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The Influence of Concrete Cylinder Size on Compressive and Tensile Strength of Semi Lightweight Pumice Concrete

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Abstract— *Concrete strength is affected by many complicated factors, one of them namely specimen size. Concrete quality control is commonly based on testing on concrete specimen, such as cylinders, or drilled Cores. The specimens like cores are various in sizes and consequently they do not conform to the specification of building code. Because the different size of concrete cylinder is probably encountered, then it is important that the mechanical properties of Self compacting lightweight concrete be discovered. This research is to explore the influence of concrete cylinder size on mechanical properties of Self compacting semi lightweight concrete and to recommends correction factor of concrete strength tested with different cylinders size to that of the standard concrete cylinder. Variables considered are h-d ratio and diameter of the concrete cylinder. The research focuses on behavior of Compressive and Tensile strength of Self compacting semi lightweight concrete. All specimens are concrete cylinders and mix proportion is kept constant, 1:1:2 of cement-sand-coarse aggregate ratio by volume, with a water-cement ratio of 0.45. The coarse aggregate is pumice with nominal maximum size of 20 mm. From observation, the concrete strength is linearly reduced as the diameter of the concrete cylinder increase. Concrete cylinders with height-diameter ratio of 2 give the optimum compressive strength and optimum tensile strength of each sample. Some correction factors that can be utilized for correcting both the compressive and tensile strength tested with various cylinders size to that of the ASTM standard concrete cylinders are also recommended.*

Keywords— *Semi lightweight pumice concrete, ratio of h/d, mechanical properties, correction factors*

I. INTRODUCTION

Concrete is building material for almost all of civil work. To cut down on total construction cost, designers often require a lightweight material because this will give a low self-weight structure. The less unit weight of the material has, the less the self-weight of the structure will be, and therefore it will totally result low cost structure. This condition will be obtained only if lightweight concrete is used as structural member. Such concrete can be produced by using lightweight aggregate, such as pumice, as coarse aggregate instead of normal aggregate. Eastern Indonesia lies on a high-risk seismic zone. So many seismic actions causing structural damages have been reported during five past years [13-17]. Consequently, more attention should be addressed to building materials used, such as concrete, in the high-risk seismic zone. From earthquake-engineering point of view, the more mass the structure has, the larger the Base hear force will be carried by the structure. This condition will endanger the structure itself as likely as not. In order to obtain less mass of but strong structure, lightweight concrete instead of conventional concrete can be used as an alternative building material.

Despite the Semi lightweight concrete application, so far, it has been few studies of mechanical properties of Semi lightweight pumice concrete. In structural design, the mechanical properties, for examples compressive strength, tensile strength, modulus of elasticity, stress-strain relationship, play an important role.

Concrete strength is governed by many complicated factors, one of them is specimen size. Based on some research [3,4,6,7,8,9,12], it is stated that nominal concrete strength is greatly influenced by the size of the specimens. However, the research is conducted either experimentally or numerically on both normal and high strength concrete, and unfortunately very few studies of Semi lightweight pumice concrete exists.

In concrete structures, quality control of the concrete is usually based on compressive testing of concrete cylinders, cubes, or even drilled cores. To assess the quality of concrete in an existing structure or the actual strength of concrete in a structure, besides non-destructive test, drilled core testing is one of alternative methods that can be applied. The specimens like drilled cores are various in sizes and consequently they do not conform to the building code. In this regard, this research is intended to find out the influence of concrete cylinder size on mechanical properties of semi lightweight pumice concrete. Moreover, this research also recommends correction factor of the compressive strength and tensile strength tested with various cylinders size to that of the ASTM standard concrete cylinder.

II. RESEARCH SIGNIFICANCE

Considering the fact that different size of concrete cylinder is still possibly used in any project site, then it is important that the mechanical properties of Semi lightweight pumice concrete be investigated. Moreover, correction factors of the compressive and tensile strength based on various cylinders size to that of the ASTM standard concrete cylinders are also recommended. This correction factors will be useful if one encounters non-standard concrete cylinders, for example drilled cores cut from in situ concrete, then it is necessary to estimate the strength which would have been obtained using a height-diameter ratio of 2.

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III. Experimental Program And Discusion

A. Material testing and Samples preparation

In this study all specimens were concrete cylinder. Diameters of the concrete cylinders were varied between 50mm to 150mm, and Cylinder depth to diameter ratio of the specimens ranged from 1 to 3. The mix proportion used in this research was kept constant 1:1:2 of cement-sand-coarse aggregate ratio by volume with a constant water-cement ratio of 0.45. In addition, nominal maximum size of pumice was 20 mm. According to testing of resistance to degradation conforming to ASTM C 131-89, it is obtained that the average ratio of the loss after 100 revolutions to the loss after 500 revolutions is 0.285, therefore the pumice can be classified as a uniform hardness aggregate. Then the average total loss of the pumice is 26.35%.

The pumice used as coarse aggregate in this study was taken from Ijo Balit village, East Lombok, West Nusa Tenggara Indonesia. Based on chemical test on the Pumice it was found that the Pumice contains eight compounds. The test was conducted at Chemistry Laboratory of University of Mataram. The compounds are completely explained in Table 1.

TABLE 1. Oxide and Compound of the Pumice

No	Chemical Substance	Composition (%)
1	S_iO_2	68.37
2	Al_2O_3	16.26
3	K_2O	2.24
4	Na_2O	3.67
5	CaO	4.93
6	MgO	2.51
7	Fe_2O_3	4.26
8	Cl	0.52

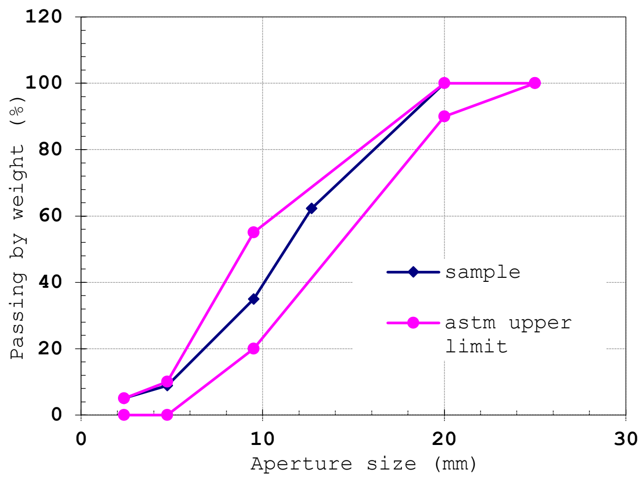

Fig. 1. Pumice Grading Curve

Furthermore, material testing conducted on Pumice were sieve analysis, Density, Specific gravity and Water absorption. Based on laboratory test, the average Bulk specific gravity SSD, Loose bulk density, and Water absorption were 1.031, 400kg/m3, and 51.54% respectively. The testing of material was carried out conforming to the ASTM C 127-15[19], C 128-07a [20], respectively. Pumice and sand grading curve based on ASTM can be referred to Figure 1 and Figure 2 respectively.

All ingredients were mixed to produce fresh concrete by using a power-driven concrete mixer, which insure homogeneous concrete for entire specimens. The concrete cylinders were cast in both steel mold and plastic mold. All concrete cylinders were tested at the age of 28 days in an air-dry condition, and cured conforming to ASTM [1,2].

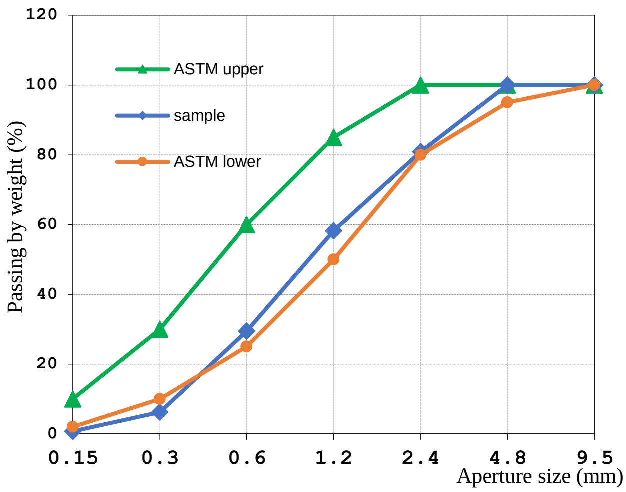

Fig. 2. Natural Sand Grading Curve

B. Compressive Strength and tensile Strength

Before compression testing and tensile testing, all concrete cylinders were cured by soaking in water for 7 days followed by 21 days drying at room temperature. In order to find plane and perpendicular end of specimens, each freshly molded concrete cylinder was capped with Portland cement and finished by trowel. Just before the compression test start, each concrete cylinder was weighed with a balance to find out the weight of the specimens. Diameter and height of the specimens were also measured. The diameter used for calculating both the compressive strength and tensile strength of the test specimens was determined by averaging two diameters measured at right angles to each other. Based on ASTM C39 and ASTM C496 [1,2], the Compressive strength and Splitting tensile strength of lightweight concrete obtained from formulas (1) and (2)

$$f'c = \frac{P}{A} \quad (1)$$

$$f_t = \frac{2P}{\pi LD} \quad (2)$$

Where:
f'c= compressive strength (MPa)
ft= Splitting tensile strength (MPa)
D=diameter of concrete cylinder (mm)
L=Length of concrete cylinder (mm)

To prevent the influence of rate of loading on the compressive strength and tensile strength, every concrete specimen was tested at a constant loading rate of about 0.2 MPa/s, and the compression machine utilized in the test was the same for all concrete cylinders.

Based on data observed, it is clear that the smaller the diameter of the specimens, the higher the compressive strength, and the optimum compressive strength of each sample is given by concrete cylinders with height-diameter ratio of 2. So does the tensile strength. The tensile strength behavior is typically the same as for compressive strength.

Traditionally, the reason for the phenomenon mentioned above could elucidated by Weibull's weak link statistical theory [11,12]. Weibull theory determines strength based on the probability of failure associated with the largest defect in the material used. The lower strength for the larger size of structures is due to the fact that the larger the structures the greater the probability to encounter the largest defect in the material. However, please note that this is only valid for one-dimensional structures.

The influence of h/d ratio on compressive strength and on tensile strength of concrete cylinders is shown in Figure 3 and Figure 4 respectively.

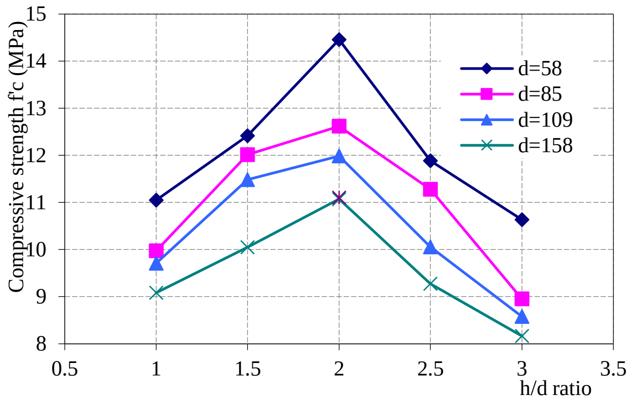

Figure 3. Typical relation between Compressive strength and h/d ratio with various diameter of cylinders

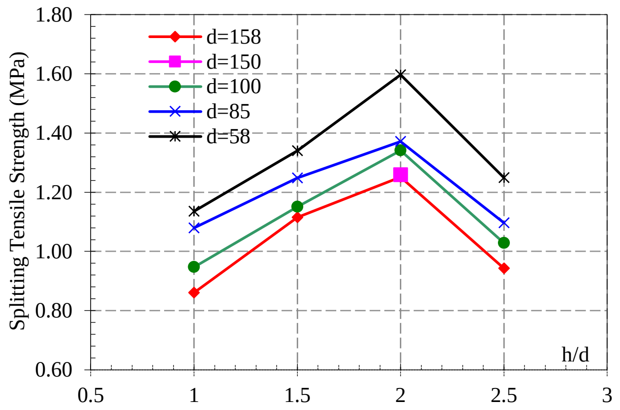

Figure 4. Typical relation between Tensile strength and h/d ratio with various diameter of cylinders

In addition, the graph of logarithm of cylinder diameter d vs. Logarithm of concrete strength is also given in Figure 5. It is outstanding that the concrete strength is linearly reduced as the diameter of the concrete cylinder increase as shown in Figure 5. This circumstance agrees with the finding of Elfahal et al. [5]. Note that Elfahal et al. did their research with both normal and high strength concrete subjected to static and dynamic load.

Based on inspection when testing, there were five types of cylinder fracture observed namely Columnar, Cone and shear, Shear, Cone and shear, and Cone in order of merit. The fracture was predominantly Columnar. Some fractures were Cone and Cone- shear, and only few concrete cylinders failed in failure mode of Cone. In addition to the type of the failure, most of the concrete cylinders begin to crack at about 50 to 70% of breaking load. The mean compressive strength and tensile strength obtained from this study were 11 MPa and 1.2 MPa respectively.

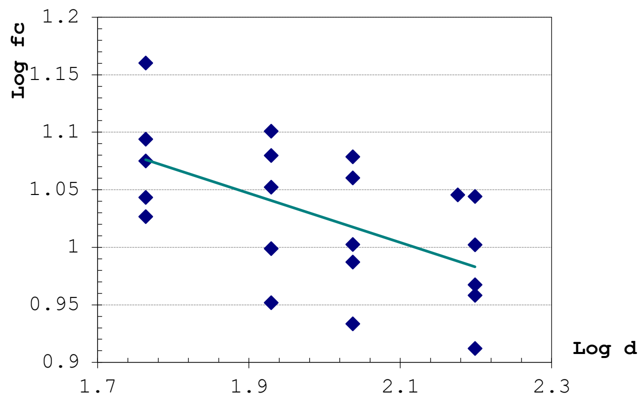

Figure 5. Compressive Strength f'c – Cylinder Diameter d Relationship

The tensile test conducted in this study was indirect tensile test, namely Splitting tensile test complying with ASTM C 496-90. Like compressive testing, all concrete specimens were various concrete cylinders, and tested at the same age as for compressive testing. The specimens also found similar curing treatment as for compressive testing. Note that the Splitting tensile test in this research was performed with concentrated load instead of distributed load. The splitting tensile strength is obtained from equation (2).

Typically, data collected indicates that the splitting tensile strength increases as the diameter of cylinder decrease. This phenomenon is shown in Figure 4 and Figure 6. This trend is similar to that of compressive strength, and the reason for this is certainly the same as for the compressive strength mentioned above. Moreover, the optimum tensile strength of each series is obtained from concrete cylinders with height-diameter ratio of 2.

Tang at al. [10] reported that Splitting tensile strength decrease at first and then increase before approaching a limit value. The result obtained suggested that load distribution is an important parameter for the split-tension cylinder used to evaluate the tensile strength of concrete. This tendency is slightly different from that of this current study. This condition is mostly because of the different load type applied in the research

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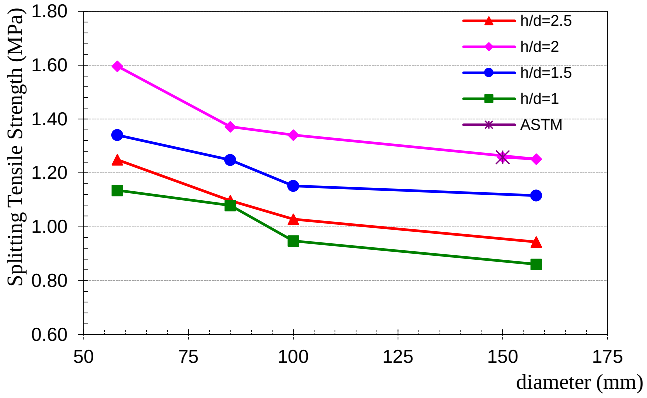

Figure 6. Splitting Tensile Strength vs Diameter of Cylinders

C. *Correction factor for compressive and tensile strength*

If one encounter non-standard concrete cylinders, then it is necessary to estimate the strength that would have been obtained using a height-diameter ratio of 2. This can be accomplished by applying some correction factors. The correction factors for both compressive strength and tensile strength can be obtained in Table 2 and 3 respectively.

TABLE 2. Correction Factor for Compressive Strength

Ratio of *h/d*	**Diameter of cylinder,*d* (mm)**			
	58	85	109	158
1	1.005	1.113	1.144	1.223
1.5	0.895	0.924	0.967	1.105
2	0.768	0.880	0.927	1.003
2.5	0.934	0.985	1.105	1.198
3	1.044	1.241	1.295	1.361

How to use the correction factors can be demonstrated as follows. Let us say that a compressive strength f'c tested with 85 by 170 mm concrete cylinder is equal to 25 MPa. If one wants to approximate to the strength which would have been found using an ASTM concrete cylinders then one can do this by using a correction factor from Table 1. From Table 1 with d=85 and h/d=2, the correction factor will be 0.880, therefore the ASTM compressive strength of the same concrete is $f'c_{(ASTM)}$ =0.88x25=22 MPa. This method can be also applied similarly to determine the tensile strength of lightweight concrete. Note that the correction factors are established by testing concrete cylinders at the age of 28 days under static loading. If the compressive strength of concrete is obtained from testing concrete cubes test, then of course further conversion factor is needed considering that different cross-sectional shapes will provide unequal strength.

TABLE 3. Correction Factors for Splitting Tensile Strength

Ratio of *h/d*	**Diameter of cylinder,*d* (mm)**			
	58	85	100	158
1	1.109	1.166	1.330	1.463
1.5	0.939	1.009	1.094	1.129
2	0.789	0.918	0.939	1.006
2.5	1.008	1.148	1.225	1.334

D. *Alkali Content of the Concrete Mix*

Some compounds of cement are categorized as minor compounds, such as K2O, Na2O, MgO. They usually amount to not more than a few per cent by mass. Two of the compounds are of interest; the Oxides of sodium Na2O and Potassium K2O, are known as Alkalis. They have been proved to react with some aggregates. Actually, there are many other chemical elements that can be categorized as alkalis such as Lithium Li, Rubidium Rb and Calcium Cs.

The product of the Alkalis-aggregate reaction cause disintegration of concrete, and have also found to affect the rate of the gain of strength of cement. Certain aggregates can react with Alkali hydroxides in cement, causing expansion and cracking over a period of years. The reaction is greater in those parts of a structure exposed to moisture. Acknowledge of the characteristics of local aggregates is essential. There are two types of alkali reactive aggregates, siliceous and carbonate.

Because lightweight aggregates, such as Pumice, are often composed of predominantly amorphous silicates, they appear to have the potential for being reactive with alkali in cement. For this reason, in areas where deleteriously reactive aggregates are known to exist, special measures must be taken to prevent the occurrence of alkali-aggregate reaction.

The alkali content of the concrete mix A (kg/m^3) can be readily calculated from the alkali content of the cement Na_2O(eqiv.) (%) and the cement content of the concrete C (kg/m^3) as follows [18]:

$$Na_2O_{(eqiv.)} = Na_2O(\%) + \left(\frac{62}{94.2}\right)K_2O(\%) = 0.58$$

Cement content of concrete, C=605kg/m^3 (Referring to mix design). Then, equivalent alkali content of concrete, A, assuming no alkali contribution to the concrete from any Na_2O and K_2O in the mineral aggregate, id est:

$$A = \frac{0.58}{100} \times C = 3.5\ \frac{kg}{m^3}$$

West [18] classifies cement according to its alkali content; High, Medium and Low alkali cement. Referring to the equivalent alkali content of cement *$Na_2O(eq.)$*, then it can be categorized as Low-alkali cement. If the concrete mix is used for structural elements that are exposed to moisture, then for durability reason the reactivity of the aggregate need to be discovered. In this regard, it is questioned whether the local pumice involved in this study will react with the alkali in the concrete mixture. This case is beyond the scope of this study, and can be a new research topic.

IV. CONCLUSION AND RECOMENDATIONS

Based on data observed, here are some conclusions that can be drawn:

1) Both compressive strength and Splitting tensile strength increase as the diameter of the cylinder decrease.
2) The optimum compressive strength and Splitting tensile strength are obtained from concrete cylinders with h/d ratio of 2
3) Correction factors for both compressive and tensile strength is introduced. This will be advantageous when one encounters non-standard concrete cylinders.

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Based on data collected along with analysis and literature survey, some recommendations related to lightweight concrete are provided as follows:

1) Chemical properties of local coarse aggregates used as concrete material such as pumice, need to be disclosed to find out whether the materials reactive with alkali content of cement. It can be a new research topic.
2) Regarding the tensile strength observed in this study, it is important that the influence of load type on the strength be discovered.

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