Effect of basalt mineral concentration as PCC cement substitution material on mortar products

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Abstract. This research was conducted to study the effect of variations in the weight concentration of basalt minerals as a PCC type cement substitution material for mortar products. The basalt powder used was able to escape from the mesh size mesh of 325 and 400. In this work, the weight of PCC cement concentration was varied from 10, 20, 30, and 40 %. The analysis shows that the basalt qualifies as a cement or pozzolan substitution material based on ASTM C618 with SiO2+Al2O3+Fe2O3 of 80.116 % and the basalt diffractogram pattern shows the basalt dominant phases namely Anorthite, Augite, Forsterite, and Quartz or Silicon Oxide. The highest compressive strength in PCC cement mortar was at the mesh size of basalt of 400 reached 4.8 MPa followed by a percentage of specific gravity of 2.6444 gr/cm3, fuel shrinkage of 3.17 %, the porosity of 1.23 % and absorption of 9.53 %. While the compressive strength of PCC cement mortar no.325 basalt mesh powder reached 4.6 MPa followed by the percentage of specific gravity of 2.4444 gr/cm3, fuel shrinkage of 3 %, the porosity of 1.33 %, and absorption of 10.05 %. The dominant phase is in the PCC type mortar, namely CASH, quartz, calcite, and portlandite.

Keywords: Mortar, basalt, cement

1. Introduction
Basalt rock is one of the non-metallic mineral resources, whose availability is quite abundant in nature. Based on data from Mineral Resources in 2011, Indonesia has non-metallic mineral resources, namely basalt rocks totalling 5,571,251.56 tons. Meanwhile, according to the Mining and Energy Office of Lampung Province, scattered basalt rock reserves amounted to 318,480,000 tons [1]. Basalt is one of the igneous rocks formed from hardened magma, without the crystallization process that is above the earth's surface [2]. The Basalt composition was consisting of 70 % of total SiO2, Al2O3, and Fe2O3, hence making basalt was suitable to be developed as a pozzolanic material or cement substitution [3].

Pozzolan is a material that contains silica and alumina compounds, which have little or no binding properties such as cement, but the shape is smooth and the compounds will react with calcium hydroxide at normal temperatures to make compounds that are like cement when it reacts with cement [4]. Pozzolan is generally used as a cement substitution material in mortar and concrete. Mortar
consists of cement, sand, water and other additives. The use of pozzolan as a cement substitution material can improve the porosity of the paste in the mortar mixture [5].

It was reported that the basalt can be used as pozzolanic material on cement paste to provide a higher compressive strength than without the addition of pozzolanic material [6], research on the use of basalt powder in mortar instead of Portland cement has an optimal compressive strength value at a concentration of 12% [7], as well as research on the ash of basalt rock used as a substitute for portland cement has the optimum value of compressive strength at a concentration of 20% [8].

Basalt powder can be used as a cement substitution material measured using the specifications of the natural pozzolan based on ASTM C618 which needs several data such as chemical components and physical properties. Important compositions of the pozzolanic activity are SiO$_2$, Al$_2$O$_3$, and Fe$_2$O$_3$ with the total composition of those components at least 70% and have particle size around 45μm (no.325 sieve). In this test, the standard mortar compressive strength was measured after 7 until 28 days [9].

In this study, mortar samples that have been made using the addition of basalt powder minerals compared to without the addition of basalt powder. The sample has been characterized using XRF testing, XRD characterization, compressive strength, weight type, porosity, absorption, and fuel shrinkage test. The optimum conditions of basalt addition have been carried out in this research based on the best value on the compressive strength, weight type, porosity, absorption, and fuel shrinkage test.

2. Research Methodology

Basalt powder preparation in East Lampung is done by crushing the basalt stone using a jaw crusher and grinding in a ball mill for 5 hours. The basalt powder is then sifted using mesh sieve no. 325 and mesh no. 400. Characterization of basalt powder was performed by XRF (Epsilon3XLE PANalytical) and XRD (PANalytical X’Pert3).

The raw materials of the mortar used are composite portland cement (PCC) from Baturaja cement company (Indonesia), beach sand from Labuhan Maringgai (East Lampung - Indonesia), water, and basalt powder (East Lampung - Indonesia). The physical characteristic of sand includes the determination of moisture content, specific gravity, sludge content, and absorption. The raw material composition of mortar is the ratio of cement: sand by 1:5 and variations in the weight concentration of basalt towards cement are 0, 10, 20, 30 and 40%.

Mortar test materials are prepared by mixing all the ingredients in each mixture composition into a mixer container. Water are then added to the mixture and stirred until homogeneous. After that, the mixture is put into a 5×5×5 cm cube mold. The specimen is flattened, coded and stored for 24 hours and removed from the mold. The treated mortar (curing) is prepared by immersing the test object into a bucket filled with water and stored for 14 days. After 14 days, the mortar specimens were tested for compressive strength and physical tests. Compressive strength testing is carried out by the Universal Testing Machines (UTM) brand compressive strength test machine.

3. Results and Discussions

Basalt XRF test results are presented in Table 1. The table shows that basalt powder has an amount of SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ of 80.116% so that it meets chemical requirements as cement substitution material or pozzolan based on ASTM C618, where the natural pozzolan requirements with SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ content are at least 70%. The content of pozzolan with a total percentage of SiO$_2$, Al$_2$O$_3$, and Fe$_2$O$_3$ is greater than 50%, and generally produces good pozzolanic material so that it can be used as a cement substitution material [10].

The results of testing basalt powder samples using XRD equipment are shown in Figure 1. The XRD diffractogram pattern of basalt powder dominated by phases including Anorthite with the highest peak located at 20 = 27.7879°, the Augite phase with the highest peak located at 20=29.7377°, the Forsterite phase with the highest peak is located at 20=29.4753°, the Quartz phase...
with the highest peak located at 2θ=26.6691°. These phases are generally composed of elements and compounds such as calcium, silica, alumina, iron oxide and magnesium. This is supported by the results of XRF testing on the basalt sample.

Table 1. XRF basalt test results.

| No. | compound | concentration (%) |
|-----|----------|-------------------|
| 1.  | SiO₂     | 48.463            |
| 2.  | Al₂O₃    | 20.143            |
| 3.  | Fe₂O₃    | 11.510            |
| 4.  | CaO      | 9.608             |
| 5.  | MgO      | 4.269             |
| 6.  | Na₂O     | 3.559             |
| 7.  | TiO₂     | 1.266             |
| 8.  | K₂O      | 0.605             |
| 9.  | MnO      | 0.195             |

\[ \text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 \quad 80.116 \]

Figure 1. XRD diffractogram pattern of basalt powder samples.

Table 2 shows the results of sand analysis showing that overall, the sand material in this study met the standard as fine aggregate for mortar mixture. Testing of compressive strength was carried out on mortar specimens measuring 5×5×5 cm for 14 days using a compressive strength testing machine (Universal Testing Machines). The test results of PCC cement mortar compressive strength in various weight concentrations of basalt powder are shown in Figure 2.

Figure 2 shows that the compressive strength of standard mortar is 2.5 MPa. The best value of the mortar compressive strength was found at basalt mesh of 400 using 10% basalt concentration. Meanwhile, the value of the mortar compressive strength of no.325 basalt mesh with weight concentrations of basalt powder 10, 20, 30, and 40 % are 4.6 MPa, 3.372 MPa, 3.092 MPa, and 2.824 MPa, respectively. These results indicate that the weight concentration of basalt powder could affect the value of mortar compressive strength. The maximum concentration of basalt powder is at 10%.
This might because PCC cement contains many organic or composite materials such as fly ash and other pozzolanic materials so that the substitution level has reached optimum levels [11].

Figure 3 shows that the density of a standard mortar is 2 gr/cm$^3$. The best value of the specific gravity of the mortar was found at the basalt mesh of 400 using 10% basalt concentration. The mortar using 325 basalt mesh size and basalt weight concentration varied from 10, 20, 30 to 40 % have the density value of 2.4444 gr/cm$^3$, 2.3556 gr/cm$^3$, 2.3 gr/cm$^3$, and 2.133 g/cm$^3$, respectively.

Figure 4 shows that the absorption of standard mortar is 13.18 %. The best absorption value of mortar was found 9.53 % in 400 basalt mesh with concentration of 10%, followed by 11.43 %, 12.35 % for basalt concentrations of 20, 30, and 40 % at 10.25 %, respectively. The mortar using 325 basalt mesh with basalt powder weight concentrations of 10, 20, 30, and 40 % has the absorbing value of 10.05 %, 10.77 %, 11.82 %, 12.49 %, respectively.

### Table 2. Analysis of sand testing

| No. | Testing          | Results    | Standard     | Information |
|-----|------------------|------------|--------------|-------------|
| 1.  | Water content    | 3.53 %     | ≤ 10 %       | Qualify     |
| 2.  | Specific gravity | 2.5343 gr/cm$^3$ | 2.4 – 2.9 gr/cm$^3$ | Qualify     |
| 3.  | Sludge levels    | 3.69 %     | ≤ 5 %        | Qualify     |
| 4.  | Absorbtion       | 9.49 %     | ≤ 13.27 %    | Qualify     |

![Figure 2. Compressive strength in various basalt concentration](image)
Figure 5 shows that the porosity of standard mortar is 1.86%. The best mortar porosity value was found 1.23%, at 400 basalt mesh and 10% concentration; followed by 1.38%, 1.54%, and 1.76% for basalt concentrations of 20, 30, and 40%. While the mortar using 325 basalt mesh with the weight concentrations of basalt powder 10, 20, 30, and 40% has the value of mortar porosity of 1.33%, 1.43%, 1.6%, 1.8%, respectively.

Figure 6 shows that the losses of standard mortar is 3.89%. The figure also shows that the best mortar fuel losses value was found at the 400basalt mesh using 10% of basalt concentration. While the mortar using with 325 basalt mesh with the weight concentrations of basalt powder of 10, 20, 30, and 40 (%) has the value of mortar porosity of 1.33 %, 1.43 %, 1.6 %, 1.8 %, respectively. The results of XRF testing on mortar specimens are presented in Table 3.
Figure 5. The effect of basalt concentration on the porosity

Figure 6. The effect of basalt concentration on the burn losses

Table 3. XRF basalt mesh mortar test results no.325 and no.400 with various weight concentration of basalt powder.

| No. | Compound | Concentration (%) |
|-----|----------|-------------------|
|     |          | Standard B325 10 % | B325 40 % | B400 10 % | B400 40 % |
| 1.  | CaO      | 65.252            | 63.798    | 54.927    | 63.942    | 55.062    |
| 2.  | SiO₂     | 26.374            | 26.413    | 26.789    | 26.501    | 26.819    |
| 3.  | Al₂O₃    | 3.686             | 4.463     | 7.919     | 4.413     | 7.835     |
| 4.  | Fe₂O₃    | 1.741             | 2.526     | 6.123     | 2.627     | 6.176     |
| 5.  | SO₃      | 1.126             | 0.969     | 0.938     | 0.411     | 0.673     |
| 6.  | TiO₂     | 1.006             | 0.892     | 1.069     | 0.141     | 1.425     |
| 7.  | MgO      | 0.459             | 0.613     | 1.429     | 0.088     | 1.108     |
| 8.  | K₂O      | 0.181             | 0.260     | 0.436     | 0.441     | 0.637     |
| 9.  | MnO      | 0.109             | 0.118     | 0.149     | 0.164     | 0.189     |
The results of XRD testing on mortar specimens are presented in Figure 7 and Figure 8. Figures 7 and 8 showed the XRD results on mortars dominated by phase $v = \text{CASH} (\text{CaAl}_2\text{Si}_2\text{O}_8.4\text{H}_2\text{O})$, $n = \text{quartz} (\text{SiO}_2)$, $l = \text{calcite} (\text{CaCO}_3)$, $u = \text{portlandite} (\text{Ca(OH)}_2)$. The highest peak CASH phase is at $2\theta=26.6543^\circ$, quartz on $2\theta=20.8682^\circ$, portlandite on $2\theta=18.0569^\circ$, calcite on $2\theta=29.4149^\circ$ which is located in the mesh of 325 mesh and 10% of basalt. Whereas in the 400 mesh and 10% basalt mesh the highest peak CASH phase is found at $2\theta=26.6568^\circ$, quartz on $2\theta=20.8737^\circ$, portlandite on $2\theta=18.8767^\circ$, calcite on $2\theta=29.4174^\circ$.

![Figure 7. Diffractogram of XRD mortar sample with basalt mesh no.325](image_url)

![Figure 8. Diffractogram of XRD mortar sample with no.400 basalt mesh](image_url)
4. Conclusion
East Lampung mineral basalt can be used as a cement substitution material in PCC cement mortar products. The optimum particle size is at the mesh of 400 and the basalt concentration of 10%. This condition gives the best value of the compressive strength, mortar density, absorption characteristic, and burn losses.

Acknowledgment
The author would like to thank the Head of the Mineral Technology Processing Center - LIPI Lampung who has allowed to conduct research.

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