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RESEARCH ARTICLE

Characteristics of Kedondong Trass and Bobos Trass as Cement Raw Material, Cirebon, West Java, Indonesia

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Abstract

The use of cement materials in construction continues to increase every year, consumes lots of raw material and emits CO_2 from clinker production. To eliminate this negative effect, alternative materials are needed. Trass is natural pozzolan which is formed from silica-alumina rich volcanic rocks. As supplementary cementitious material, trass is sufficiently durable and reduce clinker proportion in cement mixture, thus more environmentally friendly.

This research aims to determine characteristics and composition of Kedondong trass and Bobos trass, Cirebon, West Java as raw material for pozzolan cement. The study was conducted using petrography and XRD analysis to determine mineralogy of rocks. XRF analysis was carried out to determine chemical composition as well as other tests to determine trass quality.

Kedondong trass is originated from andesite intrusion and andesitic breccia, while Bobos trass is formed from hypersthene-andesite intrusion. Based on mineralogy analysis, trasses have similar mineral composition consist of plagioclase, quartz, pyroxene, hornblende, and sanidine. XRD analysis shows abundance of cristobalite and tridymite from each samples. This mineralogy is confirmed by geochemistry result, which is the samples contain more than 70% SiO_2 + Al_2O_3 and less than 4% SO_3. Other chemical characteristics that have been tested are moisture content, ignition loss, and clay content in which all of those parameters meet the industrial standard for cement material.

Keywords: Trass, Supplementary Cementitious Material (SCM), Pozzolanic Cement, Cirebon

1. Introduction

Cement production in Indonesia has dubbed to be one of the largest in the world. By the last decade, domestic sales is consistently rising every year to fulfill demand from development of national infrastructures.The highest growth is in 2011, which was 17.7% with volume of 48 million tons. Later, local and multinational cement producers are expanding their production capacity (Asosiasi Semen Indonesia, 2018). Regular Portland cement production has massive carbon footprint which significantly contribute to climate change. More than 4 billion tonnes of cement manufactured each year emits for around 8% of the world's CO_2 emissions (Lehne and Preston, 2018).

This high emissions is linked to the clinker production, a mixture of raw materials fused together by heat, for the main ingredient of cement. Clinker is a product of chemical conversion called calcination in which limestone ($CaCO_3$) is converted to lime (CaO). During its process, CO_2 is released in the kiln at 600 – 900 C (Gibbs et al., 2001) as follows:

$$CaCO_3 + heat \rightarrow CaO + CO_2 \quad (1)$$

Natural pozzolans can be used as clinker substitution in cement blends because its cementitious properties, known as pozzolanic activity. Pozzolan is defined as siliceous and aluminous materials that has little to no cementitious properties on its own, but when finely grounded and combined with calcium hydroxide in water, it has ability of hydraulic binding (Çullu et al., 2016). Benefit of pozzolans including low heat of hydration, high strength, low permeability, and low alkaline-silica reaction. Mineral deposits with pozzolanic Rocks of volcanic origin, particularly pyroclastic materials from explosive eruption possess pozzolanic properties without extensive processing. Trass is one of variety of volcanic ash which possesses pozzolanic properties.

As a volcanic active regions, Indonesia is rich in volcanic rocks which some of these are already used as natural pozzolan in national's cement industry. One of national cement manufacturer operate in the study area (Fig.1) at Palimanan, Cirebon Regency, West Java, produced ordinary Portland cement and pozzolanic cement. By local people, natural pozzolans in the study area is more commonly referred to as trass. Kedondong and Bobos are two quarries location used by the manufacturer, hence the name, Kedondong trass and Bobos trass. Aims of this study is to provide information on trass characteristics and its prospect in this country as supplementary cementitious materials (SCM).

2. Geological setting

Study area is part of Bogor Zone physiography, a Neogene sedimentary sequences intruded by many volcanic rocks, now is a strongly folded anticlinorium (Satyana et al., 2002; Van Bemmelen, 1949). Rock formations in the study area is mainly dominated by

Plio-Pleistocene volcanic rocks on top of Miocene-Pliocene marine sediments (Fig.1). Kromong Limestone consists of Miocene reef limestone complex in the northern part of study area, which is the main material for cement. Kaliwangu Formation is Pliocene marine sediments rich in molluscs, consist of shale intercalated with sand and gravel. On top of those, Plio-Pleistocene volcanic rocks are andesitic-tuffaceous Kromong Breccia, undifferentiated volcanic rocks, and andesite intrusions (Aswan et al., 2013; Djuri, 1995; Jambak et al., 2015).

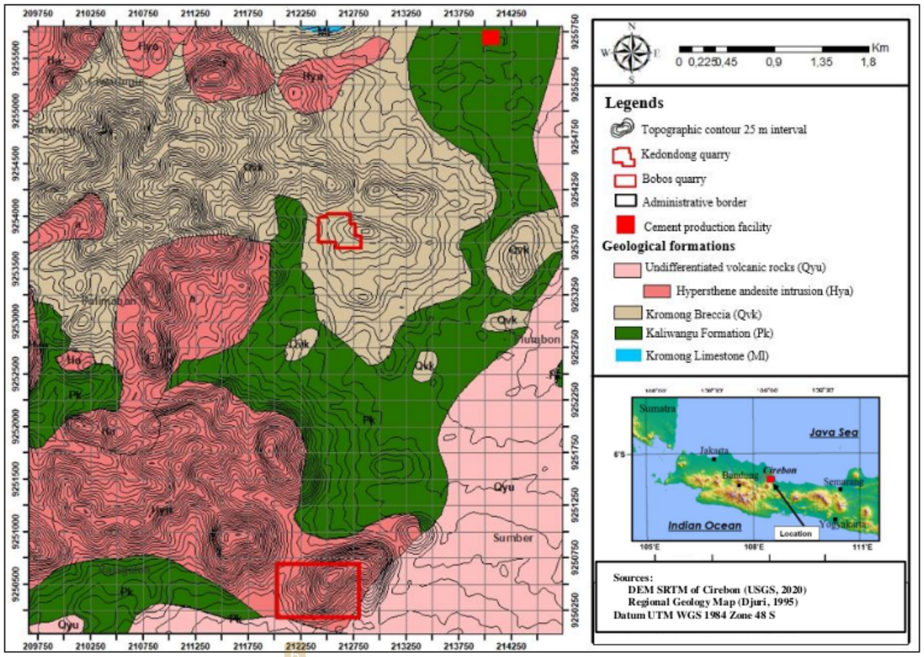

Fig 1. Location and regional geology map of study area

3. Methodology

3.1 Research methods

From geological map, the two locations have different rock type in which Kedondong trass is originated from Kromong Breccia while Bobos trass is originated from Andesite Intrusion. Samples were obtained directly in the field from existing quarries of two locations, 9 samples from Kedondong and 10 samples from Bobos. Laboratory analysis were carried out to determine characteristics of trass as follows:

a. Thin section samples were prepared to identify mineralogical and petrographical characteristics under polarizing microscope. Both fresh rock and altered rock samples were used to compare this aspect.
b. X-ray diffraction (XRD) analysis of powdered bulk samples was conducted to determine whether silica minerals were present in trass. This is to accomodate one of requirement in which trass must contain crystalline silica such as tridymite and cristobalite. Geochemistry of samples were determined using X-ray fluorescence (XRF) analysis, most importantly to identify some of the major elements comprising SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, and SO_3.
c. Moisture content was determined by weighing 100 gr of samples before and after drying 1-2 hours in the oven. For loss on ignition parameter: 1 gr of finely ground samples was heated in the crucible at 500°C for 30 minutes. Followed by igniting the samples in the furnace of 1000°C for 1 hour. After being cooled in the dessicator, samples are weighed again.
d. Clay content was determined by adsorption test: mixing 5 gr of finely ground samples 25 ml aquades using magnetic stirrer for 5 minutes, and then adding 2 ml methylene blue. Clay particle will react and adsorbed by methylene blue. Stain test on filter paper was conducted until a light blue halo showed in the paper by adding more methylene blue, that means all clay was adsorbed (Chiappone et al., 2004). The more methylene blue is added to show the blue halo, the higher is clay content in the samples.

3.2 Specifications of trass

The intrinsic capacity of pozzolans is depend of chemical composition, which is varies greatly in volcanic deposits (Yu et al., 2017). After chemical criteria meets the requirement, most raw materials need to be processed to meets the physical criteria such as fineness, moisture, and strength (Sleep and Masley, 2018). American Standard for Testing Materials (ASTM) C618-94a 1993 (ASTM, 1993) specifies standard chemical composition of raw and calcined natural pozzolans for use in concrete as shown by Table 1. According to national standard of SNI-04-1989-F (Badan Standardisasi Nasional, 1989), trass can be used in light construction with several requirements based on building classes (Table 2.). Trass commonly used for Portland Pozzolan Cement (PPC) mixture, concrete, plastering, or brick mixture.

Table 1. ASTM C618-94a 1993 for natural pozzolans.

Chemical compound	Wt % range
SiO_2	40.76 – 56.20
Al_2O_3	17.35 – 27.95
Fe_2O_3	7.35 – 13.15
H_2O	3.35 – 10.70
CaO	0.82 – 10.27
MgO	1.95 – 8.05
$SiO_2 + Al_2O_3$ minimum	70.0%
SO_3 maximum	4.0%
Na_2O maximum	1.5%
Moisture content maximum	3.0%
Loss in ignition maximum	10.0%

Table 2. Trass requirement from SNI-04-1989-F

Requirement	Class 1	Class II	Class III
1. Free moisture at 110°C in wt%	< 6	6-8	8-10
2. Fineness (% maximum of particle larger than 0,21 mm)	< 10	10-30	30-50
3. Maximum binding time in days	1	2	3
4. Compressive strength after 14 days (kgf/cm²)	100	100-75	75-50

Based on ASTM and SNI standard, PT. Indocement Tunggal Prakarsa Tbk at Palimanan Unit establishes a modified standard parameter of trass for its manufacture as shown by Table 3. To meet the standard several samples of trass must go through chemical and physical analysis such as XRF analysis, moisture, loss on ignition, and clay content. XRD analysis is also conducted to make sure any crystalline silica presents in trass samples.

Table 3. Trass quality requirement in PT. Indocement Tunggal Prakarsa Tbk Palimanan Unit

Parameter	Requirement
1. Total $SiO_2 + Al_2O_3$	Minimum 70.0 wt. %
2. SO_3	Maximum 4.0%
3. Moisture	1% – 5.6%
4. Loss on ignition	Maximum 10%
5. Clay content	Maximum 5%
6. Silica	Must be present (tridymite, cristobalite)

5. Results

5.1 Lithology of the quarries

Lithology observed in the field from the two quarry are slightly different as expected by regional geology map. Kedondong quarry which from regional geology map is part of Kromong Breccia, is covered by two type of andesitic rocks (Fig.2). The first one is andesitic breccia which characterized by moderately weathered, brownish color, cobble-pebble sized andesite fragment inside tuffaceous matrix. This breccia is intruded by dark-grey andesite which formed a morphologically distinctive intrusion hill than its surroundings. Andesite has sheeting joint structure, intensively weathered with some fresh andesite still present, composed by plagioclase and hornblende phenocryst in fine grained groundmass.

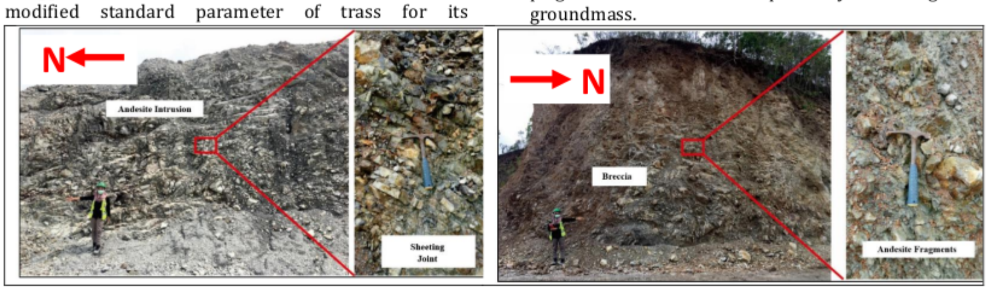

Fig 2. Lithology found in Kedondong quarry

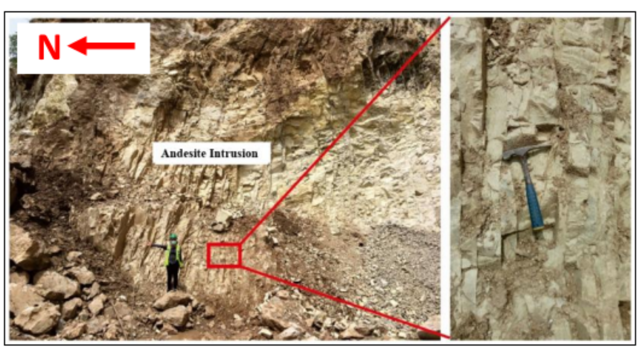

Fig 3. Weathered hypersthene-andesite in Bobos quarry

Bobos quarry located in volcanic hills morphology and identified as Andesite Intrusion from regional geology map. From the quarry observation, we also found fine grained hypersthene-andesite which consistent to the reference. Exposed rocks also exhibit moderately to highly weathered condition, resulted in softer and yellowish rocks (Fig.3). Dominant phenocryst is plagioclase with pyroxene accessory in aphanitic groundmass.

In both location, the degree of weathering greatly changes original texture, structure, and overall appearance of rocks even though the fresh rocks are still present to be observed. Beside of original rock composition, this process is important to bring in pozzolanic properties of trass deposits.

5.2 Mineralogy and petrography of rocks

Mineralogy is inspected by thin section observation of samples from both locations. While both Kedondong and Bobos have similar composition of andesitic rocks, there is slightly difference in mineralogical and petrographical aspect as shown by Table 4. Both rocks are composed of plagioclase as dominant phenocryst (40-50%), pyroxene, hornblende, quartz, and opaque mineral.

The fragments have similar composition with andesite from intrusion. Bobos andesite contains more pyroxene (hypersthene) and less glassy groundmass (Fig.6). Other than fresh hand specimens, altered samples were also being inspected through thin section, showing leached texture, altered rim in some phenocryst, and finer groundmass in all rocks. Kedondong andesite has less phenocryst and more glassy groundmass than Bobos andesite (Fig,4). Meanwhile, thin section of andesitic breccia from Kedondong shows abundant volcanic glass matrix, along with minor fine grained crystal and opaque mineral surround the andesitic fragments (Fig.5).

Table 4. Mineralogy of rocks from Kedondong and Bobos

Samples	Mineral content	Characteristics
Kedondong		
Andesite	Plagioclase (labradorite), hornblende, pyroxene, quartz, opaque minerals	Porphyritic texture, glassy groundmass
Andesitic Breccia	Volcanic glass, plagioclase, quartz, opaque mineral, hornblende	Tuff as dominant matrix supporting andesite fragments
Bobos		
Hypersthene-Andesite	Plagioclase (labradorite), orthopyroxene, hornbende, quartz, opaque mineral	Porphyritic texture, little to no glassy groundmass

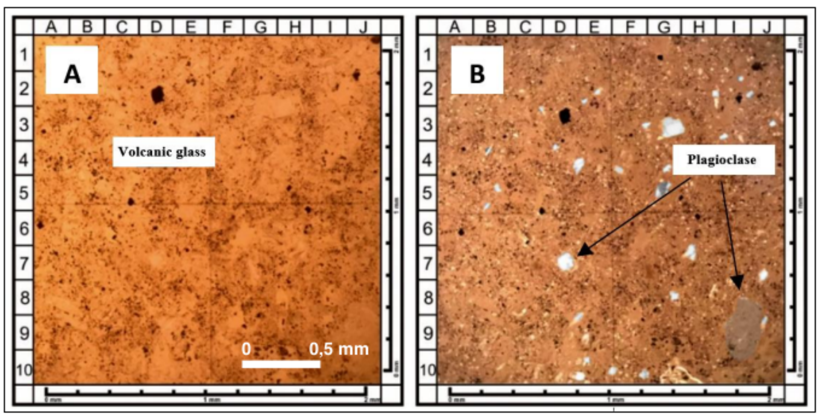

Fig 5. Thin section of matrix part from Kedondong's andesitic breccia: (A) plane polarized and (B) cross polarized

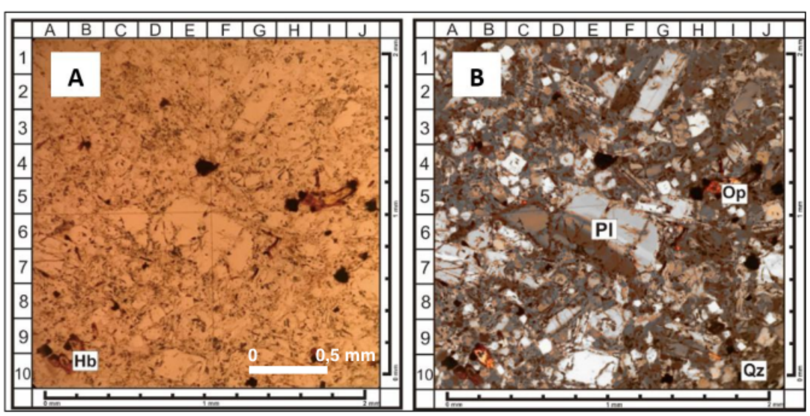

Fig 6. Thin section of Bobos andesite: (A) plane polarized and (B) cross polarized (Pl : Plagioclase, Qz : Quartz (I10), Hb : Hornblende (B10), Op : Orthopyroxene (H5))

5.3 Trass mineralogy

The result from petrographical analysis is supported by XRD analysis of powdered bulk sample, as summarized by Table 5. All of the samples show R-WP less than 10% which are considered good and fit (Toby, 2021). Although there are two different rocks in Kedondong, they are regarded as one because in this section, we are focusing on trass characteristics which is the main commodity of the quarry. According to the XRD analysis, trass samples from both quarry contain quartz, plagioclase, kaolinite, sanidine, tridymite, cristobalite, and hematite. Tridymite and cristobalite are crystalline silica which are important to contribute pozzolanic activity. Kedondong trass contains 0.67% - 9.42% tridymite and 6.0% - 20.26% cristobalite. At Kedondong quarry, samples from breccia have higher quartz content but lower in other silica. Andesite samples are relatively more weathered than breccias, so it is related to the lower abundance of quartz as resistant mineral. Bobos trass contains 0.8% – 2.52% tridymite and 0.2% - 5.36% cristobalite. The abundance of crystalline silica is differ significantly, where Kedondong trass are higher in tridymite and cristobalite than Bobos samples. This might be correspond with higher percentage of groundmass in Kedondong rocks as shown by petrographical analysis. Kaolinite as alteration product also present, in which Kedondong trass also contains at higher percentage than Bobos trass.

Table 5. Test results of XRD analysis from Kedondong and Bobos trasses (in percent)

Code	R-WP*	Quartz	Sanidine	Plagioclase	Kaolinite	Tridymite	Cristobalite	Hematite
Kedondong								
KD 1	6.86	26.48	20.17	40.55	5.37	0.84	5.73	0.86
KD 2	6.34	26.75	20.75	40.65	4.91	0.93	5.60	0.41
KD 3	6.68	25.88	20.17	41.70	5.65	0.67	5.53	0.40
KD 4	7.67	0.06	12.30	52.38	7.94	8.42	18.70	0.20
KD 5	7.92	0.55	14.35	56.73	2.64	5.47	20.05	0.21
KD 6	7.40	0.33	17.39	53.29	3.43	7.59	17.61	0.36
KD 7	8.05	0.21	17.84	49.24	5.35	8.55	18.17	0.65
KD 8	9.06	0.42	17.36	46.80	8.79	9.4	16.92	0.32
KD 9	7.58	0.19	15.62	46.60	10.57	6.81	19.80	0.41
Bobos								
SLS B1	6.69	28.95	21.01	42.6	2.83	1.48	3.13	0.13
SLS B2	6.39	30.80	20.90	42.64	1.84	0.80	3.02	0.65
SLS B3	5.48	30.87	21.21	31.18	14.31	1.26	1.17	0.13
SLS B4	6.94	27.97	20.38	47.24	0.31	1.30	2.80	0.28
B2	8.07	23.16	20.94	47.51	0.56	2.52	5.31	0.08
B3	7.93	31.55	20.71	45.60	0.46	1.38	0.30	0.20
B4	7.21	23.89	21.66	46.82	0.16	2.30	5.17	0.11
B5	6.28	33.46	20.47	42.25	2.74	0.94	0.14	0.09
B6	6.83	24.26	20.92	47.67	0.20	1.59	5.36	0.11

Table 6. Test results of geochemistry analysis using XRF method from Kedondong and Bobos trasses

Code	Moisture content (%)	LOI (%)	Clay content (%)	Major oxides (wt%)								SiO_2+ Al_2O_3
				SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	
Kedondong												
KD 1	10.80	3.26	4.4	69.69	15.84	3.39	3.37	0.00	2.97	1.41	0.024	85.5
KD 2	13.62	3.20	3.0	68.44	15.9	3.61	3.6	0.17	3.01	1.44	0.022	84.3
KD 3	4.15	2.88	2.5	71.67	15.91	3.15	2.98	0.00	3.08	1.57	0.023	87.6
KD 4	1.58	2.27	2.6	70.88	15.06	3.39	3.69	0.00	3.17	1.46	0.020	85.9
KD 5	2.83	1.88	1.6	71.21	15.04	3.25	3.77	0.06	3.37	1.48	0.021	86.3
KD 6	4.77	2.50	2.0	71.15	15.43	3.30	3.45	0.00	3.25	1.45	0.018	86.6
KD 7	3.09	1.74	1.2	71.81	15.43	3.00	3.51	0.00	3.32	1.50	0.020	87.2
KD 8	2.80	2.19	1.6	71.24	15.34	3.32	3.47	0.02	3.20	1.48	0.032	86.5
KD 9	4.08	2.68	1.4	69.67	15.82	3.32	3.69	0.00	3.11	1.54	0.026	85.5
Bobos												
SLS B1	5.05	4.37	1.6	70.52	15.12	3.03	3.60	0.39	2.99	1.55	0.037	85.6
SLS B2	6.55	5.05	2.0	70.86	15.77	2.89	3.62	0.00	3.35	1.65	0.037	86.6
SLS B3	12.8	2.68	4.6	68.21	16.10	3.17	3.05	0.28	2.66	1.59	0.035	84.8
SLS B4	4.77	2.61	2.5	70.44	15.19	3.24	3.52	0.07	3.38	1.62	0.034	85.6
B2	1.14	1.63	1.4	69.47	14.86	2.91	4.56	0.37	3.58	1.59	0.036	84.0
B3	0.93	2.6	1.2	68.75	14.76	2.61	3.69	0.00	3.57	1.57	0.028	83.0
B4	1.60	1.03	1.4	71.87	15.23	2.97	3.28	0.38	3.69	1.59	0.011	87.0
B5	4.62	2.77	2.6	70.95	15.42	3.28	2.99	0.28	3.07	1.59	0.007	86.3
B6	1.68	1.57	1.8	70.67	15.02	2.94	3.67	0.34	3.55	1.60	0.025	85.6

5.4 Chemical properties of trass

In the quarries, trasses have a variation of physical appearance that rather different than fresh rocks. Kedondong trass still contains fine-medium grained minerals between highly weathered groundmass. Bobos trass has finer mineral grains but relatively more compact than Kedondong trass. Chemical properties have been analysed from 18 samples as summarized by Table 6. Result of water content analysis showed that most of samples contain less than 5.6% moisture within the standard criteria, with the exception 4 samples have 6.55%-13.62% moisture. This high moisture results might be correlated with weather, sampling, and preparation technique as the sampling was conducted in January when rainfall is quite high. Loss on ignition (LOI) of samples ranges between 1.57% - 5.05% which is also meet the standard. Clay content in trass samples is determined by adsorption test using methylene blue. The result showed range of 0.4% - 4.6% clay content among the samples. The standard trass has less than 5% clay content.

Geochemistry have been analysed from 18 powdered bulk samples using XRF method. All samples have no striking difference chemistry as follows: SiO_2 as highest compound at 68.21% - 71.81% and Al_2O_3 at 14.76% - 16.10%, That make the sum of silica and alumina constituent at about 83.0% - 87.58%. SO_3 as one of quality parameter is present at very small amount of 0.007% - 0.037%. The chemical analysis shown the sum of $SiO_2 + Al_2O_3 > 70\%$ and SO_3 content $< 4\%$. This result is within the standard of chemistry criteria from ASTM and the manufacturer.

6. Quality of trass as SCM

Kedondong trass and Bobos trass have been used as supplementary cementitious material by PT. Indocement Tunggal Prakarsa Tbk Palimanan Unit. Bobos quarry located farther than Kedondong quarry from the production facility. Lithology of Kedondong quarry are andesitic breccia and andesite intrusion, composed of minerals such as plagioclase, quartz, pyroxene, and hornblende with abundant volcanic ash/glass. Bobos' hypersthene-andesite intrusion contains less volcanic glass due to the abundance of crystals. Volcanic glass is a highly reactive, unstable, and vulnerable to alteration. This alteration activates pozzolanic properties in material (Montanheiro et al., 2004). Tridymite and cristobalite are crystalline silica detected by XRD analysis in all trass samples. The presence of silica is also required as a condition that material has pozzolanic activity (Waani and Elisabeth, 2017).

Nearly all results from chemical test of trass samples are within the company standard and ASTM standard as well. As natural pozzolans, Kedondong and Bobos trass contain 83% - 87% silica and alumina originated from intermediate volcanic rocks. In addition to durability aspect, silica and alumina compounds are responsible for reacting with hydroxides to produce calcium silica hydrate (C-S-H).This byproduct of water and cement reaction is a strong binding agent which desired in the mixture (Sleep and Masley, 2018). Generally, the higher SiO_2 in natural pozzolans, the better pozzolanic activity (Çavdar and Yetgin, 2007). Sulfur trioxide in trass samples is far below the maximum threshold standard of 4%. Moisture content, LOI, and clay content also conform to the standards of trass. Based of all chemical requirement, Kedondong and Bobos trass can be used as one of the cementitious material to reduce clinker.

Conclusions

Kedondong trass and Bobos trass are originated from andesitic breccia and andesite intrusion, product of intermediate volcanic activity. Rock composition shows abundant volcanic glass and silica as pozzolanic agent. Trass samples have been tested chemically including silica+alumina content, sulphur trioxide content, moisture content, LOI, and clay content. The results are meet the company and ASTM standard for supplementary cementitious material. While all of chemical requirements are within standard, it is recommended to test the physical requirement which correspond to pozzolanic properties such as fineness and compressive strength.

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