Suitability of Medium-K Basaltic Andesite Pumice and Scoria as Coarse Aggregates on Structural Lightweight Concrete

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***Abstract*—This study presented an optimization of the suitability of medium-K basaltic andesite pumice and scoria as coarse aggregates on structural lightweight concrete. The testing results indicated that these pumice and scoria had a typical characteristic so that they were completely different from those existed previously. Both typical vesicular rocks also fulfilled the requirements of coarse lightweight aggregate. The mix designs of structural lightweight concrete for the specified compressive strengths yielded Portland-Pozzolan Cement (PPC) contents were relatively lower than the previous studies conducted. The property of fresh concrete tests showed that for the specified slump values, the lightweight concrete mixtures can achieved satisfactory workabilities. While the properties of hardened concrete tests showed that almost all equilbrium densities fulfilled the requirements, but three equilibrium densities of scoria lightweight concrete were slightly greater than the requirements so that they were classified as structural semi-lightweight concretes. In addition, the use of typical pumice and scoria as coarse aggregates on that concrete yielded a significant density reduction, ie. approximately 20 %. The compressive strength obtained in the tests conducted can achieved those specified in the mix designs however two pumice structural lightweight concretes did not achieve them. The ultimate strains and modulus of elasticities also remained in proportional values, while the splitting tensile strengths and modulus of ruptures were relatively low when compared with previous studies.**

Keywords-pumice, scoria, medium-K basaltic andesite, structural lightweight concrete

I. INTRODUCTION

Studies on structural lightweight concrete using pumice and scoria as a replacement for artificial lightweight aggregate have been carried out in recent years. Artificial lightweight aggregate is a highly profitable manufactory product in lightweight concrete technology. Beside its well-controlled quality, the density reduction of lightweight concrete utilizing this synthetical aggregate can reach about 28 % [29], thereby it affects the structural design results and decreases its overall costs. However, its production process is complicated, requires high thermal energy [21][23][29] and produces certainly air pollution thus the its product becomes expensive, less energy saving and less environmental friendly. Whereas, both volcanic lightweight aggregates above are abundant in nature so that they produce certain lightweight concretes that are cheaper, conserve energy and more environmental friendly. Furthermore, their applications as aggregate on lightweight concrete have been recommended by [1][6] and they can also be classified as structural lightweight concrete [2]. Unfortunately, their existences are only in certain regions, especially in volcanic regions with characteristics and qualities vary according to the location where both pyroclastic rocks are ejected. Pumice and scoria are glassy volcanic igneous rocks that have abundant vesicular textures [22]. These vesicular textures are composed of vesicles that are cavities in that extrutive rock and formed by gas bubbles trapped when the gases rich lava solidifies [43]. Pumice usually has a rhiolytic composition, light-colored, containing high microvesicles with very thin bubble walls, composed of glassy amorphous structures and its specific gravity is lower than one so that it floats initially on water [50][53]. Scoria usually has a basaltic to an andesitic composition, dark-colored, containing macrovesicles with thick bubble walls, composed of glassy fragments that may contain phenocryst and its specific gravity is greater than one thereby it sinks directly on water [51][54].

Saveral vesicular rocks that were utilized as aggregates of lightweight concrete in previous studies were, scoria from Saudi Arabia [28][37], pumice and scoria from Turkey [30][31][34][35][39], pumice and scoria from Papua New Guinea [32][33][38], pumice from New Zealand [36], pumice from Iran [41], scoria from Australia [45], pumice breccia from Central Java Indonesia [46]. Experimental observations of those studies showed that lightweight concretes obtained can be categorized as structural lightweight concretes with considering certain treatments. Furthermore, these previous studies yielded various physical and mechanical characteristics for concrete mix proportions determined by trial method or mix design method. These were due to the various characteristics or qualities of the coarse lightweight aggregates that were mentioned previously. Saveral studies also presented other applications, such as pumice from Lombok island Indonesia was used for self compacted fiber lightweight concretes [40], pumice from Japan was used as buffer materials to protect the main structure of the check dams [48] and commercial pumice was used for pervious concretes in Thailand [42].

The treatments mentioned above, may include additions of chemical water reducer or mineral admixtures and saveral kind prewetting methods that applied on coarse aggregates. The prewetting methods, such as sprinkling, conventional presoaking or vacuum presoaking are used to reduce the high absorption and high absorption rate of coarse aggregates due to its high porosity [24][29][39]. The use of the chemical water reducer admixture aims to improve the workability at low water-cement ratio in order to the compressive strength remains high [21]. While, the use of mineral admixtures, such as industrial by-product or fine powder pumice and scoria aim to improve workability, to reduce cement content and to optimize the cement hydration [23]. Since the aggregates occupy the largest portion of the total volume of concrete [21][23], then variations of aggregate characteristics and its qualities may also lead to variations in the characteristics of the concrete obtained. The high absorption of pumice and scoria aggregates will increase water requirement in the concrete mixture, the water-cement ratio also increase thereby the compressive strengths decrease significantly. Therefore, the cement contents must be increased when it wants a proportional compressive strength so that its unit price becomes more expensive. Similarly, the additions of saveral admixtures or prewetting methods will increase the cost and also prolong the production process.

Kelud volcano is an active stratovolcano with an explosive eruption located in the southern East Java Indonesia, and is one of volcanic belt of the southeastern Pacific Ring of Fire [49]. In the 1990 eruption, it produced medium-K basaltic andesite pumice and scoria simultaneously about 120 million cubic meters. Both volcanic products differed only in color but they had similar chemical, mineralogical and texture compositions, while their specific gravities were greater than water [25]. Similary, these eruption products also had similar characteristics with those in previous years [52]. Until now, the variants of these abundant typical vesicular rocks have not been explored optimally, especially for lightweight aggregate concrete and they was only used for landfills or continue shallow foundations. During this time, the eruption product exploited in large scale was only sand so that it threatens the stability of check dams and causes environmental damage. Therefore, it is necessary to empower them thereby they have a significant added value as local construction materials and at the same time, it saves the environment from the more severe damage.

The characteristics of pumice and scoria from Kelud volcano described by [25], showed that the composition of both was a combination of basalt and andesite. The content of silica and iron oxide were almost similar and clearly different from commercial pumice [26] or pumice and scoria from Papua New Guinea [32][33] or those from Yemen [47][55]. Pumice was light gray, while scoria was dark-colored and their vesicles were separated by the thin bubble walls. Their groundmasses were almost entirely glassy amorphous and each contained phenochrist assemblage of plagioclase, orthopyroxen, clinopyroxen and magnetite. Finally, those distinctions gave precisely a typical characteristic of both vesicular rocks so that it can be said to be completely different from the common pumice and scoria as defined previously.

Initial previous study was only conducted on the typical scoria and the results indicated that this typical vesicular rock can be used as coarse lightweight aggregate, however the structural lightweight concretes obtained were less satisfactory [44]. Although their dried densities fulfilled the requirements but the compressive strengths obtained were relatively low. In addition, there were also some other lacks in this study, such as the proportions of concrete mix were only determined by trial method, the slump values specified were too high, and the coarse aggregate grading were less satisfactory. Therefore, this study needed to be improved and developed more accurately so that it produced more effective and efficient structural lightweight concretes. Considering the similar characteristics between the pumice and scoria mentioned above, the typical pumice may also produced structural lightweight concrete that did not vary much with scoria. Thus the production of lightweight concrete became more practical because it was not necessary to mix between the pumice and scoria aggregates which usually have distinctly different characteristics as performed by [35]. Field observations showed that the typical pumice and scoria were highly potential for coarse lightweight aggregates with varying fragmental sizes. Their deposits are abundant and spread out evenly on the surface of the lava catchment areas or check dams thereby it is easy and inexpensive to explore. For coarse aggregate purposes, it can be collected cobble sizes, eg (100-250) mm in order to make them easier to process either manually or by using stone crusher.

The objective of this study was to optimize the suitability of medium-K basaltic andesite pumice and scoria as coarse aggregates on structural lightweight concrete practically and accurately. In this study, experimental observations of rock and coarse aggregates characteristics, property of fresh concrete and properties of hardened concrete were performed to show the accurate suitability of both vesicular rocks. The mix proportion of structural lightweight concrete were calculated more precisely based on the material characteristics using two mix design methods as presented by ACI 211.2-98 (R2004) [3]. It can be pointed out that the different characteristics of both coarse lightweight aggregates reviewed by above literature, may result a different mix proportions of structural lightweight concrete that also differ from previous studies obtained. In addition, typical pumice and scoria used as coarse aggregates were given presoaking with shorter time in order to the production process becomes faster. Portland Ordinary Cement (OPC) was replaced by Portland-Pozzolan Cement (PPC) commercialized widely in the Indonesian local market, so that the concrete production became more practical because it did not need to add mineral admixtures or pumice and scoria fine powders. Similarly, chemical water reducer admixtures were also not used in order to keep their low production costs.

II. EXPERIMENTAL PROGRAMS

The experimental programs conducted were divided into five groups which included materials, investigation on properties of intact rock cores and coarse aggregates, mix proportions for structural lightweight concrete, investigation on property of fresh lightweight concrete and investigations on properties of hardened concrete.

A. Materials

Medium-K basaltic andesitic pumice and scoria in cobbles size (100-250) mm were collected from check dams of Badak and Putih rivers in the southern slope of the volcano. Some of the samples were drilled into intact rock core specimens and their remaining were crushed into four different particle sizes of coarse aggregates with 19 mm maximum particle size. The retained weight of these four fractions consisted of 43 % on 12.5 mm sieve, 28 % on 9.5 mm sieve, 27 % on a No. 4 sieve and 2 % on No. 8 sieve, respectively. This designed grading fulfilled the requirement of lightweight aggregate according to ASTM C330-04 [6] with fine modulus was 6.69. The loss on ignition of pumice and scoria were 0.08 % and 0.26 % [25], respectively, thus they fulfilled the requirements, ie not exceeding 5% [6]. The normalweight aggregat of commercial local crushed stone were used as a control with similar grading corresponded the preceding requirement. All coarse aggregates were washed and dried so that they were relatively clean and free from deleterious substances. Photographs and zoom in the surfaces of the medium-K basaltic andesite pumice and scoria were presented in Figure 1 below. Fine aggregate was light sand river with 4.5 mm maximum particle size and grading according to ASTM C330-04 [6] with fine modulus was 2.61. Physical characteristic tests of fine aggregate was performed according to ASTM C 128-01 [8], the results were mean values that consisted of loose, oven dry density of 1464 kg/m^3, bulk specific gravity ofs 2.53, 24 hours absorption of 1.77 % and clay lump of 2.42 %, respectively. Portland-Pozzolan Cement (PPC) used was in accordance with ASTM C 595-03 [17] with specific gravity of 3.15, while clean water for drinking was used in all concrete mixtures.

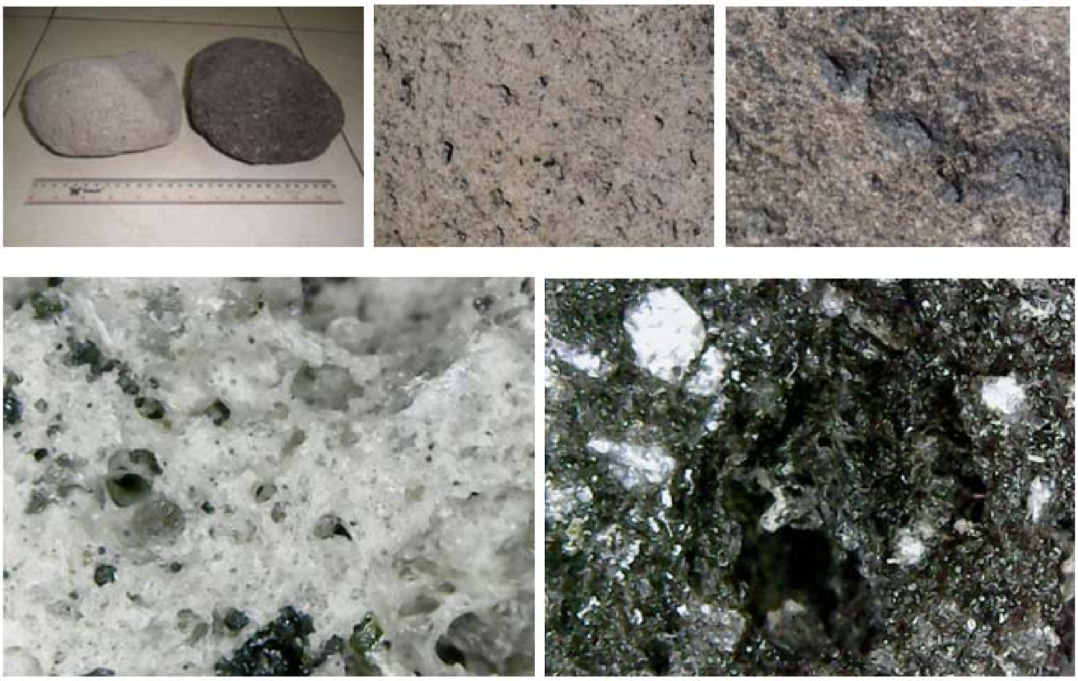

Fig. 1. Photograph and zoom in the surface of the medium-K basaltic andesite pumice and scoria

B. Investigation on Properties of Intact Rock Cores and Coarse Aggregates

Pumice and scoria unconfined compressive strength tests were carried out according to ASTM D 2938-95 (R2002) [18]. Intact rock core specimens were cylinders with 50 mm in diameter, (90-120) mm in length, and drilled by core drilling machine, while the results constituted a mean value of 10 specimens. The physical characteristic of coarse aggregates tests were conducted in accordance with ASTM C 127-01 [7] and the results were the mean value of 5 specimens. Due to its high porosity, observations were also performed on 1 hour to 96 hours absorption so that their estimated maximum absorption and the absorption rate can be obtained accurately. The tests for resistance to degradation of coarse aggregates by abrasion in Los Angelos machines was conducted according to ASTM C 131-03 [10], and for aggregate impact value were conducted in accordance with BS 812-112 [19], while the results were the mean value of 5 specimens. The comparison of properties of the coarse aggregates manufactured from pumice, scoria and crushed stone are reported in Table I, while its absorption from 1 hour to 96 hours are presented in Figure 1. From these graphs, the absorptions of 96 hours can be considered as their maximum values, so the absorption of 1 hour for pumice and scoria reached approximately 74 % and 71 %, while the absorption of 24 hours reached approximately 82 % and 80 %. Thus it can be concluded that the initial absorption rate of both lightweight aggregates were relatively high, but it did not differ significantly in subsequent hours.

TABLE I Testing Result of Characteristis of Three Aggregate Types

No	**Characteristics**	**Aggregate Types**		
		Pumice	**Scoria**	**Crushed stone**
1	Intact Rock Core Density (kg/m^3)	1.31	1.52	-
2	Compressive Strength (MPa)	5.69	6.22	-
3	Loose, Oven Dry Density (kg/m^3)	758.4	850.12	1383.83
4	Bulk Specific Gravity	1.52	1.72	2.7
5	Absorption of 1 hour (%)	14.16	10.89	-
6	Absorption of 24 hours (%)	16.12	12.27	1.5
7	Absorption 96 hours (%)	19.17	15.26	-
8	Abrassion by LA Machine (%)	59.49	58.5	18.23
9	Aggregate Impact Value (%)	53.25	48.37	9.8

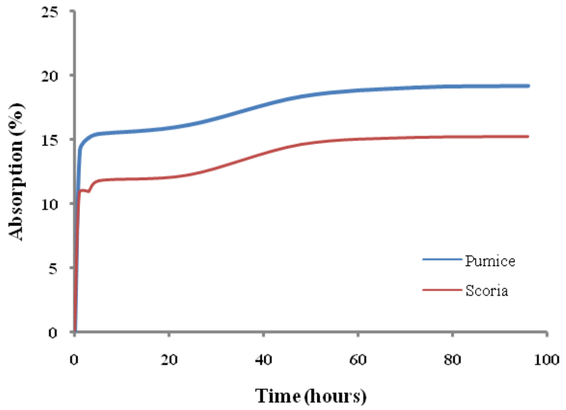

Fig. 2. Testing result of absorption of the coarse aggregates

C. *Mix Proportions for Structural Lightweight Concrete*

To optimize the suitability of typical pumice and scoria from Kelud volcano as coarse lightweight aggregates (CA), two groups of structural lightweight concrete mix proportions were designed with two methods presented by ACI 211.2-98 (R2004) [3]. Group A was designed using gravity method with an assumption that the coarse aggregate absorptions can be determined precisely at 96 hours, and the coarse aggregate factor obtained was 0.719 m^3/m^3. Group B was designed using volumetric method with a coarse aggregate factor specified was 0.68 m^3/m^3. Each group consisted of five mix proportions with compressive strengths ranged (18-30) MPa and based on average compressive strengths in accordance with Indonesian Standard SNI 2847:2013 [5]. Group C was a normalweight concrete as control designed according to ACI 211.1-91 (R2002) [4] with commercial local crushed stone as the coarse aggregate. All mix proportions were based on physical characteristics obtained from previous material tests. In all mix designs, the slump values were determined between (60-70) mm with a specified air content of 3 %. The detailed of the mix proportions of structural lighweightt concrete and controls are presented in Table II.

TABLE II Detail of the Mix Proportions of Structural Lightweight Concrete and Control

Group	**Type of Coarse Aggregates**	**Mixture Labels**	**Specified Compressive Strengths (MPa)**	**Average Compressive Strengths (MPa)**	**Mix Proportions per 1 m^3 volume (kg)**			
					PPC	**Dry Sand**	**Wet CA**	**Water**
A	Pumice	PLCAF1	18	25.0	305.81	703.82	634.93	190.00
		PLCAF2	20	27.0	322.64	687.22	631.18	201.76
		PLCAF3	25	33.3	377.32	633.30	625.94	190.51
		PLCAF4	30	38.3	423.56	587.70	626.69	190.62
		PLCAF5	32	40.3	443.97	567.57	626.30	193.95
	Scoria	SLCAF1	18	25.0	305.81	727.34	681.41	204.45
		SLCAF2	20	27.0	322.64	711.40	703.90	181.83
		SLCAF3	25	33.3	377.32	657.47	699.40	182.57
		SLCAF4	30	38.3	423.56	611.78	693.91	199.48
		SLCAF5	32	40.3	443.97	591.74	684.25	190.28
B	Pumice	PLCBF1	18	25.0	324.00	666.73	604.95	182.90
		PLCBF2	20	27.0	340.00	658.27	600.45	183.68
		PLCBF3	25	33.3	390.00	631.79	604.41	183.81
		PLCBF4	30	38.3	430.00	610.62	604.41	194.19
		PLCBF5	32	40.3	446.00	602.14	604.41	189.08
	Scoria	SLCBF1	18	25.0	324.00	666.73	658.09	174.58
		SLCBF2	20	27.0	340.00	658.27	654.41	181.39
		SLCBF3	25	33.3	390.00	631.79	641.61	189.90
		SLCBF4	30	38.3	430.00	610.62	653.28	191.45
		SLCBF5	32	40.3	446.00	602.14	649.64	195.86
C	Crushed stone	CNWF3	25	33.3	377.32	779.61	987.77	200.30

D. Investigation on Properties of Fresh Lightweight Concrete

Before concrete mixing, pumice and scoria coarse aggregates were treated by presoaking for 16 hours then dried their surfaces, while normalweight aggregate was only washed and dried their surfaces. The determinated presoaking duration was based on their high absorption rate, especially at 1 hour absorption as stated previously. Concrete mixing was conducted by a small mixer of 150 kg capacities. The slump tests were carried out in accordance with ASTM C 143M-03 [11], and the results were the mean value of three specimens and are reported in Table III.

TABLE IIII Testing Results of Slump Value and Density

Group	Mixture Label	Slump (mm)	Density (kg/m^3)				
			1 day	28 days	90 days	Oven Dry	Equilirium
A	PLCAF1	60	1939.08	1899.93	1847.36	1814.27	1864.27
	PLCAF2	68	1943.55	1908.35	1853.91	1817.56	1867.56
	PLCAF3	66	1948.45	1918.76	1859.57	1823.68	1873.68
	PLCAF4	68	1954.78	1923.58	1867.78	1829.76	1879.76
	PLCAF5	65	1956.68	1931.43	1874.54	1830.32	1880.32
	SLCAF1	60	2042.24	1943.68	1871.32	1830.88	1880.88
	SLCAF2	60	2050.99	1958.54	1885.76	1842.68	1892.68
	SLCAF3	61	2073.23	1984.87	1892.87	1859.83	1909.83
	SLCAF4	65	2081.90	2010.24	1912.45	1870.03	1920.03
	SLCAF5	63	2090.67	2021.66	1920.43	1878.51	1928.51
B	PLCBF1	62	1941.00	1907.28	1851.39	1816.34	1866.34
	PLCBF2	64	1944.00	1917.64	1860.84	1819.98	1869.98
	PLCBF3	60	1949.00	1921.40	1871.36	1828.30	1878.30
	PLCBF4	60	1955.49	1932.08	1880.30	1835.24	1885.24
	PLCBF5	63	1958.78	1940.33	1889.77	1842.14	1892.14
	SLCBF1	62	2049.89	1945.26	1878.23	1836.99	1886.99
	SLCBF2	60	2056.47	1956.34	1890.65	1846.77	1896.77
	SLCBF3	60	2072.51	1985.05	1902.66	1861.36	1911.36
	SLCBF4	61	2085.76	2011.42	1915.02	1872.43	1922.43
	SLCBF5	68	2093.56	2028.11	1927.88	1881.77	1931.77
C	CNWF3	60	2444.46	2385.66	2383.78	-	-

E. *Investigation on Properties of Hardened Lightweight Concrete*

Two types of specimens were used for this investigation, 150x300 mm cylinder for testings of compressive strength, modulus of elasticity, splitting tensile strength, and density while 100x100x400 mm prism for testing of flexural tensile strength (modulus of rupture). All specimens were internally compacted using a vibrating 12 mm diameter of steel rod, whereas demolding of all specimens were carried out after 24 hours casting. Curing specimens for mechanical characteristic tests were conducted by covering all specimens within wet burlaps for 7 days and then stored in a dry room until testing time at 28 days. While curing and testing for equilibriun density were carried out in accordance with ASTM C567-00 [12]. Compressive strength and modulus of elasticity tests were conducted according to ASTM C 39M-03 [13] and ASTM C 39M-03 [14], respectively. Splitting tensile strength tests were carried out according to ASTM C 496M-04[15], while the modulus of rupture tests were carried out according to ASTM C78-02 [16]. The results of density, splitting tensile strength and the modulus of rupture were the mean values of three specimens, whereas the results of compressive strength and modulus of elasticity were the mean values of five specimens. All testing results are presented in Table IV.

TABLE IV Testing Results of Mechanical Characteristic

Group	**Mixture Label**	**Compressive Strength (MPa)**	**Ultimate Strain (mm/mm)**	**Modulus of Elasticity (MPa)**	**Spliting Tensile Strength (MPa)**	**Modulus of Rupture (MPa)**
A	PLCAF1	20.96	0.00323	10245.81	1.89	2.39
	PLCAF2	22.24	0.00321	12506.02	2.13	2.63
	PLCAF3	27.87	0.00321	13778.36	2.53	3.35
	PLCAF4	31.01	0.00320	14775.61	2.88	3.58
	PLCAF5	30.17	0.00321	14653.60	2.79	3.47
	SLCAF1	21.71	0.00322	11049.99	1.95	2.50
	SLCAF2	23.41	0.00320	12874.75	2.15	2.79
	SLCAF3	28.10	0.00320	14103.20	2.62	3.34
	SLCAF4	32.36	0.00319	14846.03	2.92	3.83
	SLCAF5	34.11	0.00318	15433.23	3.12	3.91
B	PLCBF1	21.17	0.00322	10385.39	1.91	2.42
	PLCBF2	22.63	0.00321	12823.43	2.15	2.76
	PLCBF3	27.89	0.00321	13944.25	2.56	3.39
	PLCBF4	31.05	0.00320	14825.20	2.93	3.60
	PLCBF5	30.69	0.00320	14742.52	2.83	3.48
	SLCBF1	21.92	0.00321	11640.92	1.97	2.53
	SLCBF2	24.07	0.00320	12914.72	2.19	2.82
	SLCBF3	28.48	0.00319	14590.88	2.64	3.37
	SLCBF4	32.92	0.00318	15295.41	3.04	3.87
	SLCBF5	34.16	0.00318	15559.75	3.14	3.93
C	CNWF3	28.85	0.0029	18629.76	3.11	4.04

III. RESULTS AND DISCUSSION

A. *Properties of Intact Rock Cores and Coarse Aggregates*

Table I showed that the density of intact rock cores of the typical pumice and scoria from Kelud volcano were 1.31 kg/m^3 and 1.52 kg/m^3, respectively, these results did not show a significant difference between them. The pumice compressive strength was 5.62 MPa, which was greater than commercial pumice in Indonesia, ie (2.0-3.0) MPa [27], but lower than pumice from Turkey, ie (24.2±1.5) MPa [34]. While the scoria compressive strength was 6.99 MPa, which was lower than scoria from Turkey, ie (28.3±5.7) MPa [30], but greater than scoria from Yemen, ie (5.53-6.36) MPa [55] and scoria from Saudi Arabia, ie 4.50 MPa [37]. Both compressive strengths were considerably lower than andesite and basalt in Indonesia, ie (60-240) MPa with specific gravity ranged (2.3-2.7) [27]. These low compressive strengths were due to their high porosity and glassy amorphous microstructure that dominated the groundmasses. Furthermore, these were also indicated by their high LA abrasions, ie 59.49 % for pumice aggregate and 58.50 % for scoria aggregate, respectively, and their high aggregate impact values, ie 53.25 % and 48.37 %. These results were considerably greater than the specified requirements, ie 20 % [10][19], and also from crushed stone aggregate as control, ie 18.32 % and 9.80 %.

The loose, oven dry density of typical pumice and scoria coarse aggregates were 758.40 kg/m^3 and 850.12 kg/m^3, respectively, these results fulfilled the coarse lightweight aggregate requirements presented by [6]. This typical pumice density were greater than the density of those from Turkey, ie (358-442) kg/m^3 [35], from New Zealand, ie (560-630) kg/m^3 [36], and from Iran, ie 600 kg/m^3 [41], similar to the density of those from Kenya, ie 720 kg/m^3 [26], from Papua New Guinea, ie 763 kg/m^3 [32], from Bantul Indonesia, ie 760 kg/m^3 [46] and from Yemen, 780 kg/m^3 [47], but lower than the density of pumice from Turkey, ie (870±55) kg/m^3 [34]. While the typical scoria density was greater than the similar scoria in the initial previous study, ie 756.15 kg/m^3 [44], similar to the density of scoria from Turkey, ie (731-859) kg/m^3 [35], but lower than the density of those from Tanzania, ie 1040 kg/m^3 [26], from Turkey, ie (1518±43) kg/m^3 [30], from Papua New Guinea, ie 1150 kg/m^3 [33], from Saudi Arabia, ie (965- 996) kg/m^3 [37], and from Yemen, ie 917 kg/m^3 [47]. The bulk spesific gravity of both coarse lightweight aggregates were 1.52 and 1.72, respectively, these results fulfilled the specified requirements, ie between (1.0-1.8) [9], while for scoria, this was greater than the initial previous study, ie 1.52 [44]. These results were considerably lower than the control, ie 2.7, and greater than one thus both sink directly on water as stated previously by [25]. Thus all results obtained were completely different from those of previous studies mentioned above or common pumice and scoria defined previously. Furthermore, when both coarse lightweight aggregates are used in lightweight concrete mixtures, the possibility of segregation may become relatively small.

The absorption of 24 hours of the typical pumice and scoria coarse aggregates were 16.12 % and 12.27 %, respectively, whereas maximum absorptions were considered to be achieved at 96 hours as described above, ie 19.17 % and 15.26 %, respectively. These results were lower than the usual requirements used, ie 20 % [9] and were also considerably lower than the control, ie 1.5 %. These results were also lower than the coarse aggregate absorption of those from Kenya, ie 34.34 % [26], from Papua New Guinea, ie 37 % [32], from Turkey, ie (23±4) % [34], from New Zealand, ie (54.3-56.3) % [36], from Iran, ie 36.84 % [41], from Lombok Indonesia, ie 84.57 % [40], from Yemen, ie 31.23 % [47], and from Japan, ie (82.8-83.3) % [48]. While this scoria coarse aggregate absorption was lower than the similar scoria in the initial previous study, ie 17.86 % [44], and greater than the coarse aggregate absorption of scoria from Saudi Arabia, ie 6.9 % [37], but lower than the coarse aggregate absorption of those from Tanzania, ie 25.3 % [26], from Turkey , ie (17±3) % [30], from Papua New Guinea, ie 35.6 % [33], and from Yemen, ie 28.4 % [47]. Similarly, the observed results of absorption rate were also high so they can be considered to shorten the presoaking time of coarse lightweight aggregates in order to faster production process than the previous studies conducted by [32][33][38][46].

B. Mix Proportions for Structural Lightweight Concrete

The difference of pumice and scoria coarse lightweight aggregate characteristics presented previously, yielded also different concrete mix proportions from the previous study using similar mix design methods, such as study conducted by [38], or other studies that used trial mix methods, such as studies conducted by [32][33][34][41][47]. Table II showed that the mix proportions of typical pumice and scoria lightweight concretes were considerably different and their PPC contents obtained per m^3 of concrete volume were relatively lower than the results of previous studies. For the specified compressive strengths (18-32) MPa, the PPC contents of Group A for both lightweight aggregates ranged (305.81-443.97) kg, while for Group B ranged (324-446 kg). These results indicated that the PPC content of Group B was approximately (0.5-6) % greater than Group A thus it did not differ significantly. Similarly, the content of other ingredients in both groups were not also different significantly.

The OPC contents per m^3 of concrete volume of structural lightweight concrete from Papua New Guinean pumice were (370/442) kg with cylinder compressive strengths of (22/27) MPa [38]. The structural lightweight concrete from Papua New Guinean pumice using trial mix method with OPC contents of (430/490 kg) yielded the cylindrical compressive strengths of (22/24) MPa [32]. The structural lightweight concrete from Papua New Guinean scoria using a trial mix method with OPC contents of (425/490) kg yielded the cylinder compressive strengths of (18/22) MPa [33]. The structural lightweight concrete from Iranian pumice using trial mix method with type II PC contens of (350-500) kg yielded the cylinder compressive strengths of (20.4-30.2) MPa [41]. The structural lightweight concretes from Yamanian pumice and scoria using trial mix method with Type II PC content of 500 kg yielded the cube compressive strengths of 29 MPa and 37 MPa [47]. The structural lightweight concrete from Turkish pumice using trial mix method with OPC contents of (320-440) kg and low slump values, ie (35-40) mm yielded the cylindrical compressive strengths of (19.17-26.09) MPa [34]. Thus it can be showed that structural lightweight concretes obtained from the typical pumice and scoria as coarse aggregates in this study, produced relatively low PPC contents and then they can be more efficient.

C. Properties of Fresh Lightweight Concrete

Table III showed that the slump values of typical pumice and scoria lightweight concretes for Group A and B, ranged (60-68 mm), while for the control Group C was 60 mm. All of these testing results fulfilled the specified values in the previous mix designs, ie (60-70) mm. At these slump values, all concrete mixtures showed satisfactory workabilities, no segregation or excessive bleeding. The slump values of both lightweight concrete were almost similar to those conducted by [32], ie (52/60) mm, [33], ie (55/64) mm, [38], ie 60 mm, and [41], ie (50-60) mm, respectively.

D. Properties of Hardened Lightweight Concrete

Table III also showed the variation of density at 1 day, 28 days, 90 days, oven dry density and equilibrium density for each group and three coarse aggregates types. The equilibrium density of typical pumice lightweight concrete for Group A ranged (1864.27-1880.32) kg/m^3, while for Group B ranged (1866.34-1892.14) kg/m^3. The equilibrium density of the typical scoria lightweight concrete for Group A (SLCAF1-SLCAF4) ranged (1880.88-1920.03) kg/m^3, while for Group B (SLCBF1-SLCBF3) ranged (1886.99-1911.36) kg/m^3. These results fulfilled the requirements of structural lightweight concrete as defined by [1]. The equilibrium density of scoria lightweight concrete for Group A (SLCAF5) was 1928.51 kg/m^3, while for Group B (SLCBF4 and SLCBF5) were 1922.43 kg/m^3 and 1931.77 kg/m^3. These results were greater than the requirements of structural lightweight concrete [1] then they may be classified as structural semi-lightweight concrete [33]. The equilibrium densities of Groups A and B or for coarse lightweight aggregate types in group did not vary significantly, ie below 1 % and 3%, respectively. Comparing to the control, the density reduction for pumice lightweight concrete of Group A and B were approximately 22 % and 21 %, while for scoria lightweight concrete were approximately 20 %. These reductions were lower than lightweight concretes produced by pumice lightweight aggregate from Papua New Guinea, ie 26 % [32], and from Iran, ie 25 % [41]. These reductions were also lower than those produced by scoria lightweight aggregate from Turkey, ie 20 % [30][31], and from Papua New Guinea, ie 26 % [33].

The equilibrium density of typical pumice and scoria lightweight concretes in Groups A and B, did not increase significantly for increasing in the specified compressive strengths. The equilbrium densities were below 1 % lower than 90 days densities, either for Group A or Group B or pumice and scoria lightweight aggregates. Thus, the mix design methods and coarse lightweight aggregate types given did not differ significantly so that the approximate equilibrium density could be used appropriately. 28 days density of Group A and B were approximately (3-5) % greater than 90 days density, while for the control was only approximately 0.08 %. This difference was caused by the high moisture of both speciments at 28 days testing time that due to coarse aggregates presoaking before mixing. Furthermore, the oven dry density of Group A as well as Group B ranged (1814.27-1881.77) kg/m^3, these were lower than 2000 kg/m^3, so they can also be classified as lightweight concrete according to the requirements presented by [20].

The compressive strength of typical pumice lightweight concretes obtained for 4 mix proportions in Groups A and B ranged (20.96-31.01) MPa and (21.17-31.05) MPa, respectively, these were approximately (3-15) % greater than the specified compressive strengths, ie (18-30) MPa. However, the proportion of the fifth mix proportions (PLCAF5 and PLCBF5) can not reached the specified compressive strength, ie 32 MPa, these may be caused by its low compressive strength of pumice so that the coarse lightweight aggregates crushed first before the cement paste. The compressive strength of typical scoria lightweight concretes obtained for all mix proportions in Groups A and B ranged (21.71-34.11) MPa and (21.92-34.16) MPa, respectively, these were approximately (6-18) % greater than the specified compressive strengths mentioned above. The compressive strength of typical pumice and scoria lightweight concrete in Group A did not differ significantly with Group B, ie just below 2 %. The compressive strength of normalweight concrete obtained as the control was 28.85 MPa, this was approximately 13 % greater than the specified compressive strength, ie 25 MPa. Furthermore, this result was approximately 3 % and 2 %, respectively, larger than the typical pumice and skoria lightweight concretes in Group A and B. For comparison, the compressive strengths of pumice and scoria lightweight concrete from Papua New Guinea were (18/22) MPa with densities of (1831/1852) kg/m^3 and (22.24) MPa with densities of (1845/1875) kg/m^3 [32][33].

The ultimate strain of typical pumice lightweight concretes obtained for all mix proportions in Groups A and B ranged (0.00323-0.00321) mm/mm and (0.00322-0.00320) mm/mm, respectively. While for the typical scoria lightweight concretes ranged (0.00322-0.00318) mm/mm and (0.00321-0.00318) mm/mm, respectively. These results decreased no significantly for increasing the compressive strength obtained, similarly, there was also a significant decrease in the ultimate strains between Group A and B. These lightweight concrete ultimate strains were slightly greater than the control, ie 0.0029, and so that the ultimate strain approach given by [1], ie 0.003 for structural lightweight concrete is completely acceptable.

The modulus of elasticity of typical pumice lightweight concretes obtained for 4 mix proportions in Groups A and B ranged (10245.81-14775.61) MPa and (10385.39-14825.20) MPa, respectively. While the fifth mix proportions (PLCAF5 and PLCBF5) were 14653.60 MPa and 14742.52 MPa. The modulus of elasticity of typical scoria lightweight concretes obtained for all mix proportions in Groups A and B ranged (11049.99-15433.23) MPa and (11640.92-15559.75) MPa, respectively. These results increased significantly for increasing of the specified compressive strengths. However, these increases were not significant when they reviewed on inter groups or between coarse aggregate types. The modulus of elasticity of typical pumice lightweight concretes for Groups A and B were approximately 74 % and 76 % of the control, ie 18629.76 MPa, whereas for the typical scoria lightweight concretes were approximately 75 % and 76 %. These modulus of elasticity were not different comparing to the pumice lightweight concrete from Papua New Guinea, ie (10000/10500) MPa with compressive strengths of (18/22) MPa [32] or (8500/10500) MPa with compressive strengths of (22/27) MPa [38] and scoria lightweight concretes from Papua New Guinea, ie (12500/12750) MPa with compressive strengths of (22/24) MPa [33].

The splitting tensile strength of typical pumice lightweight concretes obtained for 4 mix proportions in Groups A and B ranged (1.89-2.88) MPa and (1.90-2.89) MPa, respectively, while the fifth mix proportions (PLCAF5 and PLCBF5) were 2.79 MPa and 2.83 MPa. The splitting tensile strength of typical scoria lightweight concretes obtained for all mix proportions ranged (1.95-3.12) MPa and (1.97-3.14) MPa, respectively. These results were relatively low, ie approximately 9 % of its compressive strengths obtained, but these still fulfilled the requirements used, ie 2 MPa [9]. The splitting tensile strength of control was 3.11 MPa and this was approximately 11 % of its compressive strength obtained. While the splitting tensile strength of typical pumice and scoria lightweight concretes in Goup A and B were approximately 82 % and 85 % of the control. The low splitting tensile strengths may be caused by the condition of both lightweight concrete specimens that were still damp at the testing time due to the coarse aggregate presoaking before mixing. The splitting tensile strengths of typical pumice lightweight concretes were almost similar to the pumice lightweight concrete from Papua New Guinea, ie (2.2/2.6) MPa with compressive strengths of (18/22) MPa [32], whereas the typical scoria lightweight concretes had also similar splitting tensile strengths with scoria lightweight concrete from Papua New Guinea, ie (2.47/2.64) MPa with compressive strengths of (22/24) MPa [33].

The modulus of rupture of pumice lightweight concretes obtained for 4 mix proportions in Groups A and B ranged (2.39-3.58) MPa and (2.42-3.60) MPa, respectively, while for the proportion of the fifth mix proportions (PLCAF5 and PLCBF5) were 3.47 MPa and 3.48 MPa, respectively. The modulus of rupture of typical scoria lightweight concretes obtained for all mix proportions ranged (2.50-3.91) MPa and (2.53-3.93) MPa, respectively. These results were also relatively low, ie approximately 12 % of the compressive strengths obtained. The modulus of rupture of the control was 4.04 MPa and this was approximately 14 % of its compressive strength. While the modulus of rupture of the typical pumice and scoria lightweight concretes in Goup A and B were approximately 83 % of the control. The low modulus of ruptures may be also caused by the damp lightweight concrete specimens as mentioned previously. The modulus of rupture of typical pumice lightweight concretes were lower than the pumice lightweight concrete from Turkey, ie (5.42-6.38) MPa with compressive strengths of (19.17-26.09) MPa [34], while the typical scoria lightweight concretes had also lower modulus of rupture than the scoria lightweigh concrete from Turkey, ie (6.7-6.8) MPa with compressive strengths of (28-29) MPa [31].

IV. CONCLUSIONS

This study proves that medium-K basaltic andesite pumice and scoria had the typical characteristics that were completely different from the common pumice and scoria or those in previous studies. This was also indicated by the experimental observation of physical and mechanical characteristics on intact rock cores or their coarse aggregates. Furthermore, the results were compared with the existed pumice and scoria in previous studies in order to show their different characteristics. Although some characteristics deviated from the requirements, however they fulfilled generally the coarse aggregate requirements so that their suitability as coarse aggregates on structural lightweight concrete can be guaranteed. The typical characteristic of pumice and scoria coarse aggregates yielded the mix proportions of structural lightweight concrete that were also different with previous studies conducted. The PPC content of both lightweight concrete mixtures obtained were relatively low so that they may reduce production costs.

The results of the property of fresh concrete indicated that for specified slump values, the typical pumice and scoria lightweight concrete mixtures can achieved satisfactory workabilities. Furthermore, although some characteristics deviated slightly, the results of the properties of hardened concrete indicated that the compressive strengths obtained in the tests can achieved their specified compressive strengths in the mix designs. Similarly, the equilibrium densities also fulfilled the structural lightweight concrete requirements, but some were classified as structural semi-lightweight concrete. Comparing to the normalweight concrete for the proportional compressive strength specified, both structural lightweight concretes had the density reductions of approximately 20 %. The ultimate strain and modulus of elasticity obtained remained proportionally, while the tensile strength and modulus of rupture were lower than the previous studies, but they still fulfilled the requirements. In general, the results of experimental observations showed that the use of typical pumice and scoria can be said to achieve its optimal suitability as coarse aggregates on structural lightweight concrete.

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