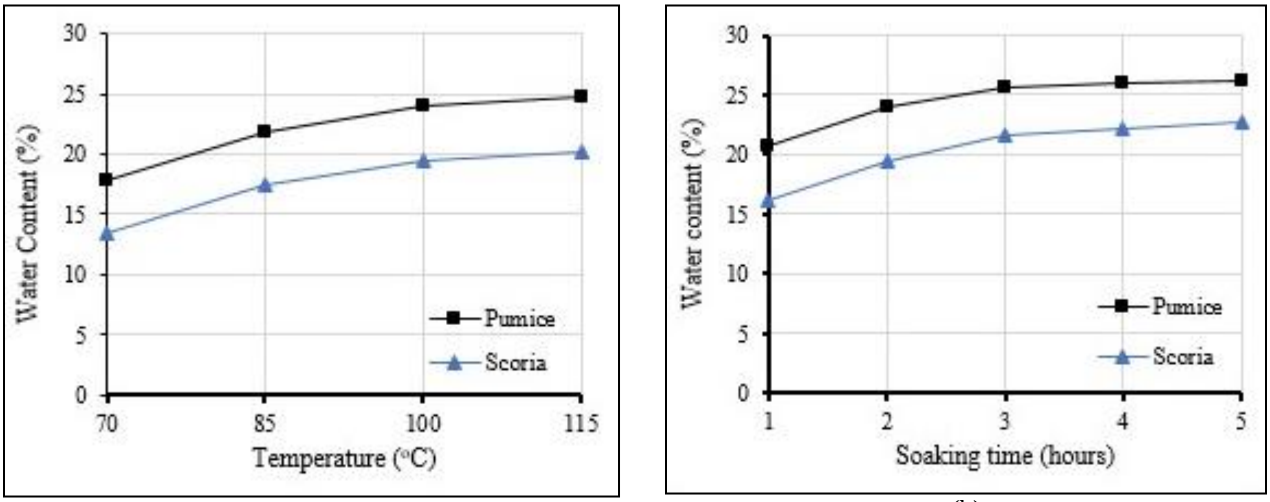
Characteristics	Type of Coarse Aggregates		
	Pumice	Scoria	Crushed Stone
Loose, oven dry density (kg/m^3)	710.65	802.73	1384.78
Bulk specific gravity	1.48	1.67	2.68
24-hours absorption (%)	16.73	12.84	1.46
96-hours absorption (%)	19.42	15.72	-
Abrasion by LA machine (%)	59.78	57.85	16.95
Fineness Modulus	6.65	6.65	6.65

2.3 Lightweight Coarse Aggregates Treatments Methods

To determine the effectiveness of three treatment methods, the water content tests were carried out first according to Indonesian stardard of SNI-1971-2011 [33] for three oven-dry specimens with a weight of 3500 grams each. These tests were conducted before mixing the lightweight concretes, and the results were the mean value of three specimens. Method A was carried out in two stages, the first was to investigate the water content of preheated lightweight coarse aggregates subjected to four preheating temperatures in the range of 85^o C to 115^o C with a constant soaking time of 2 hours. The second was to investigate the water content of preheated lighweightt coarse aggregates at the constant temperature of 100^o C subjected to five soaking times in the range of 1 to 5 hours. For Method B, the investigation of water content at the room temperature was carried out for five soaking times in the range of 1 to 5 hours. For Method C, the investigation of water content at the room temperature was carried out for five mixing times in the range of 5 to 25 minutes with water in the concrete mixer. Similarly, the weight loss of lightweight coarse aggregates was also measured due to impact with mixing blades in the concrete mixer or with other aggregate particles. This was conducted because they were sufficiently brittle due to the presence of high porosity and amorphous glass microstructure. Meanwhile, the amount of water content was calculated by the following formula [33]:

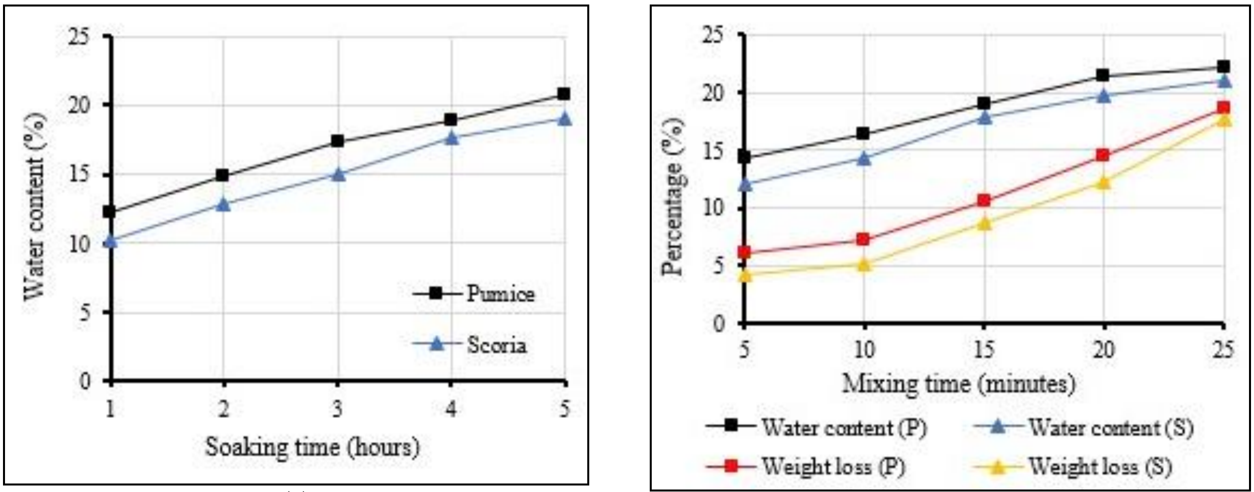
$$w = \frac{W_1 - W_2}{W_2} 100\% \quad (1)$$

where w is water content (%), W_1 is the weight of lightweight coarse aggregate after being treated (gram) and W_2 is the weight of oven dry lightweight coarse aggregate (gram). The testing results for both lightweight coarse aggregates are given by Fig. 2 and Fig. 3.



(a) (b)

Fig. 2 - Method A (a) soaking time of 2 hours, and; (b) preheating temperature of 100° C



(a) (b)

Fig. 3 - (a) Method B, and; (b) Method C

Fig. 2(a) showed the results of the water content of pumice and scoria coarse aggregates in the Method A. For the constant soaking time of 2 hours, the water contents at the preheating temperature of 100° C were 23.99% for pumice and 19.46% for scoria. Under this preheating temperature, the water contents increased significantly, while for values above it, the water contents increased less significantly. Fig. 2(b) presents the water contents in constant preheating temperature of 100° C. The water contents in the range of 1 to 2 hours of soaking time increased significantly, while for values above 2 hours, the water contents also increased less significantly. Thus, these values can be applied in the Method A when producing lightweight concretes conducted. Fig. 3(a) showed the results of Method B, the water contents increased proportionally during direct soaking time in the range of 1 to 5 hours. For this reason, the soaking time of 3 hours was taken as a practical consideration, where the water contents were 17.37% for pumice and 15.04% for scoria. Fig. 3(b) showed the results of Method C, the water contents also increased proportionally during the mixing time in the range of 5 to 25 minutes with water in the concrete mixer. However, it can be seen that the percentages of weight loss after 10 minutes increased significantly. Thus, the mixing time of 10 minutes can be taken in Method C, where the water contents were 16.39% for pumice and 14.26% for scoria.

From the above results, the similar treatment methods can be applied to pumice and scoria coarse aggregates during the production of lightweight concretes. In the Method A, the lightweight coarse aggregates were preheated in a thin steel plate container using two gas stoves and the temperature of 100º C can be reached within 45 minutes. After preheating, they were immediately soaked in plastic buckets for 2 hours and then drained to dry their surfaces. In the Method B, they were directly presoaked in the plastic buckets for 3 hours and then drained to dry their surfaces. Meanwhile, in the Method C, they were premixed with water in the concrete mixer for 10 minutes and then drained to dry their surfaces. The photographs of three lightweight coarse aggregate treatments are presented by Fig. 4. The average water contents of both coarse aggregates during the production are presented in Table 2.

(a) (b) (c)

Fig. 4 - Lightweight coarse aggregate treatments (a) Method A; (b) Method B, and; (c) Method C

Table 2 - Results of mix design of structural concretes

Type of Coarse Aggregate	Group	Label	Specified Compressive Strength (MPa)	Mix Proportion per 1 m^3 Volume (kg)				Water Content of CA (%)
				OPC	Water	Dry Sand	Damp CA	
Pumice	A	PLCA1	20.00	322.64	170.48	712.79	634.10	24.61
		PLCA2	25.00	377.32	178.09	658.85	625.74	23.84
		PLCA3	30.00	423.65	173.59	611.94	630.82	23.97
	B	PLCB1	20.00	322.64	210.26	711.37	595.74	17.47
		PLCB2	25.00	377.32	200.88	659.51	602.30	17.26
		PLCB3	30.00	423.65	208.88	612.55	594.92	17.75
	C	PLCC1	20.00	322.64	215.73	712.79	588.85	15.12
		PLCC2	25.00	377.32	213.33	658.85	590.49	15.54
		PLCC3	30.00	423.65	218.18	611.94	586.23	15.21
Scoria	A	SLCA1	20.00	322.64	170.79	734.28	692.30	21.45
		SLCA2	25.00	377.32	173.11	679.24	690.33	20.91
		SLCA3	30.00	423.65	173.38	634.12	688.85	20.75
	B	SLCB1	20.00	322.64	200.21	733.54	663.61	15.76
		SLCB2	25.00	377.32	200.99	679.72	661.97	15.70
		SLCB3	30.00	423.65	195.53	634.75	666.07	15.96
	C	SLCC1	20.00	322.64	206.13	735.01	656.23	14.28
		SLCC2	25.00	377.32	207.88	679.72	655.08	14.18
		SLCC3	30.00	423.65	207.30	633.80	655.25	14.12
Crushed Stone	D	NC2	25.00	351.58	212.34	806.40	974.67	-

2.4 Mix Design of Structural Concretes

Two groups of structural lightweight concrete were designed by Weight Method according to ACI 211.1-98(R2004) [34]. In this method, the maximum absorption of coarse aggregates was precisely assumed at 96 hours. Pumice and scoria lightweight concretes were designed by considering the three above treatment methods and expressed in Groups A, B and C. Each group consisted of three mix proportions with the specified compressive strengths of F1 = 20 MPa, F2 = 25 MPa and F3 = 30 MPa. Group D was a normal concrete as a control, and its mix proportion was designed according to ACI 211.1-91(R2002) [35] with the specified compressive strength of F2 = 25 MPa. The average compressive strengths were calculated in accordance with Indonesian Standards of SNI 2847:2019 [36]. The slump value of all mix proportions was approximately determined in the range of 25 to 70 mm whereas air content was specified in the range of 2% to 3%. The river sand was in dry condition but both lightweight coarse aggregates were in damp condition. The water proportions in the concrete mixture were calculated based on the existing water content and absorption of coarse and fine aggregates. The results of mix design were expressed in weight proportions of material per 1 m^3 volume and are presented in Table 2. In accordance with the treatment methods given, the proportions of water increase in Group A, to B and C due to the decreases of water content in the lightweight coarse aggregates. The slump values are significantly reduced because during production, water was put into the mixer first and then coarse aggregate, river sand and Portland cement. The cement content of control at the similar specified compressive strength is lower than both lightweight concretes. To maintain satisfactory workability, the water content must increases and the water-cement ratio also increases so that the compressive strength becomes low. Therefore, the OPC content must be increased to obtain the high compressive strength for previous satisfactory workability. In addition, the difference in the mix proportion between pumice and scoria lightweight concretes is less significant because their physical characteristics also differ less significantly.

2.5 Physical Characteristic Tests of Fresh and Hardened Concretes

The concrete mixings were conducted using the concrete mixer with 170 liters' capacity and during the production of both lightweight concretes, the workability of fresh lightweight concretes were investigated to evaluate the effectiveness of treatment method. The tests of slump value were performed according to ASTM C143/C143M-10 [37] for three specimens and the mean value are presented in Table 3. The cylinder specimens of 150×300 mm were used for density tests which comprised 1 day, 45 days, oven dry and equilibrium density. The compaction of specimens was internally conducted by a 12 mm diameter steel rod vibrator. All specimens were demolded 24 hours after casting and cured by covering them in wet burlap for 7 days, furthermore they are placed in an open and dry room until the test conducted at 45 days. The curing and equilibrium density tests were carried out according to ASTM C567/C567M-14 [38] for three specimens. These three specimens represented the values of their physical characteristics expressed by their mean values and standard deviations, and the mean value are given in Table 3.

Table 3 - Physical characteristics of fresh and hardened concretes

Coarse Aggregate	Group	Label	Slump Value (mm)	Density (kg/m^3)			
				1 Day	45 Days	Oven Dry	Equilibrium
Pumice	A	PLCA1	58	1842.41	1751.25	1674.95	1724.95
		PLCA2	60	1853.67	1776.47	1686.91	1736.91
		PLCA3	59	1865.94	1792.53	1697.79	1747.79
	B	PLCB1	30	1843.78	1751.64	1676.98	1726.98
		PLCB2	31	1853.01	1777.55	1686.62	1736.62
		PLCB3	32	1866.46	1791.43	1698.53	1748.53
	C	PLCC1	25	1842.78	1753.71	1675.72	1725.72
		PLCC2	26	1854.03	1776.66	1687.19	1737.19
		PLCC3	27	1867.36	1795.68	1699.14	1749.14
Scoria	A	SLCA1	62	1930.57	1865.05	1762.88	1812.88
		SLCA2	58	1941.43	1879.29	1773.47	1823.47
		SLCA3	60	1954.01	1912.61	1786.88	1836.88
	B	SLCB1	30	1931.08	1866.76	1762.86	1812.86
		SLCB2	31	1942.69	1882.44	1774.41	1824.41
		SLCB3	30	1956.28	1922.21	1786.57	1836.57
	C	SLCC1	27	1930.01	1870.53	1762.70	1812.70
		SLCC2	28	1942.80	1880.69	1775.07	1825.07
		SLCC3	26	1955.23	1921.33	1785.72	1835.72
Crushed Stone	D	NC2	58	2363.68	2301.02	-	-

2.6 Mechanical Characteristic Tests of Hardened Concrete

Two typical specimens used were 150×300 mm cylinder for compressive tests as well as splitting tensile tests and 100×100×400 mm prism for bending tests. Casting, compacting, demolding and curing for all specimens were carried out as before. The tests of compressive strength and chord modulus of elasticity were carried out according to ASTM C39/C39M-16 [39] and ASTM C469/C469M-14 [40] for three specimens. Similarly, the tests of splitting tensile strength as well as the bending tests to obtain the modulus of rupture were also according to ASTM C496/C496M-11 [41] and ASTM C78/C78M-10 [42] for three specimens. These three specimens also represented the values of their mechanical characteristics expressed by their mean values and standard deviations. All tests used a compression testing machine with a capacity of 2000 kN. The testing setup is presented by Fig. 5 whereas the results are presented in Table 4.


(a) (b) (c) (d)

Fig. 5 - Testing setup (a) compressometer; (b) compressive test; (c) splitting tensile test, and; (d) bending test

Table 4 - Mechanical characteristics of hardened concretes

Type of Coarse Aggregate	Group	Label	Compressive Strength (MPa)	Chord Modulus of Elasticity (GPa)	Splitting Tensile Strength (MPa)	Modulus of Rupture (MPa)
Pumice	A	PLCA1	20.54	12.34	2.26	3.71
		PLCA2	25.36	14.42	2.59	4.04
		PLCA3	30.39	16.36	2.91	4.47
	B	PLCB1	21.25	12.56	2.30	3.82
		PLCB2	26.12	15.02	2.63	4.16
		PLCB3	30.80	16.44	2.93	4.57
	C	PLCC1	21.11	12.59	2.25	3.87
		PLCC2	26.05	14.87	2.64	4.15
		PLCC3	30.45	16.67	2.96	4.64
Scoria	A	SLCA1	22.23	13.21	2.34	3.91
		SLCA2	27.09	15.34	2.71	4.16
		SLCA3	32.04	17.32	3.11	4.61
	B	SLCB1	22.68	13.39	2.32	3.94
		SLCB2	27.18	15.82	2.76	4.20
		SLCB3	32.46	17.75	3.18	4.77
	C	SLCC1	22.12	13.48	2.33	3.97
		SLCC2	27.18	15.92	2.76	4.30
		SLCC3	32.40	17.83	3.18	4.81
Crushed Stone	D	NC2	26.41	22.46	2.96	4.49

3. Results and Discussion

3.1 Lightweight Coarse Aggregate Characteristics

Table 1 shows that the average abrasion by the LA machine for pumice and scoria coarse aggregates, are relatively high and exceed the specified requirement of ASTM C535-16 [32], i.e. 20% and greater than the local crushed stone as the control. This indicates that their compressive strengths are relatively low [8], [9], [13] due to the high porosity and the amorphous glass microstructure as mentioned previously. The average loose, oven dry density fulfills the specified coarse lightweight aggregate requirement according to ASTM C330/C330M-17 [43], i.e. lower than 880 kg/m^3. The average bulk specific gravities also fulfill the specified requirement of SNI 03-2461-2002 [44], i.e. in the range of 1.0 to 1.8. The average 24-hours absorptions are also lower than that of the specified requirement of SNI 03-2461-2002 [44], i.e. 20 %. Meanwhile, the average 96-hours absorptions are 19.42% and 15.72%, respectively and considered as the maximum absorptions. The oven dry densities of both lightweight coarse aggregates are smaller than those of the studies mentioned previously [3], [7] while the others are almost similar. The density as well as specific gravity **is** lower than the control whereas the 24 hours' absorption and abrasion by LA machine are higher than the control. Thus, these pumice and scoria can be utilized as coarse aggregates of structural lightweight concrete.

3.2 Lightweight Coarse Aggregates Treatment Methods

Table 2 shows the average water contents of pumice and scoria coarse aggregates during lightweight concrete productions. The average water contents of Group A are greater than Group B and C, it means that Method A provides the highest water contents. Method B provides the moderate water content, when the soaking time is increased, the water content also increases significantly, but it will prolong the production time. Meanwhile, Method C provides the significant weight loss of lightweight aggregates that will affect their mix proportions. Some of the coarse aggregate becomes fine aggregate due to impact with the mixing blades in the concrete mixer or with other aggregate particles. In addition, their surfaces were eroded and became smoother so it may reduce the bond with cement paste. Method A requires the heat energy in low quantity; it only needs the preheating temperature of 100° C for 45 minutes and 2 hours for soaking the lightweight coarse aggregates. It can significantly shorten the production time of both lightweight concretes that is shorter than that of 18 hours presoaking method [3], [7] or 24 hours presoaking method [8]-[12]. Its production time is significantly shorter than the SSD presoaking method [16]-[18] which is difficult to be determined. However, its production time is longer than the premixing method with water and admixtures in the concrete mixer for 30 minutes and 10 minutes [13], [14] or the similar method for 3 to 4 minutes [15]. These premixing methods can significantly shorten it, because they used admixtures including water reducer and mineral that can improved the workability, but they will increase the concrete mixture cost. Moreover, the production time of Method A is significantly longer than the vacuum saturated presoaking method [19], [20], but it needed a special equipment that was complicated and expensive. Method A is more practical because it needs simple equipment, then it may be considered as the effective coarse aggregate treatment method for pumice and scoria lightweight concretes.

3.3 Physical Characteristics of Fresh and Hardened Concretes

Table 3 shows the average slump values of pumice and scoria lightweight concretes and control. The average slump values of Group A are greater than Group B and C, it means that Method A provides the most satisfactory workability compared to two other methods, there were no segregation or excessive bleeding in the concrete mixtures. In Method B, the average slump values decrease significantly, and the concrete mixtures are rather difficult to work. Meanwhile, in Method C, both lightweight concretes began to be stiff and difficult to work because the average slump values may be the lower bound given. Fig. 6(a) and Fig. 6(b) show that for increasing water content in coarse lightweight aggregates, the slump value of pumice and scoria lightweight concretes also increases significantly. The average increase in slump value from Method C to A is approximately 55%, from Method B to A is about 48% whereas from Method C to B is about 13%. Thus, the coarse aggregate treatment method significantly affects the workability of lightweight concretes.

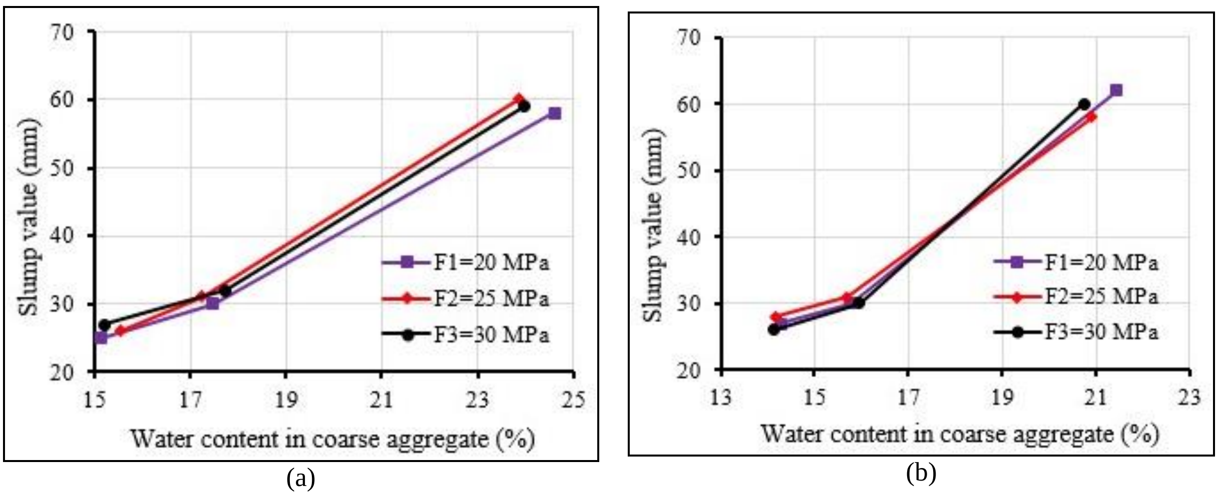
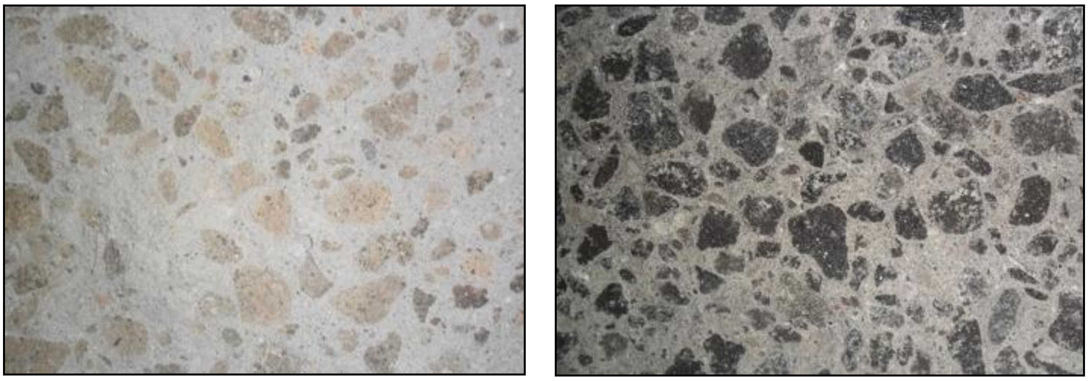


Fig. 6 - Diagram of water content in coarse aggregate and slump value (a) pumice, and; (b) scoria

Table 3 also shows the average density of 1 day, density of 45 days, oven dry density and equilibrium density for cases mentioned previously. The average equilibrium densities of both lightweight concretes fulfill the structural lightweight concrete requirement as defined by ACI 213R-14 [2], i.e. in the range of 1680 kg/m^3 to 1920 kg/m^3. The deviation of equilibrium densities in Group A, B and C are not significantly different, i.e. lower than 0.2%. Meanwhile, for the three proportions of lightweight concretes, they increase less significantly because the specified compressive strength also increases from 20 MPa to 30 MPa. It means that the coarse aggregate treatment method does not affect the equilibrium density. When they are compared to control, the average reduction of equilibrium density is 24% for pumice lightweight concrete and 21% for scoria lightweight concrete. The 45 days' densities are still relatively high so they may not be used to approximate their equilibrium densities. In addition, the difference in the equilibrium density of both lightweight concretes is also less significant because the reason are mentioned before. Fig. 7 shows the distribution of coarse aggregate on the cross section of hardened concretes, it can be seen that the particle size of coarse aggregates spread evenly according to the previous gradation designed, so that the compactness of both lightweight concretes may become maximal.

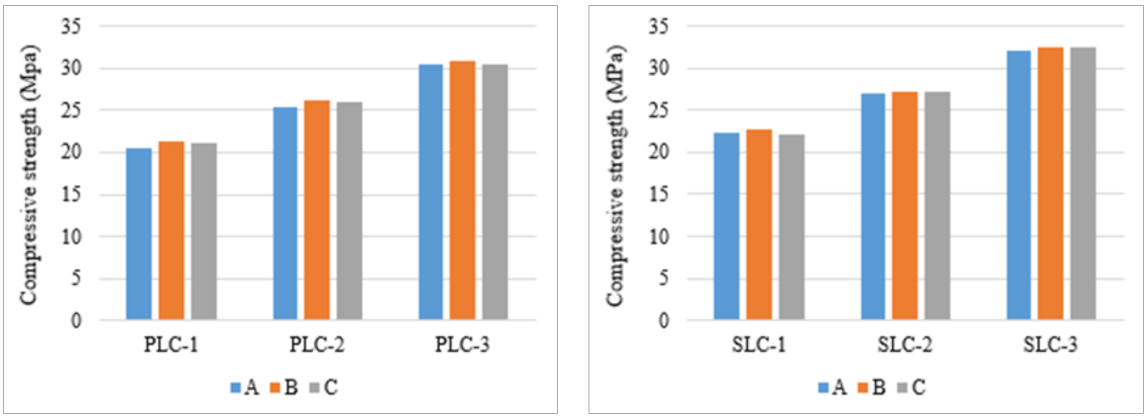


(a) (b)

Fig. 7 - Cross section of hardened concretes (a) pumice lightweight concrete, and; (b) scoria lightweight concrete

3.4 Mechanical Characteristics of Hardened Concrete

Table 4 shows that the average compressive strengths of pumice lightweight concretes for three mix proportions in Groups A, B and C, fulfill the specified compressive strength, i.e. (20-25-30) MPa. Similarly, the scoria lightweight concretes also fulfill this specified compressive strength. Fig. 8 shows the effect of coarse aggregate treatment method on their compressive strengths. Although there are large differences in slump value, the compressive strengths in Group A, B and C are not significantly different, i.e. their deviation is lower than 3%. The lightweight coarse aggregates in Group B and C may absorb water in the lightweight concrete mixtures because their water contents are sufficiently low, the water cement ratios decrease, and the compressive strengths increase. However, they are relatively weaker than the transition zone and the cement paste, and then they may fail first [2], [27]. Thus, the coarse aggregate treatment method does not affect the compressive strengths. Additionally, the difference of compressive strength between pumice and scoria lightweight concretes is also less significant due to the reason mentioned before.



(a) (b)

Fig. 8 - Effect of coarse aggregate treatment method on compressive strength (a) pumice lightweight concrete, and; (b) scoria lightweight concrete

The average chord modulus of elasticity of pumice lightweight concretes for three mix proportions in Groups A, B and C does not significantly differ. Similarly, this condition is also applied to scoria lightweight concretes. The deviation of modulus of elasticity is lower than 4%, so that the coarse aggregate treatment method does not affect it.

Their magnitudes increase significantly with increasing the compressive strengths because in general they are proportionally related [25], [26]. The percentages of chord modulus of elasticity are 66% and 70%, when compared to the control. This low modulus of elasticity is also caused by the high porosity and the amorphous glass microstructure in both coarse lightweight aggregates. Moreover, the difference of modulus of elasticity of both lightweight concretes is also less significant.

The average splitting tensile strengths of pumice lightweight concrete for three mix proportions in Groups A, B and C differ less significantly. Similarly, this condition is also applied to scoria lightweight concretes. The deviation of splitting tensile strength is lower than 3%, it means that the coarse aggregate treatment method does not affect it. These magnitudes also increase significantly with increasing the compressive strengths because in general they are proportionally related [24], [26]. These may be due to the prolongation of tests to 45 days so that the moisture in both lightweight concretes are reduced [25]. The percentages of splitting tensile strength are 88% and 91%, when compared to the control. These percentages are about 10% when compared to their compressive strengths. Also, the difference in the splitting tensile strength of both lightweight concretes is also less significant due to the reason mentioned previously.

The modulus of rupture of pumice lightweight concrete for three mix proportions in Groups A, B and C differ less significantly. Similarly, this condition is also applied to scoria lightweight concretes. The deviation of modulus of rupture is lower than 5%, it means that the coarse aggregate treatment method does not affect it. These magnitudes also increase significantly with increasing the compressive strengths because in general they are proportionally related [24], [26]. These moduli of rupture increase when compared with the previous studies [3], [7], and these increases are rather significant when compared to the splitting tensile strengths. These may be caused by the prolongation testing time to 45 days, the surface of the prism specimen drier than inside and the maximum flexural tensile strengths located in the outer tensile zone increase quite significantly. The percentages of these moduli are 92% and 94% for pumice and scoria lightweight concretes, when compared to the control. These percentages are about 15% when compared to their compressive strengths. Moreover, the difference in the modulus of rupture of both lightweight concretes is also less significant due to the reason mentioned before.

3.5 Failure Mode

Fig. 9 shows the failure modes of three kinds of testing carried out. For compressive tests, the majority of concrete cylinder specimens showed a cone failure mode whereas some of that showed a columnar failure mode. These results are similar to those of concrete using commercial scoria aggregate from Australia [45]. For splitting tensile tests, all specimens showed a splitting failure mode at their vertical diameters. Meanwhile, for three-point loading of bending tests, the mayority of concrete prism specimens showed a flexure failure mode in the mid-span and some of that showed it slightly away from the mid-span. It seems visually that the failure modes of both lightweight concretes occured in the lightweight coarse aggregates while in the normal concrete as control, the coarse aggregates did not fail. However, this should be investigated with SEM testing so that it is truly proven.

(a) (b) (c)

Fig. 9 - Failure mode (a) compressive test; (b) splitting tensile test, and; (c) bending test

4. Conclusions

This study showed the effect of coarse aggregate treatments on characteristics of lightweight concrete using typical pumice and scoria from Kelud volcano, Indonesia as coarse aggregates. From three coarse aggregates treatment methods evaluated, it obtains the most practical and effective treatment method for producing the pumice and scoria lightweight concretes. However, some weaknesses in mechanical characteristics remain an issue that needs to be considered when these lightweight concretes are produced. Preheating to temperature of 100^{o} C and then soaking for 2 hours produces the structural lightweight concretes with satisfactory workability so it can be considered as the effective coarse aggregate treatment method for producing them. The production of lightweight concretes with direct presoaking method needs a prolongation of soaking time whereas the premixing method with water in the concrete mixer should be avoided because the surface of the coarse lightweight aggregates are eroded to be smoother, their workability are adequately low, the fresh lightweight concretes are relatively stiff, difficult to work and the results may tend to be porous. The coarse aggregate treatment methods do not affect all physical and mechanical characteristics of both lightweight concretes. The equilibrium density and compressive strength measured, meet the structural lightweight concrete requirements with density reduction between 21% and 24% so that they can reduce the self-weight of structural element. The chord modulus of elasticity, splitting tensile strength and modulus of rupture obtained are sufficiently low so that they must be considered throughout in structural lightweight concrete design.

Acknowledgement

This research was funded by Faculty of Engineering, Brawijaya University, Indonesia with a contract number: 117/UN10.F07/PN/2019. The author thanks the technical staff of the Laboratory of Construction Materials and Structures, Department of Civil Engineering for all assistances during execution programs.

References

[1] ACI Committee 213. (2014). Guide for structural lightweight aggregate concrete. ACI 213R-14. Detroit: American Concrete Institute.
[2] ACI Committee 213. (2003). Guide for structural lightweight aggregate concrete. ACI 213R-03. Detroit: American Concrete Institute.
[3] Chandra, S. & Berntsson, L. (2003). Lightweight Aggregate Concrete, Science, Technology and Applications," Norwich-New York: Noyes Publications/William Publishing.
[4] Suseno, H. (2018). Perilaku Retak dan Prediksi Lebar Retak Pelat Satu Arah dari Beton Ringan Batu Apung dan Skoria Bertulang. Dissertation in Indonesian. Department of Civil Engineering, Brawijaya University. Malang, Indonesia.
[5] Bourdier, J. L., Pratomo, I., Thouret, J. C., Boudon, G., & Vincent, P. M. (1997). Observation, stratigraphy and eruptive processes of the 1990 Eruption of Kelut Volcano, Indonesia. Journal of Volcanology and Geothermal Research, 79, 181-203.
[6] Nakada, S., Zaennudin, A., Maeno, F., Yoshimoto, M., & Hokanishi, N. (2016). Credibility of volcanic ash thicknesses reported by the media and local residences following the 2014 eruption of Kelud Volcano, Indonesia. Journal of Disaster Research, 11, 1, 53-59.
[7] Maeno, F., Nakada, S., Yoshimoto, M., Shimano, T., Hokanishi, N., Zaennudin A., & Iguchi, M. M. (2019). A sequence of a plinian eruption preceded by dome destruction at Kelud Volcano, Indonesia, on February 13, 2014, revealed from tephra fallout and pyroclastic density current deposits. Journal of Volcanology and Geothermal Research, 382, 24-41.
[8] Suseno, H., Soehardjono, A., Wardana, I. G. N., & Rachmansyah, A. (2017). Suitability of Medium-K basaltic andesite pumice and scoria as coarse aggregates on structural lightweight concrete. International Journal of Engineering and Technology, 9, 4, 3318-3329.
[9] Hossain, K. M. A. (2004). Properties of volcanic scoria based lightweight concrete. Magazine of Concrete Research, 56, 2, 111-120.
[10] Hossain, K. M. A. (2004). Properties of volcanic pumice based cement and lightweight concrete. Cement and Concrete Research, 34, 283-291.
[11] Hossain, K. M. A., Ahmed, S., & Lachemi, M. (2011). Lightweight concrete incorporating pumice based blended cement and aggregate: mechanical and durability characteristics. Construction and Building Materials, 25, 1186-1195.
[12] Aslani, F. & Ma, G. (2018). Normal and high-strength lightweight self-compacting concrete incorporating perlite, scoria, and polystyrene aggregates at elevated temperatures. Journal of Materials in Civil Engineering, 30, 12, 04018328-1-19.
[13] Tchamdjou, W. H. J., Cherradi, T., Abidi, M. L., & Pareira-de-Oliveira, L. A. (2018). Mechanical properties of lightweight aggregates concrete made with Cameroonian volcanic scoria: Destructive and non-destructive characterization. Journal of Building Engineering, 16, 134-145.

[14] Shannag, M. J. (2011). Characteristics of lightweight concrete containing admixtures. Construction and Building Materials, 25, 658-662.
[15] Shannag, M. J., Charif, A., & Dghaither, S. (2014). Developing structural lightweight concrete using volcanic scoria available in Saudi Arabia. Arabian Journal for Science and Engineering, 39(5), 3525-3534.
[16] Syaiful Islam, A. B. M., Al-Kutti, W., Nasir, M., Alharbi, F. S., & Alsaidan, M. N. (2018). Development of lightweight concrete using Saudi scoria aggregate: A preliminary study. Conference paper of Smart Cities Symposium 2018. Bahrain, Bahrain, paper #8005264349.
[17] Hossain, K. M. A., & Lachemi, M. (2007). Strength, durability and micro-structural aspect of high performance volcanic ash concrete. Cement and Concrete Research, 37, 759-766.
[18] Widodo, S., Satyarno, I., & Tujono, S. (2014). Experimental study on the potential use of pumice breccia as coarse aggregate in structural lightweight concrete. International Journal Sustainable Construction Engineering & Technology, 5, 1, 1-8.
[19] Al Naaymi, T. A. (2015). Assessment of pumice and scoria deposits in dhamar-rada' volcanic field SW-Yemen, as a pozzolanic materials and lightweight aggregates. International Journal of Innovative Science, Engineering & Technology, 2, 9, 386-402.
[20] Green, S. M. F., Brooke, N. J., MacSaveney, L. G., & Ingham, J. M. (2011). Mixture design development and performance verification of structural lightweight pumice aggregate concrete. Journal of Materials in Civil Engineering, 23, 8, 1211-1219.
[21] Kabay, N. & Akoz, F. (2012). Effect of prewetting methods on some fresh and hardened properties of concrete with pumice aggregate. Cement and Concrete Composites, 34, 503-507.
[22] Harding, M. A. (1995). Structural lightweight aggregate concrete. The Aberdeen Group. Available in: www.concreteconstruction.net.
[23] ACI Committee 304. (2008). Placing concrete by pumping methods. ACI 304.2R-96(R2008). Detroit: American Concrete Institute, 2008.
[24] Shetty, M. S. (2006). Concrete technology: Theory and practice (7th ed). New Delhi: Chand & Company Ltd.
[25] Neville, A. M. (2011). Properties of concrete (5th ed). Harlow: Pearson Education, Ltd.
[26] Wight, J. K., & McGregor, J. G. (2012). Reinforced concrete, mechanics and design (9th ed). New Jersey: Prentice-Hall, International, Inc.
[27] Mehta, P. K., & Monteiro, P. J. M. (2014). Concrete: Microstructure, properties and materials (4th ed). New York: McGraw-Hill.
[28] Young, J. F., Mindess, S., Gray, R. J., & Bentur, A. (2007). The science and technology of civil engineering materials. New Jersey: Prentice Hall.
[29] Badan Standardisasi Nasional. (1989). Spesifikasi bahan bangunan bagian A (Bahan bangunan bukan logam) (Indonesian version). SK SNI S-04-1989-F. Bandung: BSN.
[30] ASTM Committee C33/C33M. (2016). Standard specification for concrete aggregates. ASTM C33/C33M-16. West Conshohocken: ASTM International.
[31] ASTM Committee C127. (2012). Standard test method for density, relative density (specific gravity), and absorption of coarse aggregates. ASTM C127-12. West Conshohocken: ASTM International.
[32] ASTM Committee C535. (2016). Standard test method for resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles machine. ASTM C535-16. West Conshohocken: ASTM International.
[33] Badan Standardisasi Nasional. (2011). Cara uji kadar air total agregat dengan pengeringan (Indonesian version). SNI-1971-2011. Jakarta: BSN.
[34] ACI Committee 211.2. (2004). Standard practice for selecting proportion for structural lightweight aggregate concrete. ACI 211.2-98(R2004). Detroit: American Concrete Institute.
[35] ACI Committee 211.1. (2002). Standard practice for selecting proportion for normal, heavyweight, and mass concrete. ACI 211.1-91(R2002). Detroit: American Concrete Institute.
[36] Badan Standardisasi Nasional. (2019). Persyaratan beton struktural untuk bangunan gedung (Indonesian version). SNI 2847:2019. Jakarta: BSN.
[37] ASTM Committee C143/C143M. (2010). Standard test method for slump of hydraulic-cement concrete. ASTM C143/C143M-10. West Conshohocken: ASTM International.
[38] ASTM Committee C567/C567M. (2014). Standard test method for determining density of structural lightweight concrete. ASTM C567/C567M-14. West Conshohocken: ASTM International.
[39] ASTM Committee C39/C39M. (2016). Standard test method for compressive strength of cylindrical concrete specimens. ASTM C39/C39M-16. West Conshohocken: ASTM International.
[40] ASTM Committee C469/C469M. (2014). Standard test method for static modulus of elasticity and Poisson ratio of concrete in compression. ASTM C469/C469M-14. West Conshohocken: ASTM International.
[41] ASTM Committee C496/C496M. (2011). Standard test method for splitting tensile strength of cylindrical concrete specimens. ASTM C496/C496M-11. West Conshohocken: ASTM International.
[42] ASTM Committee C78/C78M. (2010). Standard test method for flexural strength of concrete (using simple beam with third-point loading). ASTM C78/C78M-10. West Conshohocken: ASTM International.

[43] ASTM Committee C330/C330M. (2017). Standard specification for lightweight aggregates for structural concrete. ASTM C330/C330M-17. West Conshohocken: ASTM International.
[44] Badan Standardisasi Nasional. (2002). Spesifikasi agregat ringan untuk beton ringan struktural (Indonesian version). SNI 03-2461-2002. Jakarta: BSN.
[45] Lau, I., Setunge, S., & Gamage, N. (2014). Properties of concrete using scoria lightweight aggregate concrete. Proceeding of 23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23). Byron Bay, Australia, 9-12 December 2014, 95-100.