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# Thermal conductivity and compressive strength of lightweight mortar utilizing Pumice breccia as fine aggregate

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**Abstract**

Pumice Breccia is a natural material which is available in a vast deposit of volume in Indonesia, especially in Yogyakarta area. The main characteristics of this type of rock are lightweight and having low thermal conductivity. Pumice breccia utilization is expected to support the implementation of green building concept by minimizing electrical power needs that may be required for setting the room temperature (air conditioning system). The aim of this study is to evaluate the effect of pumice breccia utilization as fine aggregate in various compositions on the thermal conductivity and compressive strength of the mortar. This study conducted using the experimental method to determine the thermal conductivity and compressive strength of each variation of the mortar. Two (2) types of mortar were investigated in this research. The first type is normal mortar using sand as the fine aggregate with mixture compositions variations of 1 Pc (Portland Cement):4 Ns (Sand), 1 Pc:6 Ns, and 1 Pc:8 Ns, which are labeled as MN1, MN2, and MN3. The second type of mortar is pumice breccia mortar that utilizing pumice breccia material as fine aggregate with mixture compositions variations of 1 Pc (Portland Cement):4 Pb (Pumice Breccia), 1 Pc:6 Pb and 1 Pc:8 Pb, named as MP1, MP2, and MP3. All composition of mortar mixtures is prepared based on the volume ratio. Test results show by using the Pumice Breccia as fine aggregate in the mortar mixtures, the thermal conductivity of the normal mortar can be reduced nearly considerably. Even though, the reduction in compressive strength is observed in all the compositions of mortar mixtures, based on SNI 03-6882-2002, still the Pumice Breccia based mortar can be classified into the type-O mortar that can be used for partition walls, protective and decorative purposes.

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## 1. Introduction

The increase of human population led to the rapid development of the construction industry. The existence of a business center buildings, offices, education and housing become a necessity that cannot be avoided. In accordance to the development of construction technology, the need of complementary infrastructure inside the building is also increasing. One of building fixtures which is largely use is air conditioning system (Air Conditioner). It is widely used for almost every type of buildings, starting from skyscraper, educational buildings to housing. The use of AC (Air Conditioner) has given rise to negative effects such as global warming.

One of the main triggers of global warming caused by the use of AC is that Chlorofluorocarbons (CFCs) gas which is resulted from the cooling process. Increased use of AC in the building is very risky to accelerate the depletion of the ozone layer of the earth. It will lead to global warming acceleration. Any reduction of temperature in the air-conditioned room will always be followed by the increase of outdoor temperature. In addition, the use of air conditioning system in the building also spent large energy consumption. It encourages governments in various countries to pursue policies for energy saving, especially associated with the electricity consumption for lighting and air conditioning. For each additional one degree Celsius of thermostat, it will be able to save 3-5% of the air conditioning cost [1].

In order to minimize the negative impact of the use of air conditioning system in the building, it has developed the concept of environmentally friendly building (green building) by minimizing the need for air conditioning system. To minimize the need for air conditioning system, it is necessary to develop the wall material becomes capable to reduce the propagation of heat from the outdoors that will fit into the room. To develop a heat-absorbing wall material, it is necessary to develop such kind of materials that have quite small thermal conductivity. In general, building materials that save a lot of pores and has low specific gravity will have a lower thermal conductivity or better thermal insulating capability.

Experimental research on foamed concrete (FC) exhibits that thermal conductivity increases with increasing density, as expected. For the low density specimen of FC, more foam is incorporated in the concrete, and, as a result, a high amount of air pores are formed inside. As air is a good insulator, the thermal conductivity of FC was found to be lower than that of lightweight concrete. The thermal conductivity of FC and lightweight concrete is lower than that of normal weight concrete, conventional block and brick, which are conventionally used in construction field [2].

Pumice breccia is a type of coarse grained pyroclastic rocks with its breccia fragments dominated by pumice with highly variable shape and size, white-gray color, and its matrix consisting of limestone with amorphous silica. Pumice breccia is formed by the volcanism activity. Therefore, it can be found abundantly along the volcanic line in Indonesia. The location that had been identified as the largest pumice breccia deposit area is Semilir Formation. The Semilir Formation is typically originated from products of a very explosive volcanic activity. It is a widespread mountainous area at the southern part of Java Island. The formation is widely distributed from the west side at Pleret and Piyungan areas in Bantul Regency, Special Province of Yogyakarta until Eromoko area in Wonogiri Regency, Central Java Province in the east [3]. Based on the official data which is released by the center of investation resources development in the Indonesian Ministry of Public Works, the Special Province of Yogyakarta has 2.50 billion $m^3$ deposit of pumice breccia which is located in Bantul, Gunung Kidul and Sleman region [4]. Pumice breccia having relatively low density therefore it is met the requirements to be used as lightweight aggregate [5].

In this research, pumice breccia which can be found abundantly in Indonesia proposed to be utilized as the fine aggregate for the development of insulating mortar. The main objectives of this research are: (1) evaluating the effect of pumice breccia utilization as fine aggregate in various compositions on the thermal conductivity, and (2) examining compressive strength of several mortar types which are using pumice breccia as fine aggregate.

## 2. Material and Methods

The mixtures were prepared with blended cement which satisfies to the requirements in the Indonesian National Standards [6]. The detail of its chemical compounds is presented in Table 1.

Table 1: Chemical composition of Portland cement

| Chemical Compounds | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | LoI |
|---|---|---|---|---|---|---|---|
| Mass (%) | 23.13 | 8.76 | 4.62 | 58.66 | 0.90 | 2.18 | 1.69 |

The coarse aggregate of all concrete mixtures utilize continuously graded crushed lightweight pumice breccia from Bawuran Mountain, Bantul District in the Special Province of Yogyakarta which is one of the largest pumice breccia deposits in Indonesia. This pumice breccia has dry-loose bulk density of 760 kg/m$^3$ with particle density of 1620 kg/m$^3$ which is satisfied to the technical specification of lightweight aggregate. Therefore, it is proposed to be utilized as coarse aggregate in the mixtures. The fine aggregate prepared using pumice breccia with maximum size of 4.8 mm, and in air-dried condition before mixing process. Detail of mixes proportion between Portland cement (Pc), natural sand (Ns), and pumice breccia (Pb) in this research can be found in the following Table 2.

Table 2: Mixture proportion of nine (9) series of mortar mixtures

| No | Samples type | Volume ratio |
|---|---|---|
| 1 | MN1 | 1Pc : 4Ns |
| 2 | MN2 | 1Pc : 6Ns |
| 3 | MN3 | 1Pc : 8Ns |
| 4 | MNP1 | 1Pc : 2Ns : 2Pb |
| 5 | MNP2 | 1Pc : 3Ns : 3Pb |
| 6 | MNP3 | 1Pc : 4Ns : 4Pb |
| 7 | MP1 | 1Pc : 4Pb |
| 8 | MP2 | 1Pc : 6Pb |
| 9 | MP3 | 1Pc : 8Pb |

## 3. Experimental Works

Hardened properties of mortar mixes were evaluated based on its thermal conductivity and compressive strength after 28 days of mortar age. Thermal conductivity evaluation was conducted for all the mortar variants using cylinders with 40 mm in diameter and 5 mm height. Compressive strength examination for all variants was done on standard cubes with 50 mm x 50 mm x 50 mm dimension. The thermal conductivity and compressive strength of the mortars was determined as the average of those five specimens for each variant. The experimental setting for thermal conductivity and compressive strength test can be observed in Fig. 1.

a 

b 

Fig. 1. Experimental setting; (a) thermal conductivity measuring apparatus; (b) compressive strength test

For determination of thermal conductivity of each sample, the calculation was carried out using standard formula as follows:

$$\Delta t_R = \frac{\Delta t_{1,2} + \Delta t_{2,3} + \Delta t_{3,4} + \Delta t_{7,8} + \Delta t_{8,9} + \Delta t_{9,10}}{6} \text{ (ºC)} \quad (1)$$

$$\lambda'_a = \frac{\Delta t_R}{\Delta t_a} x \frac{L_a}{L_R} \lambda_R \text{ (W/m.ºC)} \quad (2)$$

$$\lambda'_b = \frac{\Delta t_R}{\Delta t_b} x \frac{L_b}{L_R} \lambda_R \text{ (W/m.ºC)} \quad (3)$$

$$\lambda = \frac{L_b - L_a}{\frac{L_b}{\lambda'_b} - \frac{L_a}{\lambda'_a}} \text{ (W/m.ºC)} \quad (4)$$

where

$\Delta t_{1,2}$ : temperature change between first and second node
$\Delta t_a$ : temperature change of sample "a"
$\Delta t_b$ : temperature change of sample "b"
$\Delta t_R$ : average of temperature change
$L_a$ : height of sample "a" (5 mm)
$L_b$ : height of sample "b" (10 mm)
$L_R$ : 30 mm
$\lambda$ : thermal conductivity
$\lambda'_a$ : thermal conductivity of sample "a"
$\lambda'_b$ : thermal conductivity of sample "b"
$\lambda_R$ : thermal conductivity of copper rod (372.16 W/m. ºC)

While following formula was used to determine the compressive strength of each mortar sample

$$f'_{ck} = \frac{P}{A} \quad (5)$$

where

$f'_{ck}$ : compressive strength of cube (MPa)
P : compression load (N)
A : area ($mm^2$)

## 4. Results and discussion

Experimental results of nine types of mortar which were evaluated to determine the thermal conductivity and compressive strength can be observed in Table 3 as follows.

Table 3: Thermal conductivity and compressive strength of nine (9) series of mortar mixtures

| No | Samples type | Average thermal conductivity (W/m.ºC) | Average compressive strength (MPa) | Mortar type based on SNI: 03-6882-2002 |
|---|---|---|---|---|
| 1 | MN1 | 0.63 | 5.21 | N |
| 2 | MN2 | 0.61 | 3.45 | O |
| 3 | MN3 | 0.53 | 1.66 | - |
| 4 | MNP1 | 0.50 | 3.33 | O |
| 5 | MNP2 | 0.49 | 2.91 | O |
| 6 | MNP3 | 0.40 | 2.17 | - |
| 7 | MP1 | 0.37 | 3.99 | O |
| 8 | MP2 | 0.35 | 2.55 | O |
| 9 | MP3 | 0.29 | 0.46 | - |

Test results show by using the Pumice Breccia as fine aggregate in the mortar mixtures, the thermal conductivity of the normal mortar can be reduced nearly considerably. It can be observed that thermal conductivity decreases in accordance with the decrease of mortar compressive strength, as expected. For the low compressive strength of mortar, more air pores are formed inside. As air is a good insulator, the thermal conductivity of mortar was found to be lower than that of normal mortar. The thermal conductivity of lightweight mortar that utilizing pumice breccia as fine aggregate is lower than that of normal weight mortar which is conventionally used in construction field

Even though, the reduction in compressive strength is observed in all the compositions of mortar mixtures, based on the Indonesia National Standard of mortar specification for construction works; SNI: 03-6882-2002, still the Pumice Breccia based mortar can be classified into the type-O mortar that can be used for partition walls, protective and decorative purposes [7].

Simple steady state heat transfer analysis also performed to get an initial information regarding the effectiveness of the use of mortar utilizing pumice breccia as fine aggregate in decreasing the inside room temperature buildings in the Indonesian coastal region with assuming that outdoor temperatures is around 36 °C. The numerical analysis was conducted using Strand7 software. The model will only assign convection coefficients, and assumed that there is no radiative heat transfer, as it is not significant over the range of temperatures considered. Analysis result shows that using Class-O pumice breccia mortar the indoor temperature will be 23.1 °C and when using normal mortar the indoor temperature will be 24.5 °C. The finite element model of heat transfer analysis can be found in Fig. 2 as follows.

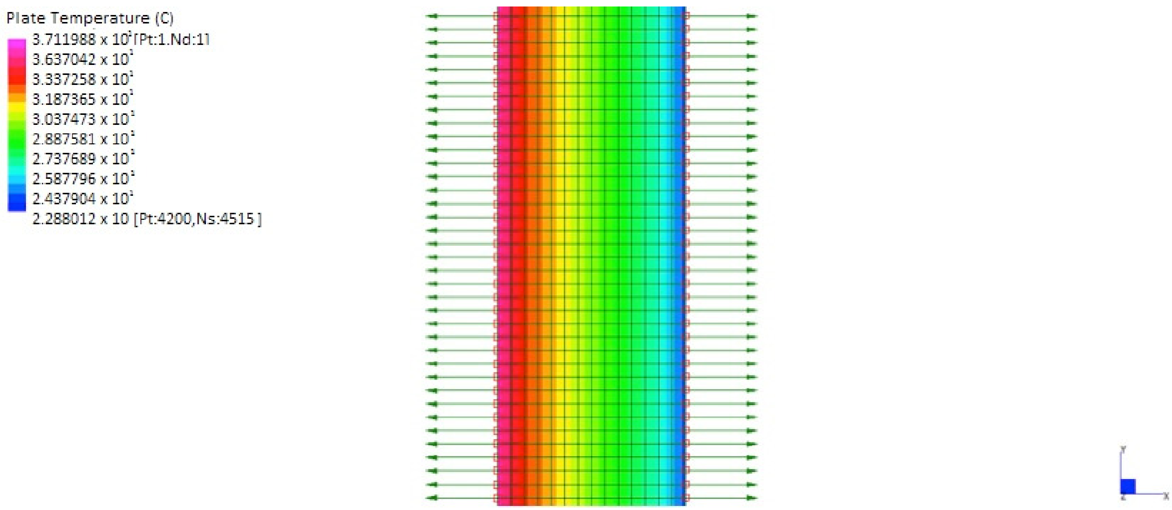


Fig. 2. Finite element model of steady state heat transfer analysis in building wall using Strand7

## 5. Conclusions

Based on the tests results of the hardened properties of pumice breccia lightweight concrete, the following conclusions can be drawn:

- Utilization of pumice breccia as fine aggregate in the mortar mixtures will effect to the thermal conductivity reduction significantly. The thermal conductivity can be reduced nearly 40%.
- Thermal conductivity of mortar specimens can be reduced in accordance with the decrease of mortar compressive strength. Based on the Indonesia National Standard of mortar specification for construction works; SNI: 03-6882-2002, still the Pumice Breccia based mortar can be classified into the type-O mortar that can be used for partition walls, protective and decorative purposes.

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**References**

[1] R. Cluett, Small actions that add up to large energy savings for Earth Day, 2014 (April 22), retrieved from: http://aceee.org/blog/2014/04/small-actions-add-large-energy-saving.
[2] U.J. Alengaram, B.A. Al Muhit, M.Z. bin Jumaat, M.L.Y. Jing, A comparison of the thermal conductivity of oil palm shell foamed concrete with conventional materials, Materials and Design 51, (2013), 522–529.
[3] S. Bronto, S. Mulyaningsih, G. Hartono, and B. Astuti, “Waduk Parangjoho dan Songputri: Alternatif Sumber Erupsi Formasi Semilir di daerah Eromoko, Kabupaten Wonogiri, Jawa Tengah,” Jurnal Geologi Indonesia, Vol. 4 No. 2, pp. 79-92, 2009. (In Indonesian).
[4] Pusat Pembinaan Sumber Daya Investasi, Sistem informasi Sumber Daya Investasi: Potensi Material Konstruksi Propinsi DI Yogyakarta, Kementerian Pekerjaan Umum, 2013 (September 14), retrieved from: http://www.pusbinsdi.net/main.php?page=potensi_material&type=&op=detail&id_prop=12. (In Indonesian).
[5] S. Widodo, I. Satyarno, S. Tudjono, Experimental study on the potential use of pumice breccia as coarse aggregate in structural lightweight concrete, International Journal of Sustainable Construction Engineering & Technology (ISSN: 2180-3242) Vol 5, No 1, 2014, 1-8.
[6] Badan Standarisasi Nasional, SNI: 15-0302-2004: Pozzolan Portland Cement, BSN, 2004. (In Indonesian).
[7] Badan Standarisasi Nasional, SNI: 03-6882-2002: Spesifikasi Mortar untuk Pekerjaan Pasangan, BSN, 2002. (In Indonesian).