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Utilization of blast furnace solid waste (Slag) as cement substitution material on mortar manufacture

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ABSTRACT

Slag is defined as a waste material produced from iron ore smelting process in blast furnace. The slag was derived from Research Center for Mineral Technology located in Tanjung Bintang Lampung Selatan with particle size of 80,100, and 120 mesh. The percentages of slag used as cement substitution were 10%, 20%, and 30% from total volume. Test pieces was made by compressing all mixture material in 50 x 50 x 50 mm cubical mortar mold. Physical test of mortars, such as : porosity test, density test and compressive strength test were performed. Based on physical test of samples, it was shown that the higher ratio of slag used in cement substitution gives higher mortar porosity. Substitution of 10% slag with size of 100 mesh produced the porosity of 3.45%, while the substitution 20% and 30% slag with the same size, produced 5.08% and 5.76% porosity, compared with the standard of mortar which was 5.12%. The compressive strength test with 10% slag substitution was 19.3 Mpa, while 20% substitute slag gave the compressive strength of 19.1 Mpa and 30% substitute slag has compressive strength value of 18.7 Mpa. The standard mortar is 17.2 Mpa. However, beside of slag substitution ratio, the slag particle size also affected the compressive strength and porosity. Based on the results explained, the substitution of slag as a substitute for cement in mortar strength was still above the mortar standard.

1. INTRODUCTION

Many Researches about concretes or mortar have been done to improve the strength of concrete in terms of material aspects. Most of these studies focused with material substitution derived from industrial waste, whether rough or smooth aggregates, act as binder material or additive materials to increase the adhesive quality of concrete. One of the example is slag. Slags are produced from smelting of iron ore wastes that have almost the same physical characteristic as nature sand. The aim of this research study was to see the impact of adding slag from iron smelting waste to the cement mixture ingredients to improve concrete's strength. According to Antoni (2007), slag is defined as waste material derived from iron smelting process, where the process is using furnace, with addition of fuel burning, and ashes blown in the air. In metal casting process, iron ore or iron scrap is melted with a combination of limestone, dolomite or chalk. Steel manufactures begin with the reduction of steel impurities ion, i.g aluminums, silicon, and phosphor. To eliminate steel impurities, limestones rich in calcium ions were needed. Slag, which is made out of the mixture of aluminum, silicon, and phosphor, reacted at temperature of 1600 ^{0}C to form a liquid, then cooled to form crystal. Slags can be used as cement mixture and as aggregate substitution (Antoni,

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2007). Slag was side product made from smelting steel, which come from oxidation colonies in melting conditions, then separated from steel liquid phase throughout the smelting process in blast furnace (Josephson et al., 1997). Slags are generally formed as lumps and need preparation in application. Slags usually are used for road material, concrete aggregate, as a cement raw material because having pozzolan character (Lewis, 1982 ; Mitsufuji et al., 2000). There is a maximum limit of slag application for cement using copper slag over of 15 % caused decrease of compressive strength. The effective ratio of copper slag used is at 28 ages with 15 % variation and increasingly smooth of slag grain increase the contribution to concrete quality (Muhammad, 2015). Slags from blast furnace waste were made into mortar with dimension of 5 x 5 x 5 cm, with cement and sand ratio of 4:1. Slags used as cement substitution in mortar had variation of volume 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 75%, and 100%, respectively. Utilization of steel slags as cement substitution or mix materials should be not over than 20 % of volume (Nofrizon, 2009). Other added material are water, aggregate or cement. The function of this material is to change the characteristic of mortar or cement in pasta to comply with certain conditions or economical reason like energy saving (Nawy,1996).

Mortar is a mixture of cement, water, and sand with different compositions. As a binding material, mortar must have standard fluidity. The standard fluidity is useful to determine of mortar strength on wall plastering, so it can withstand the compression force and can not be destroyed (Mulyono, 2003).

2. METHODS

2.1 Materials and Tools

The materials used for this research were slags from blast furnace (Research unit for mineral workshop), sands, cement, and water. While the tools used were grinding ball mill, meshing 80 mesh, 100 mesh, 120 mesh and 50 x 50 x 50 mm cubical mortar mould, measuring cups, and compression strength test equipment.

The primary data gathered during experiment were physical test data, including compressive, porosity dan density test. The samples were soaking for 3 days prior the tests performance.

2.2 Procedure

The composition of raw materials used for this research was originated from the Research Unit for Mineral processing. The chemical composition of slags can be seen in Table 1.

Table 1. The Composition of Raw Material

Size of Sample	% weigh		
	Sands	Cements	Slags
Standard	60	40	-
Slag Mesh 80	60	30	10
	60	20	20
	60	10	30
Slag Mesh 100	60	30	10
	60	20	20
	60	10	30
Slag Mesh 120	60	30	10
	60	20	20
	60	10	30

The physical test performances:

- Compressive strength test

Standard test method for compressive strength of cylinder concrete specimens was referred to ASTM C39M-01. This test method is conducted by applying a compressive axial load to specimen with a surface area (mm^2) and force (N) which was within a prescribed range until failure occurs. Compressive strength of the specimen calculated by dividing the maximum load attained during the test by the cross-sectional area of specimen. The shape of specimen was cubic with size and certain age (SNI 03-6825-2002, 2002)

Compressive strength $\left({}^{Kg}/{}_{Cm^2} \text{ atau Mpa}\right) = \sigma m$

$$\sigma m = {}^{PMax}/{}_{A} \quad (1)$$

Where σm the compressive strength of mortar (Mpa) was, $PMax$ was the maximum compressive force (Newton), and A was the sectional area of specimen (mm^2).

- Porosity test

Porosity test testing methods was referred to ASTM C231-97, with the principle of submersion the specimen during 24 hours. Porosity was ratio of porous in the specimen. The porous usually contains of water or air which were interconnected and named mortar capiler. The mortar capiler would be remain even though the water had evaporated so this capiler reduced density of mortar. The increase of porous directly parallel with porosity value. As porosity has an effect to the decresed of mortar strength (Murdock and Brook, 1990).

$$\text{Porosty (\%)} = \frac{W_2 - W_1}{W_1} \times 100\ \% \quad (2)$$

Where W_1 was dry weight (gr), W_2 was weigth after absorb water saturated (gr)

- Density

Density was defined as weight on volume unit of materials devided by weight of water in the same volume

$$\text{Density} \left({}^{gr}/_{cm^2} \right) = \frac{m}{V} \quad (3)$$

Where m was mass of specimen, V was water volume

The research methodology was firstly study literature, then doing laboratory experimental. Literature studies were used for finding relevant references with this research. In laboratory experiments, samples preparations were done by making of mortar with the addition of blast furnace slag as a cement substitute with the size of specimen are 50w x 50h x 50l mm. The data were collected by conducting physical test, which are compressive strength, porosity and density tests. The procedure to make mortar was by initially refining slag of blast furnace with grinding ball mill, then meshing it to make slags with particle size of 80 mesh, 100 mesh, and 120 mesh. Afterwards, slags were weighing to produce mortar with composition ratio of 10%, 20%, 30%, and 40 % slags (calculated based on cement weights), and then added 60% of sand. All the ingredients then mixed and stirred in the mixer while water was added until pasta was formed. The pasta then molded with a size of 50 x 50 x 50 mm, left for one night, then the mortar was removed from models and submerged in water for three days.

3. RESULT AND DISCUSSION

Raw material slag from blast furnace and micro structure scanning with SEM can be seen in Figure1 and Figure 2

Based on Figure 1, it can be described that the slags from blast furnace have smooth surface and glasslike structure, but the characteristic is brittle and fragile. The formation of slags is reaction resulted from limestone and iron ore that consist of many impurities such as oxide, and the function of limestone as flux is to help catalytic and binding reaction by chemical and eliminate the impurities like silica. In this reaction, iron oxide reduces to be iron dioxide, oxidation carbon to be carbon dioxide, and impurities to be slag like glass which separated and released.

Figure 2 explain the SEM scanning of the slag from blast furnace. It showed that the crystal structures are dominated by calcite which has irregular cubic form, covered by fine grained quartz distribution, porous surface and smooth like glass [11]. The Chemical composition of slag is presented in Table 2.

Table 2. Chemical Composition of Slag

NO	Component	Composition (%)
1	CaO	40.23%
2	SiO_2	28.45%
3	MgO	4,28%
4	Al_2O_3	5.67%
5	Fe_2O_3	0.54%
6	Mn O	0.63%
7	TiO_2	0.55%
8	SO_3	0.26%

Figure 1. Slag from Blast Furnace Waste Type Glass

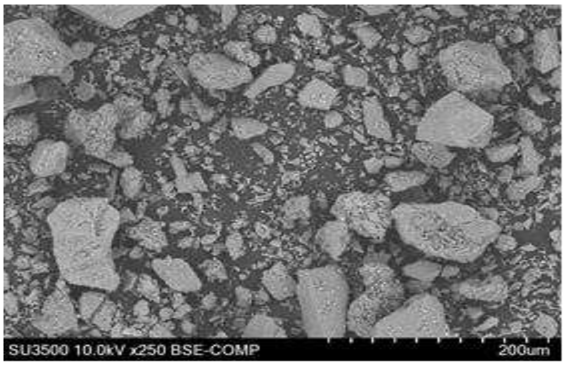

Figure 2. SEM Of Slag (250 X)

Table 3. Physical Test Result

Size of Samples	Cement Subtitutes (%)	Physical Tests		
		Porosity (%)	Compressive strength (MPa)	Density (gr/cm^3)
Standard	w/o Slags	5.12	17.20	1.78
Slag Mesh 80	10	6.53	16.65	1.70
	20	6.06	16.30	1.67
	30	11.41	15.04	1.55
Slag Mesh 100	10	3.45	19.29	2.32
	20	5.08	19.13	2.26
	30	5.76	18.71	2.11
Slag Mesh 120	10	3.33	19.70	2.40
	20	3.55	19.20	2.31
	30	5.62	18.83	2.15

Based on the chemical analysis from slag, the chemical compositions of slag are dominated by limestone, silica, magnesium, and alumina. This slags are formed from iron ore impurities, when the iron ore is melting in blast furnace at temperature of 1600 °C , reacted with calcium from limestone then added in melting process. Limestone acts as a flux which is needed for binding of impurities from iron ore, such as silica oxide, mangan, alumina, and sulfur. These bonds formed lumps named slags. Slags composition are dominated of silica, calcium, and alumina, make slag suitable to be utilized as cement substitution material because they have characteristic of pozzolan. Mixture of slag and cement would be more hydrated. Formation reactions of slags are written as follows:

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

$SiO2(s) + CaO(s) \rightarrow CaSiO3(l)$

$Al_2O_3(s) + CaO(s) \rightarrow Ca(AlO_2)_2(l)$

$P_2O_5(s) + 3CaO(s) \rightarrow Ca_3(PO_4)_2$

- Physical test of mortar to find of physical strength of mortar.

The tests include compressive strength test, porosity test, and density test. The physical tests results based on the composition of slag and cement can be seen in Table 3.

The result of compressive strength of mortar in each percentage composition of cement with size variation after submergence for 3 days. The samples for compressive strength test and the equipment of compressive strength can be seen in Figure 3 dan Figure 4.

The result of compressive strength test can be seen in Figure 5.

Slag composition of 10% with size of 80 mesh, give the compressive strength value of 16.65 Mpa, while the 100 mesh had the biggest compressive strength value of 19.29 Mpa, and the 120 mesh give compressive strength value of 19.70 Mpa. The compressive strength of 20% slag substitution with 80 mesh is 16.30 Mpa, and for size 120 Mesh, the compressive strength is 19.20 Mpa. The compressive strength for 30% slag substitution size 80 mesh is 15.40 Mpa, while for 100 mesh, the compressive strength is 18.71 Mpa and for 120 mesh, the compressive strength is 18.73 Mpa.

Figure 3. The Samples for Compressive Strength Test

Figure 4. Compressive Strength Machine

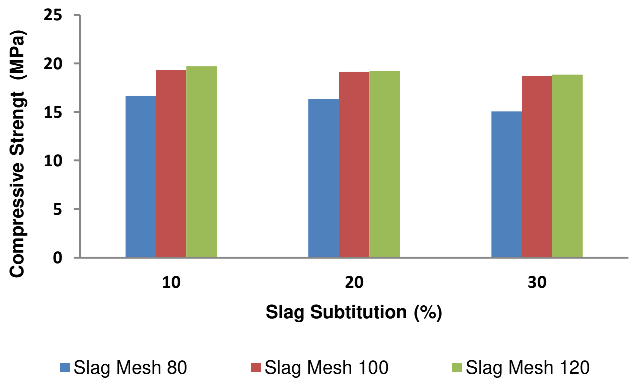

Figure 5. Slag Mesh Variation Vs Compressive Strength

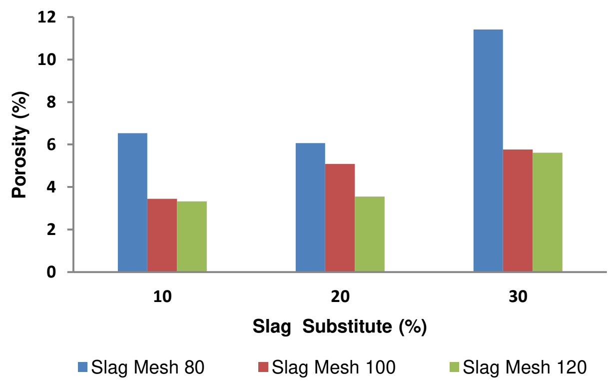

Figure 6. Porosity Test Result

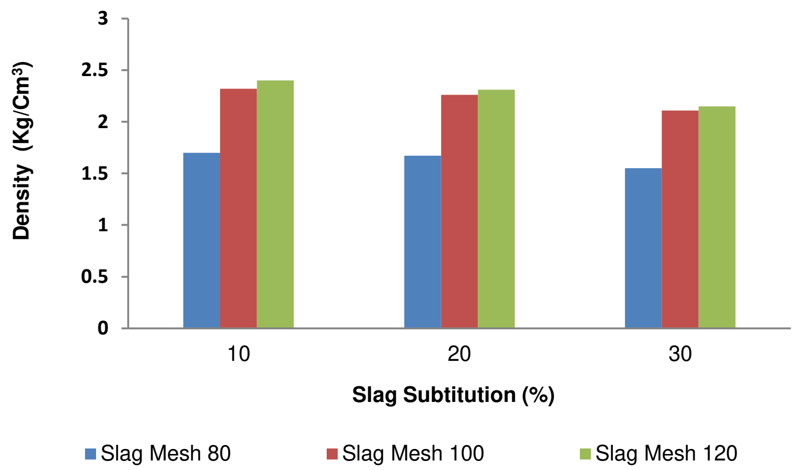

Figure 7. Density Test Result

Based on the compressive strength test result, the values are influenced by particle size of slag. Compressive strength value with particle size of 80 mesh is higher than 100 mesh and 120 mesh is slightly higher than 100 mesh. Referring to these results, it can be concluded that hydration process of cement and slag with higher size would have longer reaction than the fine grain slag. The hydration process start from outside of cement grain which has smoother grained particles of cement and slag, then hydration process goes faster and make the particles timing bind become shorter resulting in more rapid mortar strength. (Widojoko, 2010). Furthermore, slag chemical characteristics also have influence on compressive strength, because composition of slag that contains of SiO_2 and CaO, can form C-S-H bounding compound (calcium silicate hydrate). This bounding compound is more massive so that can produce higher compressive strength especially with more fine grain, due to the fact that the slag is organic material with cement characteristic. The free limestone contents in cement will be optimally used by slag as an organic material, so it will produce bounding compound (Salain, 2009). However, the quantity of slag substitution for cement should not be too much and excessive because the bounding compound in cement will be replaced by slag as organic material. The slag substitution not to be more than 20%, because it will reduce mortar compressive strength.

The porosity test was done to see the absorption level in mortar because the higher of absorption means the bigger porosity. The porosity test result can be seen in Figure 6.

Based on Figure 6, it shows that the more subtle slag size results in the smaller porosity. This is occurred when slag substitution for cement is 10% and size is 80 mesh then the porosity result is 6.53%. In addition, when size is 100 mesh, the porosity is 3.45%, and with size is 120 mesh the porosity continues to decline into 3.33%. In 20% slag substitution, when particle size is 80 mesh, the porosity is 6.06%, when it is 100 mesh then the porosity is 5.08%, and when mesh sizing is 120 the porosity decrease into 3.55%. In 0% substitution slag, when mesh sizing is 80, the porosity is 11.41%, when mesh sizing in 100, the porosity value decrease to 5.76%, and in 120 mesh the porosity is 5.62% more decreased. The decrease of porosity is directly parallel with the fineness of the slag material.. This is because of fine particles, which is derived from slag, can fill up the pores inside the mortar, that make the mortar more solid and can decrease the area that supposed to be fulfilled with water. Reducing the slag particle size will cause decrease on mortar porosity, because slag particle will rapidly react to hydration process.

Density test was performed to know the effect of slag substitution on mortar density. Density test result can be seen in Figure 7.

4. CONCLUSION

The result shows that slag particle size is affected by slag physical properties, such as compressive strength, porosity, and density. The best physical properties of slag occurred when particle size is 100 mesh, which generates the best results in terms of compressive strength, porosity, and density, compared to particle size 80 and 120 mesh. Furthermore, 10% slag substitution are able to generate greater compressive strength, porosity, and density than slag substitution of 20% and 30%. Slag can be used for cement substitution or for cement replacement in mortar production. It is more preferable to use slag with particle size of 100 mesh and not more than 10 – 20 % slag substitution, because slag substitution of 10% already has higher physical quality than mortar standard without slag addition. There are relations between compressive strength with porosity and density. Smaller porosity generates higher compressive strength and higher density.

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