JOURNAL OF NATURAL SCIENCES AND MATHEMATICS RESEARCH

Available online at http://journal.walisongo.ac.id/index.php/jnsmr

Green Concrete Made From Iron Slag Waste

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Recived: 27 November 2015, Revised: 5 December 2015 Accepted: 30 December 2015.

Abstracts

Synthesis of green concrete has been carried out by using iron slag waste of PT Inti Jaya Steel Jrakah, Semarang. Geopolimer (*green concrete*) is an aluminosilicate inorganic polymer with chain Si-O-Al that can be synthesized from material rich in silica and alumina with sodium hydroxide as an activator. Iron slag chemical content analysis indicated that this material is a part of pozzolan material with each individual components weight as follow: SiO_2: 4.55%, Al_2O_3: 2.54%, CaO: 11.43%, Fe_2O_3: 77.10%, MnO_2: 1.43 and other minerals: 4.07%. The mole ratio of SiO_2/Al_2O_3 of iron slag waste of PT Inti Jaya Steel Jrakah, Semarang is quite high at 3.05. Although the ratio is high, it is still can be synthesized using an activator solution of NaOH and increasing the drying time to 3 days and 24 hours of curing time at 60°C temperature to help the process of water molecule condensation in the geopolymerisation process. Characterized concrete (green concrete) that has been formed shows that the maximum compressive power can be achieved at composition ratio of Iron slag/ Na-silicate /NaOH /H_2O of 55/10/4/8, with compressive power of 11.254 MPa.

Key Word: Iron slag; Green Concrete; Waste.

1. Introduction

Iron slag waste which is a remainder of the steelmaking process is categorized as hazardous and toxic waste (B3). In 2010 the production of iron slags in Indonesia only around 800 thousand tons per year. Each ton of steel production generates 20 percent of the iron slag waste. Industrial waste treatment is required primarily on iron slag waste so that the impact of the environmental pollution can be reduced [1]. The Ministry of Environment states unequivocally that the steel slag waste was included in the hazardous and toxic waste (B3). The steel industry expects that the slag waste can be used for infrastructure projects. B3 waste utilization steel industry in the field of road pavement has not been done, especially in the field of cement concrete pavement, as well as the assessment of the environmental aspect is still very limited, especially the study of the characteristics of B3

and its toxic nature to the environment. In accordance with current regulations, in particular the Government Regulation No. 85/1999 on the management of hazardous and toxic (B3), steel ore is included in the B3 waste from specific sources, namely from the activities of the Steel Industry.

PT. Inti Jaya Steel, one of the steel factories in Semarang, located in Jrakah sub-district of Tugu district of Semarang. This steel factory produces steel and the remaining solid waste (iron slag) that is disposed around 10-15 tonnes of rice fields every day. If the waste is left exposed to air containing oxygen (O_2), the metal (including Fe) will oxidize into metal oxides. Rusty iron then will easily eroded and contaminate the soil and become contaminants on the soil. Furthermore, when the rains come, the majority of waste will be carried away by rain water into rice fields and watersheds around the factory. Water contaminated with these metals, when consumed will lead to the accumulation of metals in the body and cause cancer to death.

According to the explanation above, a more serious treatment to handle industrial waste of PT. Inti Jaya Steel should be carried out. Iron slag waste generated should be handled or utilized properly because of the potential environmental problems. The iron slag waste contains several compounds that are similar in composition to the cement composition such as SiO_2, CaO, MgO, Al_2O_3, MgO, Al_2O_3, Fe_2O_3.

Iron slag is a byproduct of the steel industry. The chemical content of iron slag waste typically vary depending on the base material and the steel-making process, including CaO, SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, and P_2O_5. The general mineral content of iron slag consist of olivine, merwinite C_3S, C_2S, C_4AF, C_2F, RO (CaO free) which has the same content as of cement [2,3]. The existence of C_3S, C_2S, C_4AF and C_2F on iron slag makes this material similar to cement that makes this blend has the potential to be used as concrete. However, because of the iron slag low cooling its cement mineral activity is much lower than Portland cement [4,5]. Research conducted by Wang and Yan stated that steel slag hydration level is much lower than cement, although their hydration process are very similar to each other.

Chemical content in iron slag allows the substitution of cement usage in the manufacture of environmental friendly concrete (Green concrete). Green concrete is the concept of recycling in an environmentally sound concrete industry, it suits to its purpose, does not deplete natural resources, and has a perspective on the future so as to create a condition where there will be a sustainable development (sustainable development).

The concept of recycling is essential to the use of natural materials so that it can be reduced or even be replaced. One of the recycled materials that can be used is iron slag. Iron slag is solid waste in the form of small chunks obtained as byproducts from steel making process in a blast furnace. In this article, In this article, researcher is report on Industrial Waste Utilization Optimization of Iron Steel slag of PT. Inti Jaya Steel Jrakah, Semarang as Concrete (Green Concrete).

2. Experiments Procedure

Starting Material Characterization

Iron slag in the form of lumps/ chunks as small as pebbles, crushed and then sieved and analyzed in advance for its chemical properties, among others by phase analysis using XRD, and by chemical composition analysis using XRF. The Na silicate that is being used is the technical sodium silicate. These technical sodium silicates are then analyzed first using AAS method to determine the exact percentage of the content in the Na Silicate.

Making Activator solution

Activator solution are made by mixing NaOH with distilled water beforehand. Exothermic reaction system NaOH solution will last for 24 hours. After the exothermic reaction stopped, the NaOH solution then can be mixed with the Na silicate as a binder [6,7].

Synthesis of Green Concrete

Green concrete synthesis (geopolymer) is done by mixing the iron slag with an activator solution. This mixing is done first by hand for 2 minutes followed by a mixer for approximately 5 minutes until homogeneous [8,6]. The mixture is poured into molds plastic cylinder with a diameter of 1.5 cm and 3 cm high (high and diameter ratio of the cylinder are 1: 2) [9,10]. The Pouring is gradually vibrated for 15 minutes to make it more compact and to reduce air bubbles [11]. The result is called pellets or specimen. The Pellets are then being kept untouched at room temperature for at least 1 hour until it can be released from the mold [12]. The pellets that have been removed from the molds are then being laid out into a baking dish and covered with plastic to prevent a sudden evaporation of water that can cause pellets or specimen to crack [13].

Characterization of Green Concrete

Characterization of the properties of green concrete (geopolymer) produced include mechanical characterization that is compressive strength. Geopolymer cylinder compressive strength testing performed using compressive strength testing machine (Universal Testing Machine) in Civil Engineering Laboratory UNNES. The test object geopolymer cylindrical form with a diameter of 1.5 cm and a height of 3 cm is pressed with a certain load until specimen are shattered and broken. Each testing is using three test objects in order to get an average compressive strength. Compressive strength measurements performed at 1 and 28 days age of pellets for specimen with variations of SiO_2/Al_2O_3 by increasing SiO_2 mol and Al_2O_3 mol.

3. Results and Discussion

Preparation and Characterization of Starting Material

Iron slag used in this study is the result of iron slag/ steel combustion of PT Inti Jaya Steel Jrakah Semarang. Before being used in the geopolymer synthesisf, iron slag are crushed and sieved first to remove dirt (sand or gravel) that may exist during the retrieval process. Iron slag are then roasted at a temperature of 120°C for 24 hours to remove excess of moisture, then cooled at room temperature and are ready to characterize.

Characterisation of the chemicals and mineral content of iron slag phase is important because the physical and chemical properties of iron slag are greatly affected the synthesis process and the resulting geopolymer. The Chemical content of iron slag were then analyzed using XRF (X-Ray Fluorescence) and the mineral phase component analysis of iron slag are analyzed using XRD (X-Ray Diffraction) method.

The particle shape and size of iron slag affect the activity of iron slag. The larger and more well-ordered the particle shape of iron slag, the more non-reactive it is (difficult to dissolve in alkali) because the surface area-of-touch with the solvent, in this case the solution of NaOH as enablers, getting smaller. Physically, the appearance of Iron slag of PT Inti Jaya Steel, Jrakah Semarang are in the form of chunks like large pebbles, and after being crushed and sifted, the chunks form become sand like powder with blackish brown color.

Iron slag of PT Inti Jaya Steel, Jrakah Semarang composition analysis is done at the Chemical Laboratory of the State University of Malang. The XRF method (Table 1) states that the fly ash contains a heterogeneous component with major components (major amount) as follow: the weight of SiO_2: 4.55%, the weight of Al_2O_3: 2.54% the weight of CaO: 11.43%, the weight of Fe_2O_3: 77.10%, MnO_2: 1.43 and other minerals amounted to 4.07%

Table 1. Iron slag of PT Inti Jaya Steel, Jrakah Semarang Chemical Composition

Oxide Content iron slag	Amount (%)
SiO_2	4,55
Al_2O_3	2,54
CaO	11,43
Fe_2O_3	77,10
MnO_2	1,43
Other Minerals	2,95

The information of content of SiO_2 and Al_2O_3 in iron slag are necessary in order to understand the ratio of SiO_2/Al_2O_3 starting material. The ratio of SiO_2/Al_2O_3 starting material greatly determine the chain formation of Si-O-Al geopolymer. The ratio of SiO_2/ Al_2O_3 in iron slag will also affect the necessary conditions for the formation of green concrete. The weight ratio of SiO_2/Al_2O_3 in the Iron slag PT Inti Jaya Steel, Jrakah Semarang is 1.79 or when converted into mole ratio of SiO_2/Al_2O_3 is 3.05. The conversion of percent composition by weight to the composition by mole per gram of iron slag are shown in Table 2.

Tabel 2. The conversion of percent composition by weight to the composition by mole per gram of iron slag

Fly Ash Component	Component Weight per 1 Gram Fly Ash	Component Mole Amount in every 1 Gram fly Ash (mol)
SiO_2(4,55%)	0,046	0,00076
Al_2O_3(2,54%)	0,025	0,00025
CaO (11,43%)	0,114	0,00204
Fe_2O_3(77,10%)	0,771	0,00482
MnO_2(1,43)	0,014	0,00016
Other Minerals (2,95%)	0,030	

The result of Iron slag mineral phase analysis of PT Inti Jaya Steel, Jrakah Semarang using X-ray diffraction with a wavelength of 1.54060 Å using wavelength radiation from the Cu target tube, in a voltage of 40.0 kV, 30.0 mA current. Difractogram peak observation areas carried out at from 3.000 to 90.00 degrees (Figure 1).

The Analysis result stated that the iron slag contain mostly amorphous aluminosilicate phase with Quartz and Mullite their main mineral content. Identification is done by matching the pattern of X-ray diffraction with diffraction according to standard JCPDS (Joint Committee of Powder Diffraction Standard). Sharp peaks at 2θ = 20.94; 26.64; 50.38; 54.95 and 60.02 shows the existence of the main mineral (Q) Quartz (SiO_2). Sharp peaks at 2θ = 33.31 and 42.94 shows the phase (M) Mullite ($3Al_2O_3.2SiO_2$). These sharp peaks is showing crystalline phases that are not reactive. Their broad hump at 2θ between 20 and 37 showed an amorphous phase.

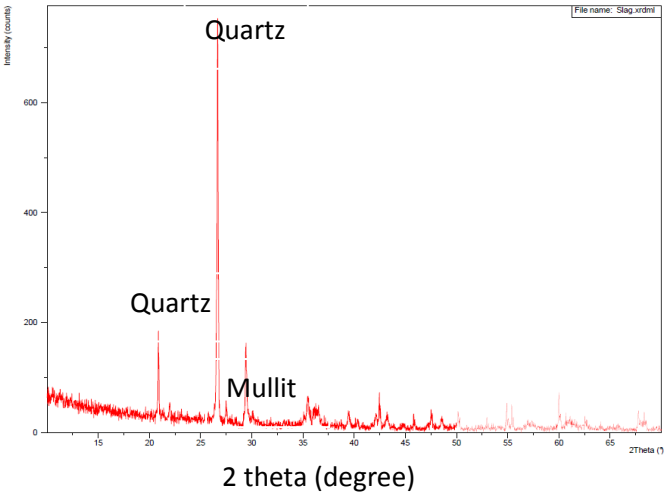

Figure 1. Difractogram of Iron slag PT Inti Jaya Steel, Jrakah Semarang

Amorphous silica and alumina are believed to be more reactive and have greater solubility in the strong alkali rather than the crystalline phase [14]. In the manufacture of green concrete, not all silica (SiO_2) and alumina (Al_2O_3) in iron slag can be dissolved in strong alkali. The more number of the amorphous aluminosilicate in the iron slag, the more reactive the iron slag will be, and the more silica and alumina dissolved. Furthermore, the more number of the silica and alumina dissolved in strong alkali, the more the formation of aluminosilicate gel in green concrete. The green concrete Synthesis preceded by dissolution of silica and alumina, thus forming a silicate and aluminate monomers that will condense and form a gel of aluminosilicate with main chain Si-O-Al. Therefore, the ratio of silica and alumina in an amorphous phase iron slag has an important role in the formation of aluminosilicate gel in geopolymer.

The adding of Na_2SiO_3 or sodium silicate (alkaline activator) in the manufacture of green concrete is functioning as a binder. The addition of this sodium silicate also aims to increase the dissolved of Si species so that there will be enough oligomeric silicates to extend the chain structure. Na_2SiO_3 composition analysis used in this study is conducted by using AAS method. The chemical composition in percent by weight and moles in each gram of sodium silicate is shown in Table 3.

Tabel 3. The Chemical Composition in each gram Natrium Silicate

Na_2SiO_3 Component	Weight Percentage (%)	Moles in each Gram (mol)
Na_2O	47,52	0,00766
Al_2O_3	0,20	0,00002
SiO_2	41,27	0,00688
CaO	3,40	0,00061
Other Minor Components	7,61	

Activator solution was made by dissolving NaOH into distilled water. NaOH used in this study had a purity of 99% and each gram of NaOH (Mr = 40 g / mol) will donate 0.025 mol species Na + and 0.025 mol OH- species.

Synthesis of Green Concrete

Green Concrete is a geopolymer concrete. The Information of mole ratio of SiO_2/Al_2O_3 starting materials will greatly determine the characteristics of green concrete that will be created. Mole ratio of SiO_2/Al_2O_3 starting material is determined by the chemical composition of the oxide content in it. The starting materials manufacture of green concrete will be in the form of iron slag, Na silicate and sodium hydroxide, so the total moles of SiO_2 derived from iron slag and Na silicate that were added.

The study was conducted by varying the weight of iron slag (a solid material or solid) added, while the number of Na silicate, NaOH and H_2O (liquid material or liquid) are set to be fixed as shown in Table 4. This research was conducted in order to obtain the composition of the initial S/L subsequently used as a standard for composition at various SiO_2/Al_2O_3 mole. This research also tried to varying the weight of iron slag in order to produce variations in the S/L ratio. The addition of iron slag started at 35 grams of weight, because at this composition, the preparation of pasta green concrete is still possible (watery, but it can already be printed). The extra weight of iron slag until it forms a paste that cannot be printed is on the weight addition of 65 grams of iron slag. In Table 4, the variations of iron slag weight addition on the production of green concrete can be seen clearly.

The composition variation of the iron slag will produce a different mole ratio of SiO_2/Al_2O_3. The variations of S/L (the ratio of the weight of the solid/liquid) are done on the composition of the S/L = 1.591 and then varying the S/L to increase to S/L = 2.727. The limit of S/L variations to increase or decrease is until the mixture of iron slag, Na silicate, NaOH and H_2O produce paste that cannot be printed anymore because it is too thick nor too thin.

Paste is printed on the plastic cylindrical mold with a diameter of 1.5 cm and 3.0 cm high (ratio of high and diameter of the cylinder is 1: 2) (and being vibrated for 15 minutes to make it more compact and to reduce air bubbles). Paste is released from the mold as soon as the paste gets thickens and hardens. The printing result is called pellets or specimen. Pellets are placed in a baking dish with a closed plastic to reduce sudden loss of water. These pellets are then dried for 3 days and kept in the oven for 24 hours at a temperature of 60°C and tested with compressive strength test at age of 28 days.

Green Concrete Characterization

Table 4 shows the result of the measurement of compressive strength of geopolymer concrete with iron slag weight variation, with fixed weight of Na-silicate, NaOH, and H_2O. Based on Table 4.4 it can be seen that the increase in weight of iron slag that were added, the greater the ratio S/L green concrete is formed, and the more

decrease in ratio of moles of SiO_2/Al_2O_3. Figure 2 is a graph of the relationship between the S/L ratio and the compressive strength resulted from this study.

Table 4. Data of measurement result of compressive strength of geopolymer concrete with iron slag weight variation adding.

Iron slag (g)	Na-Silicate (g)	NaOH (g)	H_2O (g)	Mol SiO_2/Al_2O_3	S/L	Compressive Strength (Mpa)
35	10	4	8	10,937	1,591	2,371
40	10	4	8	9,951	1,818	3,595
45	10	4	8	9,183	2,045	3,671
50	10	4	8	8,570	2,273	11,254
55	10	4	8	8,067	2,500	3,824
60	10	4	8	1,401	2,727	3,748

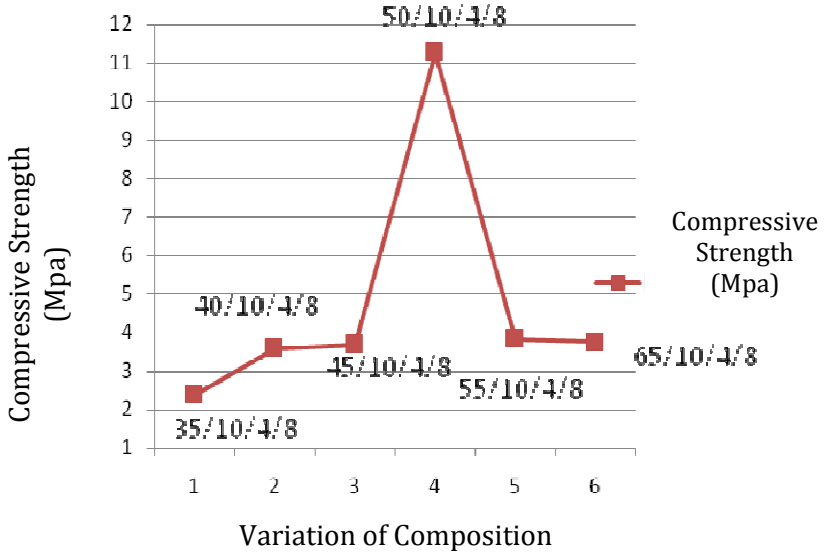

Figure 2 Graph of relationship between S/L Ratio and compressive strength

Figure 2 shows that the compressive strength initially increased in line with the S/L ratio until the S/L with the strongest compressive strength, and then decline thereafter. The optimum compressive strength achieved in the S/L ratio = 2.273 which is equal to 11.254 MPa. On reaching the S/L ratio = 2.500, the geopolymer concrete compressive strength decreased. This is due to a lot of iron slag are added, the more brittle the green concrete is formed, thus lowering the compressive strength. The theory by Chindaprasirt et al [15], stated that the ease of workmanship of paste will increase with the addition of water, but the addition of more water will actually make the power lower.

The more the ratio of S/L, the smaller the water content in the geopolymer will be. Evaporation of the water left a little bit too empty cavities (pores), so that the compressive strength is on the rise, but when the S/L has reached its optimum, the compressive strength will decline. Evaporation of much more water will leave a lot of empty space (cavity) which will reduce the strength of geopolymer [12]. The Compressive strength will decrease as the amount of water is no longer be able to balance the amount of solid

material (iron slag) that were added. In addition, unreacted Iron slag are in fact will lower the compressive strength.

4. Conclusion

Analysis of the iron slag chemical content of PT Inti Jaya Iron Steel, Jrakah Semarang showed that this material is included as pozzolan material, with contents of silica and alumina. The mole ratio of SiO_2/Al_2O_3 in the iron slag of Inti Jaya Steel, Jrakah Semarang is 3.05. The iron slag of PT Inti Jaya Steel, Jrakah Semarang can be synthesized into green concrete by increasing the drying time for 3 days, and the curing time for 24 hours at a temperature of 60°C since it has a high mole ratio of SiO_2/Al_2O_3 in order to assist the process of condensation on the geopolimerization.

Acknowledgment

The author wish to thank LP2M Universitas Islam Negeri Walisongo Semarang for financial support in this research.

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