GREEN STRUCTURAL LIGHTWEIGHT CONCRETE UTILIZING MEDIUM-K BASALTIC ANDESITIC PUMICE AND SCORIA

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ABSTRACT

This study presented observations of the suitability of medium-K basaltic andesitic pumice and scoria as a coarse aggregate on structural lightweight concrete that was environmental friendly and energy saving. Testing results indicated that this typical pumice and scoria fulfilled the requirements as a coarse lightweight aggregate. The mix design of specified compressive strengths yielded a lower proportion of Portland Pozzolan Cement (PPC) than previous studies. Testing results of fresh concrete showed a satisfactory workability at determined slump values without segregation and excessive bleeding. Testing results of hardened concrete showed that the density reduction was about 20 %, but there was a density of scoria lightweight concrete that exceeded slightly the requirements. All compressive strengths complied with the requirement but there was a pumice lightweight concrete that did not reach the specified compressive strength. The modulus of elasticity and splitting tensile strength were relatively low compared to normalweight concrete as control, whereas drying shrinkage was lower than in previous studies.

Keywords: *green lightweight concrete, pumice, scoria, environmental friendly, energy saving*.

1. INTRODUCTION

Structural lightweight concrete is a concrete that uses a total lightweight aggregate or combination where the minimum compressive strength at 28 days is 17 MPa and the equilibrium density ranges (1120-1920) kg/m^3. While lightweight aggregate comprises coarse aggregate (CA) and fine aggregate (FA) with air dry densities are less than 880 kg/m^3 and 1120 kg/m^3, respectively. The coarse aggregate has an evenly porous texture so that it is light, hard, solid structure and can be either artificial or natural aggregate. The artificial lightweight aggregate is a patent and manufacturing product, one of which is derived from thermochemical sintering process of expanded natural material or industrial by-product. Whereas the natural lightweight aggregate is a volcanic eruption product, such as pumice and scoria.

The use of lightweight concrete is for structural elements such as beams, columns, plates, shear walls and thin shells either in high rise buildings, stadiums, bridge superstuctures, maritime structures and others. The production of lightweight structural concrete requires more careful accuracy and high quality control so that it is usually more widely used in precast and prestressed concrete elements. The porous character of coarse lightweight aggregate gives a typical characteristic of the lightweight concrete so that the density will decrease significantly. Comparing with normaweightl concrete, the self weight reduction is about 28%, therefore, it will affect the structural element design. Economically, the unit price of structural lightweight concrete is 20% more expensive than normalweight concrete [26], because of high cement consumption and also high price of artificial lightweight aggregates. However, the overall cost of structures will decrease significantly due to the self weight reduction which is usually dominant in structures.

Artificial lightweight aggregates were the most typical aggregate used in structural lightweight concrete and developed very widely. These synthetic aggregates are a patent product of particular enterprise with the trade name according to the base material used. One example is Leca (light expanded clay aggregate) from Sweden which is the product of sintering a fine clay paste with a slight lime in a rotating kiln and a temperature range (1100-1200) ^{o}C. During the combustion process, the paste will expand due to the presence of chemical decomposition gases trapped in the heat mass. Then after gradual cooling, porous aggregates will be formed with a hard and dense crystal structure and various particle sizes. The porosity in the groundmass is relatively high and distributed evenly so that the density decreases significantly.

The quality of artificial lightweight aggregates is very well controlled, but the production is quite complicated and requires high thermal energy so that the price becomes relatively expensive. These manufacturing process do not conserve energy and also produce air pollution due to the release of the remaining gases during sintering. Thus this product becomes less environmental friendly and does not support energy saving program. Another alternative use of lightweight aggregate is the utilization of volcanic lightweight aggregates such as pumice and scoriaproduced by the eruption of volcano. These volcanic aggregates are inexpensive because they are abundant in nature, especially in Indonesia and the most important thing is that these volcanic aggregates will produce green structural lightweight concretes that are more environmental friendly and energy saving. Pumice and scoria are volcanic igneous rocks that produced by explosive eruption of volcano with porous textures and amorphous glass structures and slight or no mineral crystals. Pumice is pale white with high porosity and light so that floating in the water at the beginning, while scoria is dark or black, porous, dense, hard with spesific gravity is greater than 1 so that submerged directly in water.

Several studies on the use of pumice and scoria lightweight concretes have been carried out in recent years, such as scoria from Saudi Arabia, pumice and scoria from Turkey, Pumice and scoria from Papua New Guinea, pumice from New Zealand, pumice from Iran, scoria from Australia, pumice breccia from Bantul Indonesia, pumice and scoria from Yemen. The results indicated that lightweight concretes obtained can be categorized as structural lightweight concrete with some type of prewetting of coarse aggregate or addition of mineral and chemical admixtures or fine powder of pumice or scoria as additives. These coarse aggregate prewetting were used to reduce the high absorption and high absorption rate due to the high porosity of lightweight aggregate. While the addition of admixtures and additives aims to improve the workability of concrete mixtures and optimize hydrations between cement and water. Other studies were pumice from Lombok Island Indonesia for self-compacted concrete, pumice from Japan as buffer material for protecting of main weir structures, and commercial pumice for porous concrete in Thailand.

Kelud volcano is an active strato volcano with an explosive eruption type located in southern East Java and one part of the volcanic belt of the Pacific Ring of Fire. In the 1990 eruption, this volcano produced medium-K basaltic andesitic pumice and scoria simultaneously about 120 million m^3, both of which differ only in color but the chemical composition, mineralogy and texture were similar, while their spesific gravity were also almost similar and larger than 1. The characteristics of this eruption product were also similar to eruptions that occurred in previous years. The chemical compositions showed that the silica content was almost similar so that they had similar chemical characteristics, ie intermediate (acid-base). The similarity of the characteristics mentioned above had given a typical characteristics of the two volcanic rocks so that they were different from those already present. Until now, these typical pumice and scoria had not been explored optimally, especially for lightweight aggregates. Initial previous study was only performed on scoria and the result indicated that this typical scoria can be used as coarse lightweight aggregate, but the result was less satisfactory because mix proportions of scoria lightweight concrete were only designed by trial and error method and need to be further improved and developed. Field observations showed that pumice was denser and harder while scoria was lighter than the existing types so that they were potential to be used as lightweight aggregates. The existence of both volcanic rocks was abundant on the southern slopes of the volcano and outspreaded on the surface of the lava catchment areas, thus it will be easy and inexpensive to explore.

The purpose of this study was to evaluate the suitability of typical pumice, to improve and develop the typical scoria from Kelud volcano as coarse aggregates on lightweight concrete so that both were more effective and efficient as local building materials. Practically, mix proportions of structural lightweight concretes were designed more accurately and based on raw materials available widely in the local market so that they were in accordance with local conditions. Ordinary Portland Cement (OPC) was replaced by Portland Pozzolan Cement (PPC) which was available widely in Indonesian market. Admixtures were not used in concrete mixtures while the accelerated aggregate presoaking was selected in order to obtain a faster concrete production. The distinctive characteristic of typical pumice and scoria may yield mix proportions of lightweight concrete that were different from previous studies because the aggregates occupy the total volume of the concrete. Similarly, the replacement of the cement type, the removal of the admixtures and the acceleration of the aggregate presoaking also differentiated with existing works previously. This research also added an insight of structural lightweight concrete utilizing pumice and scoria aggregates that are abundant in Indonesia but did not yet rapidly developed like other countries.

2. MATERIALS AND METHODS

2.1. Materials

The medium-K basaltic andesitic pumice and scoria were collected from check dams of the Badak and Putih Rivers on the southern slope of Kelud volcano in Blitar district. Both volcanic rocks were crushed in four distinct fractions of coarse lightweight aggregates with 19 mm maximum particle size. These four coarse aggregate fractions were determined based on the percentage of retained weight on the sieve in accordance with SNI 03-2461-2002 [39] or ASTM C 330-04 [9]. The grading of this coarse aggregates consisted of 43 % by weight on the 12.5 mm sieve, 28 % on the 9.5 mm sieve, 27 % on the No. 4 sieve and 2 % on the No. 8 sieve, respectively. The normal coarse aggregate of local gravel with similar grading mentioned above was selected as control. Fine Aggregate was a lightweight natural sand from Konto River which is located on the northern slope of the volcano in Malang district. The lightweight sand was screened with 4.75 mm maximum particle size and the grading fulfilled the requirements according to SNI 03-1968-1990 [36] or ASTM C 330-04 [9]. Portland Pozzolan Cement (PPC) was in accordance with SNI 15-0302-2004 [41] and possessed a specific gravity of 3.15. While water used in concrete mixtures was clear water for drinking.

2.2. Fine and Coarse Aggregate Characteristics

Testings of physical characteristic of all coarse aggregates were carried out in accordance with SNI 03-4804-1998, SNI 1969: 2008 and ASTM C127-01, while the result was the mean value of 5 specimens. The two coarse lightweight aggregates were relatively high porous, in order to be obtained a maximum absorption, observations were carried out accurately up to 96 hours. The abrassion of coarse aggregates were performed by Los Angeles Machine in accordance with SNI 2417:2008 and the result was the mean value of 5 specimens. While testings of physical characteristics of the fine aggregate was carried out in accordance with SNI 03-4804-1998, SNI 1970:2008 and ASTM C128-01, while the result was the mean value of 5 specimens. The results of physical characteristics of fine and coarse aggregates are presented in Table 1.

Table 1 : Physical Characteristic of Fine and Coarse Aggregates

No	Physical Characteristics	Type of Aggregates			
		Sand	Pumice	Scoria	Local Gravel
1	Oven dry density (kg/m^3)	1464	758.40	850.12	1383.83
2	Bulk spesific gravity	2.53	1.52	1.72	2.70
3	24 hours Absorption (%)	1.77	16.12	12.27	1.50
4	96 hours Absorption (%)	-	19.17	15.26	-
5	Abrassion by LA machine (%)	-	59.49	58.50	18.23
6	Fine Modulus	2.61	6.69	6.69	6.69
7	Clay lump (%)	2.42	-	-	-

2.3. Mix Designs of Structural Lightweight Concrete

Two groups of mix design of the structural lightweight concrete were based on two types of coarse lightweight aggregate, ie pumice and scoria, the third group was the control of normalweight concrete mixture with local gravel as coarse aggregate. Each group of structural lightweight concrete consisted of five mix proportions whereas the control consisted of only one mix proportion. The calculation of mix proportion of the structural lightweight concrete were based on ACI 211.2-98 (R2004), while the mix proportion of the control was based on ACI 211.1-91 (R2002). The average compressive strength in all concrete mix designs were determined by SNI 2847:2013. The result of mix proportion of all concretes are presented in Table 2, where the fine aggregates were in dry condition while the coarse aggregates were in wet condition after presoaking for 16 hour.

Table 2. Results of Mix Designs of Structural Lightweight Concrete and Control

No	Type of Coarse Aggregates	Mixture Label	Specified Compressive Strength (MPa)	Mix Proportion per m^3 Volume (kg)			
				PPC	FA	CA	Water
1	Pumice	PLCF1	18	305.81	703.82	634.93	190.00
		PLCF2	20	322.64	687.22	631.18	201.76
		PLCF3	25	377.32	633.30	625.94	190.51
		PLCF4	30	423.56	587.70	626.69	190.62
		PLCF5	32	443.97	567.57	626.30	193.95
2	Scoria	SLCF1	18	305.81	727.34	681.41	204.45
		SLCF2	20	322.64	711.40	703.90	181.83
		SLCF3	25	377.32	657.47	699.40	182.57
		SLCF4	30	423.56	611.78	693.91	199.48
		SLCF5	32	443.97	591.75	684.25	190.28
3	Local Gravel	CNCF2	25	377.32	779.61	987.77	200.30

2.4. Fresh Concrete Characteristics

Observations of fresh concrete characteristics comprised slump value, air content and fresh density of each concrete mixture made. Pumice and scoria coarse aggregates were presoaked for 16 hours to reduce their high absorption and high absorption rate so that all concrete mixtures were workable. Concrete mixings were carried out by a mixer of 150 kg capacity. Slump tests were performed according to SNI 1972:2008 [44], air content tests were conducted according to SNI 3418-2011 [49], while fresh density tests were carried out in accordance with SNI 1973:2008 [45]. All testing results were the mean value of 3 specimens. Testing results of two fresh lightweight concretes and control characteristics are presented in Table 3.

Table 3. Testing Results of Fresh Concrete Characteristics

No	Mixture Label	Slump Value (mm)	Air Content (%)	Fresh Density (kg/m^3)
1	PLCF1	60	3.97	1939.08
	PLCF2	68	3.96	1943.55
	PLCF3	66	3.94	1948.45
	PLCF4	68	3.92	1954.78
	PLCF5	65	3.91	1956.68
2	SLCF1	60	3.85	2042.24
	SLCF2	60	3.84	2050.99
	SLCF3	61	3.83	2073.23
	SLCF4	65	3.82	2081.90
	SLCF5	63	3.82	2090.67
3	CNCF2	60	2.96	2444.46

2.5. Hardened Concrete Characteristics

Observations of hardened concrete characteristics consisted of equilibrium density, compressive strength, modulus of elasticity and splitting tensile strength, whereas drying shrinkage was observed as the durability of concrete. The specimen of 150x300 mm cylinder was used for testing of equilibrium density, compressive strength, modulus of elasticity, and splitting tensile strength, respectively. While the specimen of 75x75x285 mm prism was used for testing of drying shrinkage. All specimens were internally compacted by a 12 mm diameter of steel rod vibrator, while demoldings were performed 24 hours after casting. Curings for physico-mechanical characteristic tests were performed by covering all specimens within wet burlaps for 7 days and then stored in a dry room until testing. Curings for equilibriun density tests were carried out in accordance with SNI 3302:2008. Testings of compressive strength, modulus of elasticity and splitting tensile strength were carried out at 28 days, while drying shrinkage tests were carried out at 90 days. The compressive strength, modulus of elasticity, splitting tensile strength, equilibrium density and drying shrinkage tests were carried out according to SNI 1974-2011, SNI 03-4169-1996, SNI 03-2491-2002, SNI 3402:2008 and ASTM C 157M-03, respectively. Each of testing results was the mean value of 3 specimens. The testing results of hardened concrete characteristics of both lightweight aggregates and control are presented in Table 4.

Table 4 : Testing Results of Hardened Concrete Characteristics

No	Mixture Label	Equilibrium Density (kg/m^3)	Compressive Strength (MPa)	Modulus of Elastisity (MPa)	Splitting Tensile Strength (MPa)	Drying Shrinkage (MS)
1	PLCF1	1864.27	19.99	10446.60	2.01	476.88
	PLCF2	1867.56	22.04	12814.11	2.03	474.19
	PLCF3	1873.68	27.28	13135.35	2.04	458.77
	PLCF4	1879.76	30.33	14608.56	2.07	436.92
	PLCF5	1880.32	30.71	14647.86	2.10	431.54
2	SLCF1	1880.88	21.70	11084.61	2.04	455.46
	SLCF2	1892.68	23.82	12592.75	2.07	451.33
	SLCF3	1909.83	28.48	13587.91	2.08	442.77
	SLCF4	1920.03	32.99	14581.44	2.10	424.79
	SLCF5	1928.50	34.31	15058.84	2.13	419.56
3	CNCF2	2385.66	28.85	18629.76	3.11	298.67

3. RESULTS AND DISCUSSION

3.1. Fine and Coarse Aggregate Characteristics

Testing results of aggregate characteristics presented in Table 1 showed that the sand used in concrete mixtures satisfied the fine aggregate requirements. With oven dry density of 1464 kg/m^3, this sand was relatively light compared to local sands with oven dry density over 1600 kg/m^3 and below the upper bound of 1750 kg/m^3. The natural grading also satisfied the requirements with fine modulus 2.61, while the 24 hours absorption and the clay lump were also lower than specified values in the requirements. Oven dry, loose density of pumice and scoria aggregates were 758.40 kg/m^3 and 850.12 kg/m^3, respectively, thus they also fulfilled the coarse lightweight aggregate requirements and lower than the local gravel of 1383.83 kg/m^3 as control. The spesific gravity of both coarse lightweight aggregates were 1.52 and 1.72, these values also fulfilled the specified requirements, furthermore these two values were greater than 1 so that the probability of aggregate segregation in the concrete mixtures becomes lower. The amount of 24 hours absorption for pumice and scoria aggregates were 16.12% and 12.27%, respectively, these results were greater than the control of 1.50%. While the maximum absorption of both coarse lightweight aggregates measured at 96 hours were 19.17% and 15.26%, respectively, these results also satisfied and were lower the specified requirements of 20%. However, the abrassion by Los Angelos Machines of both coarse lightweight aggregates were relatively high, namely 59.49% and 58.50%, these were greater than the specified requirements of 27% and the control of 18.23%. These high abrassions indicated that the compressive strength of both coarse lightweight aggregates were low. The grading designed of the three coarse aggregates also fulfilled the requirements with fine modulus 6.69, while the clay lump was very small because three coarse aggregates were in clean condition after presoaking or washing and drying their surfaces.

3.2. Mix Designs of Structural Lightweight Concretes

All concrete mix designs were based on fine and coarse aggregate characteristics obtained from the above testing results. The proportion of structural lightweight concretes were calculated by Gravity Method with assumption that the maximum absorption of coarse lightweight aggregates can be determined precisely at 96 hours of observation. The amount of slump value and air content were specified between (60-70) mm and (2-3)%, respectively, while the average compressive strengths for each proportion were determined according to SNI 2847:2013. The calculation results presented in Table 2, showed that in order to achieve the specified compressive strength of (18-32) MPa, the proportion of PPC were in the range (305.81-443.97) kg per m^3 volume. These results were lower than the proportion of OPC of the structural lightweight concrete studies using pumice and scoria from Papua New Guinea or pumice and scoria from Yemen.

3.3. Fresh Concrete Characteristics

Table 3 showed that slump values for both lightweight concretes and control fulfilled specified values between (60-70) mm. At these obtained slumps, the concrete mixture showed a satisfactory workability, no segregation and no excessive bleeding. The amount of air content of pumice and scoria concretes ranged (3.82-3.97)%, these values were greater than the specified value, ie (2-3)%. While the air content for normalweight concrete as control was 2.96 % and satisfied the provisions taken. The slump value of both lightweight concretes were almost similar to those that had been conducted by, while air contents were lower than these studies. These may be caused by the lower absorption of pumice and scoria from Kelud volcano than Pumice and scoria from Papua New Guinea so that the porosity of both were also lower. However, the air content of the pumice and scoria lightweight concretes from Kelud volcano was not different significantly. The wet density varied according to the mix proportion of structural lightweight concretes, as well as types of coarse aggregates obtained from pumice and scoria, but these variations were less significant. The variation of density between pumice and scoria lightweight concretes was reasonable because their aggregate densities were also different, whereas the aggregate occupies the greater part of the total volume of the concrete.

3.4. Hardenend Concrete Characteristics

Table 4 showed that for the mix proportion determined, the equilibrium density of pumice lightweight concrete ranged (1864.27-1880.32) kg/m^3 with compressive strength of (19.99-30.71) MPa. Thus these pumice lightweight concretes can be categorized as structural lightweight concrete [1]. For the mix proportion of 1 to 4 (SLCF1-SLCF4), the equilibrium density of scoria lightweight concretes ranged (1880.88-1920.03) kg/m^3 with compressive strength of (21.70-32.99) MPa. Thus, these scoria lightweight concretes can also be categorized as structural lightweight concrete. However, the fifth mix proportion of scoria lightweight concrete (SLCF5), although the compressive strength is large, the equilibrium density did not satisfy the requirements so that it can be called semi-weight structural lightweight concrete. Comparing with the normalweight concrete as control, the density reduction was 21.46% for pumice coarse aggregate and 19.95% for scoria coarse aggregate. When they were applied in structures, these reductions will significantly affect designs of other structural elements.

For pumice lightweight concretes, the compressive strength obtained from the tests satisfied the specifed compressive strength of (18-30) MPa except the fifth mix proportion (PLCF5). This may be caused by the low compressive strength of pumice so that it crushed first before the cement paste that was stronger. While for scoria lightweight concretes, the compressive strength satisfied all specified compressive strengths of (18-32) MPa. Comparing with the control, these compressive strengths were also not significantly different. The modulus of elasticity for all mix proportions of both lightweight concretes were lower than control. These may be caused by high porosity of both volcanic rocks as a source of coarse aggregates so that deformations increased. This low modulus of elasticity further reduces the stiffness of structural element that will increases the deflection. The amount of modulus of elasticity obtained by testings was roughly similar to previous studies conducted by with approximately equal compressive strengths.

The splitting tensile strength for all mix proportions for pumice and scoria lightweight concrete were relatively low but still satisfied the specified requirements of 2 Mpa and lower than the control. These results were also lower when compared with previous studies conducted by. This may be caused by the condition of both lightweight concretes at 28 days of testing was still moist due to aggregate presoaking before concrete mixing. As it is known that the concrete tensile strength is affected by the moisture of the material at the time of the test, the higher moisture the tensile strength will decrease. The drying shrinkage for all the mix proportions of pumice and scoria lightweight concrete were relatively greater than control but still lower than the requirement of 600 MS. These results were also lower when compared with previous studies conducted by. Therefore, these typical pumice and scoria coarse aggregates will produce lightweight concretes with fewer cracks that increase their durability.

4. CONCLUSION

This study showed that medium-K basaltic andesitic pumice and scoria can be used as coarse aggregates on structural lightweight concrete that were environmental friendly and energy saving. Although any characteristics did not fulfill the requirements, but these typical pumice and scoria aggregates can be satisfied the requirements of coarse lightweight aggregate. From the result of mix designs, pumice and scoria structural lightweight concrete yielded the proportion of PPC that were lower than existed studies so that the unit price also becomes cheaper. These structural lightweight concretes yielded about 20% density reduction with compressive strength according to specified requirements. Therefore, they can reduce significantly their self weight and affect the structural element design and overall structure cost. The modulus of elasticity and splitting tensile strength were relatively low compared to normalweight concrete as control, thus they will be less rigid and rapidly cracked when were used as structural elements. These pumice and scoria lightweight concretes yielded low drying shrinkage so that the microcracks will be less and the concrete durability increases.

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