The influence of various slag mineral concentrations to physical properties of paving block products and its characteristic

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Abstract. Slag is a waste product from steel industry that has unique properties. In the presence of water, slag reacts with calcium hydroxide at ordinary temperatures to form compounds with cementations’ properties. Based on this property, slag can be used as a partially cement substitution. The influence of various slag concentration to paving block physical properties and characteristic were studied in this research. Sample paving blocks casted without addition of slag and with addition of 5 %, 15 %, 25 %, and 35 % of slag are compared. Also, the grain size of slag with 60 and 80 mesh is also compared. This research shows that the greater variation in the concentration of slag minerals makes compressive strength tends to decrease, and the absorption and porosity tend to increase. The highest compressive strength test is achieved by sample of paving block with addition of 5 % slag and has 80 mesh of grain size. Hydration of cement and slag to formed calcium silicate hydrate reaction take place in the sample which cause strong bonding among all solid material. XRD characterization shows the phase formed dominated by the four phases, gismondine (CaAl₂O₆·4H₂O), quartz (SiO₂), calcite (CaCO₃), and C-S-H (1:5 CaOSiO₂·xH₂O).

Keywords: Paving block; steel industry slag; slag mineral concentration; cement substitution

1. Introduction
The growth in the population and industry lead to the infrastructure development. The most common infrastructure development that can be found is a residential road that use asphalt as a binder to create a solid road. However, nowadays many people use paving block as a residential road material due to the fact that it is cheaper and has aesthetics value. Paving block is one type of casted concrete with a man-made system which has a certain shape and size. Increasing public demand for the use of paving blocks will affect the availability of raw materials, especially cement. Therefore, it is expected that the manufacture of paving blocks using new materials will be an alternative with the aim of reducing the use of cement [1].

From previous researches [2][3], fly ash as one of wastes in industry used as partially cement substitute in concrete due to its pozzolan properties, and so does the slag. Slag itself is a waste product formed during iron making process in steel industry. Most of the slag was thrown away due to the fact that it only contains impurities of metal. However, the slag has unique properties such as reaction with
calcium hydroxide at ordinary temperatures in the presence of water to form compounds with cementation properties (pozzolan properties). Based on this property, slag can be used as a substitution for cement. The effect of fineness should also be considered for the substitution of cement [4]. Here, we reported the result of experiment on the manufacture of paving block by using Portland Composite Cement (PCC) type, sand of Maringgai beach, rough aggregate (gravel) and the addition of different concentration of slag material as partial substitution material for cement.

2. Methodology
The preparation for the sample was done by crushing the slag rock into powder size by Ball mill for ± 3 hours. Later on, the slag powder is sifted using mesh sieve No. 60 and 80. X-ray fluorescence (XRF) and X-Ray Diffraction (XRD) were used for the characterization of slag powder with the specification XRF Epsilon3xle Bench Top to determine the content of oxide, XRD PANalytical X'Pert3 Powder to identify the formed phases.

Raw material in producing paving block sample is PCC type cement, beach sand from Maringgai Lampung Timur, water, rough aggregate (andesite rocks) from Lampung Selatan, and slag. The sample materials base ratio used was cement: sand: Coarse aggregate = 1:3:3.5 in gram. A variations of slag substitution was 0, 5, 15, 25, and 35% bases on cement weight. Then the water/cement ratio (FAS) that used is 0.75.

All materials are loaded into the mixing machine for 5 minutes, then 100 ml water was added and stirred continuously until all the ingredients were well blended and homogeneous. Later, the 5x5x5 (cm³) cube mould was used to cast the sample. The sample then allowed to dry for 24 hours, where each sample being coded and weighed. The samples were then soaked in water for 14 days followed by weight measurement for determination of physical property and its compressive strength. Meanwhile for the characterization of samples, XRF and XRD were used.

The compressive strength was measured using equation (1):

$$ \sigma = \frac{P}{A} \left( \frac{N}{mm^2} \right) $$

Whereas $\sigma$ is compressive strength (Kg/cm²), $P$ is Load (Kg), and $A$ is surface area (cm²). For porosity and absorption, the measurement was conducted using equation (2) and (3):

$$ \text{Porosity} = \frac{w_1-w_2}{V} \times 100\% $$

$$ \text{Absorption} = \frac{w_1-w_3}{w_2} \times 100\% $$

where $w_1$ is initial sample weight (gr), $w_2$ is sample weight after curing (gr), $V$ is volume (cm³), and $\rho$ is water density (g/cm³).

3. Results and Discussions

3.1. XRF characterization of slag material
Table 1 showed slag samples that have the highest oxide compounds containing of SiO₂ 25.898 %, Fe₂O₃ 25.420 %, CaO 23.243 %, Al₂O₃ 20.938 %, and MgO 2.131 %. This result showed that the number of SiO₂ + Al₂O₃ + Fe₂O₃ is around 72.256 % which means the Chemical requirement as material substitution of cement has been fulfilled. It also has an adequate Pozzolan properties based on ASTM C618 requirements namely ozzolan type N containing 70 % of SiO₂ + Al₂O₃ + Fe₂O₃.

Diffractogram of the slag was shown in Figure 1. As we can observe, the slag was dominated by following phases, namely Quartz, Calsite, Gehlenite, Hedenbergite, and Magnetite. The highest peak was Gehlenite phase on $2\theta$ = 31.3132°. Then magnetite at peak $2\theta$ = 67.794°, Hedenbergite on at peak $2\theta$ = 35.502°, CaCO₃ at peak $2\theta$ = 36.267°, and SiO₂ at Peak $2\theta$ = 24.522°, respectively. These phases were also composed of substances and compounds such as calcium, silica, alumina, iron oxide and magnesium.
Table 1. XRF Test results of slag minerals.

| No | Oxide compounds     | Percentage (%) |
|----|---------------------|----------------|
| 1  | MgO                 | 21.31          |
| 2  | 2O₃                 | 20.938         |
| 3  | SiO₂                | 25.898         |
| 4  | K₂O                 | 0.292          |
| 5  | CaO                 | 23.243         |
| 6  | TiO₂                | 0.680          |
| 7  | MnO                 | 1.613          |
| 8  | Fe₂O₃               | 25.420         |
| 9  | SiO₂ + Al₂O₃ + Faith₂O₃ | 72.256         |

Figure 1. Diffractogram pattern for XRD slag samples

3.2. Compressive strength of sample
As can be seen in Figure 2, compressive strength of the sample without slag addition is 8.612 MPa. While the values of compressive strength sample with 5 %, 15 %, 25 % and 35 % slag addition on slag grain size 60 mesh were 9.115 MPa, 8.044 MPa, 7.236 MPa and 5.528 Mpa, respectively. The values of compressive strength for sample with 5 %, 15 %, 25 % and 35 % slag addition of on slag grain size 80 mesh were 9.652 MPa, 8.854 MPa, 7.836 MPa and 6.712 Mpa, respectively. The highest compressive strength achieves by 5 % slag addition. A higher compressive strength value was caused by the reaction of calcium hydroxide with slag mineral powder that has pozzolan properties to finally produce calcium silicate hydrate that have the effect for hardened.
3.3. Absorption value

Based on Figure 3, the absorption value of sample without slag addition is 8.89 % whereas absorption values of sample with 5 %, 15 %, 25 % and 35 % slag addition at slag grain size of 60 mesh were 6.61 %, 9.26 %, 9.70 % and 9.91 %, respectively. The absorption values of sample with 5%, 15%, 25% and 35% slag addition at slag grain size of 80 mesh were 5.88 %, 9.05 %, 9.34 % and 9.73 %, respectively. The large absorption rate in sample means there was a pores or cavity inside the sample and it was an indication of low durability due to paving blocks easily absorb water and this causes strength degradation of paving block. The highest durability achieves by addition of 5 % slag with grain size 80 mesh.
3.4. Porosity testing

Porosity testing showed the sample without slag addition has a porosity value of 0.77%; whereas porosity values of sample with 5 %, 15 %, 25 % and 35 % slag addition at slag grain size of 60 mesh were 0.59 %, 0.83 %, 0.87 % and 0.92 %, respectively. The porosity values of sample with 5 %, 15 %, 25 % and 35 % slag addition at slag grain size of 80 mesh were 0.49 %, 0.81 %, 0.83 % and 0.87 %, respectively (Figure 4). According to research [5], the decrease of porosity indicates that the size of the pores between mixtures become smaller. These pores formed in sample due to less hydration occur in the sample, calcium silicate hydrate (C-S-H) were not sufficient enough to bind all solid material in whole compact material.

![Figure 4. Correlation of slag mineral concentrations with porosity](image)

3.5. XRF characterization of sample

From XRF characterization data, CaO and SiO$_2$ compound have higher quantity compare to other compounds (Table 2). These compounds were reacted with water to form calcium silicate hydrate that will bind all solid material in the sample. The quantity of other material beside CaO and SiO$_2$ were increased along with an addition of slag as a partly substituent cement.

3.6. XRD characterization of samples

From overall XRD characterization of sample, mineral phase dominated by the four phases, gismondine (CaAl$_2$O$_6$·4H$_2$O), quartz (SiO$_2$), calcite (CaCO$_3$), and C-S-H (1.5 CaO·SiO$_2$·xH$_2$O). this characterization describes calcium silicate hydrate (C-S-H) reaction take place in the sample (Figure 5 and 6). Even though the highest C-S-H belong to a sample without slag addition but with a proper amount of slag as a partly cement substituent, it can achieve the highest compressive strength more than a sample without slag addition.
Table 2. XRF Paving block characterization results.

| No | Oxide compounds | Percentage of slag mineral substitution (%) | Standard | Mesh 60 | Mesh 70 |
|----|-----------------|--------------------------------------------|----------|--------|--------|
|    |                 |                                            | 5 | 35 | 5 | 35 |
| 1  | Cao             | 51.265                                     | 39.884 | 34.953 | 40.098 | 35.997 |
| 2  | SiO₂            | 31.202                                     | 34.971 | 40.973 | 36.886 | 41.691 |
| 3  | Fe₂O₃           | 7.791                                      | 9.286 | 10.678 | 10.724 | 10.922 |
| 4  | 2O₃             | 5.489                                      | 7.018 | 5.619 | 8.025 | 6.679 |
| 5  | SO₃             | 1.023                                      | 2.589 | 2.597 | 2.603 | 2.615 |
| 6  | MgO             | 0.924                                      | 1.345 | 1.390 | 1.392 | 1.395 |
| 7  | TiO₂            | 0.812                                      | 1.250 | 1.372 | 1.287 | 1.376 |
| 8  | K₂O             | 0.769                                      | 0.867 | 0.946 | 0.935 | 0.954 |
| 9  | MnO             | 0.247                                      | 0.320 | 0.560 | 0.330 | 0.567 |

Figure 5. XRD characterization of sample with a slag concentration of 0 %, 5 %, and 35 % (60 mesh)
Figure 6. XRD characterization of sample with a slag concentration of 0 %, 5 %, and 35 % (80 mesh).

4. Conclusion
Based on tests and discussions that have been carried out on all variations of the paving block sample, slag can be a material substitution for cement, not for all cement but only a small portion. From this study the maximum portion was 5 %, lower compressive strength produced when the addition of slag is increased.

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