Study of Fine Artificial Lightweight Aggregate (ALWA) from Sidoarjo-Mud and Fly Ash with Different Calcination and Composition

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Abstract: Sidoarjo mud is the result of an erupting mud volcano in Porong, Sidoarjo, Indonesia. It is the largest mud volcano in the world. The utilization of mud is developed to increase the value of the mud so that it can create incomes. This study investigates the characteristics of Fine Artificial Lightweight Aggregate (ALWA) from Sidoarjo Mud and fly ash. Fine ALWA was made from 100% Sidoarjo mud FA, 70% sidoarjo mud 30% fly ash, and 50% sidoarjo mud 50% fly ash. Every composition was calcinated at 1000°C (for 4 and 6 hours) and at 1050°C (for 4 and 6 hours). Every composition is tested for spesific gravity, density, absorption and analys XRay Diffraction and Scanning Electron Microscope (SEM). The result shows that the lowest spesific gravity (1,9 kg/m^3), lowest density (993.63 kg/m^3), and lowest absorption (10.50%) occur in 50 sidoarjo mud of 50 fly ash 1050C and 360 mnt when calcinated. XRay Diffraction analisys shows that all of the variations are dominated by quartz, anorthide, and hematite. Scanning Electron Microscope show the different structure of the different composition.

1 INTRODUCTION

The eruption of Sidoarjo Mud started in May 2006. Since then, Sidoarjo Mud has covered more than 640 hectares. With the monte carlo simulation (Rudolph, Karlstrom, & Manga, 2011), it is estimated that there is a 50% chance of the eruption lasting 41 years and a 33% chance that it lasts 84 years. Various attempts hace been made to reduce mud deposit. Efforts to reduce sediment around the blast are also carried out by utilizing it into ready-made products.

One effort to utilize Sidoarjo Mud is to process it into building materials. The use of sidoarjo mud as a building material is expected to have a major impact on the reduction of the deposit volume. In this study, building materials developed from Sidoarjo mud are in the form of artificial lightweight aggregates.

There has been some previous research on the manufacture of artificial lightweight aggregates using explanded clay. To be a lightweight clay, aggregate must be given additional obsidian with a certain composition and then burned to sintering conditions at 1150˚C (Husin & Sugiharto, 2008). Sidoarjo mud was also being burned and given additional ingredients form fly ash or silica sand to become artificial lightweight aggregates (Lasino, 2007).

Lasino's study (2007) added fly ash to produce aggregates with maximum addition of 30% fly ash and was burned at the highest temperature, at 1000˚C. The effect of the amount of addition of fly ash on physical behavior such as density, spesific gravity, and aggregate water absorption in previous studies is unknown. Therefore, this study addressed this question by giving additional fly ash up to 50% artificial aggregate mixture with a higher calcination temperature at 1050˚C. Besides, it also compares chemical compound in every composition by Xray Diffraction and the structure of material by scanning electron microscope.

2 METHOD AND MATERIAL

2.1 Sidoarjo Mud

Sidoarjo Mud is a fine-grained material, blackish gray, high plasticity, and high dry shrinkage (Lasino,

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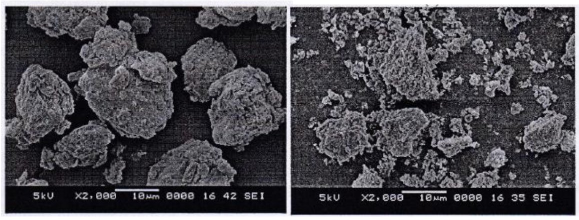
2007). Sidoarjo-mud consists of many compounds as presented in table 1.

Table 1: compound of Calcined Sidoarjo-Mud 800°C-2 hours (Lasino, 2007).

Compound	% weight
SiO_2	52.79
Al_2O_3	26.35
Fe_2O_3	8.51
TiO_2	-
CaO	1.97
MgO	2.53
Na_2O	2.08
K_2O	2.86
SO_2	0.98
Lost material	1.92

The compounds of calcined Sidoarjo-mud can also be known with XRD analysis shown in picture 1.



(a) (b)

Figure 2: SEM Micrograph from dry Sidoarjo-mud and Calcined Sidoarjo-Mud (800°C-2hours).

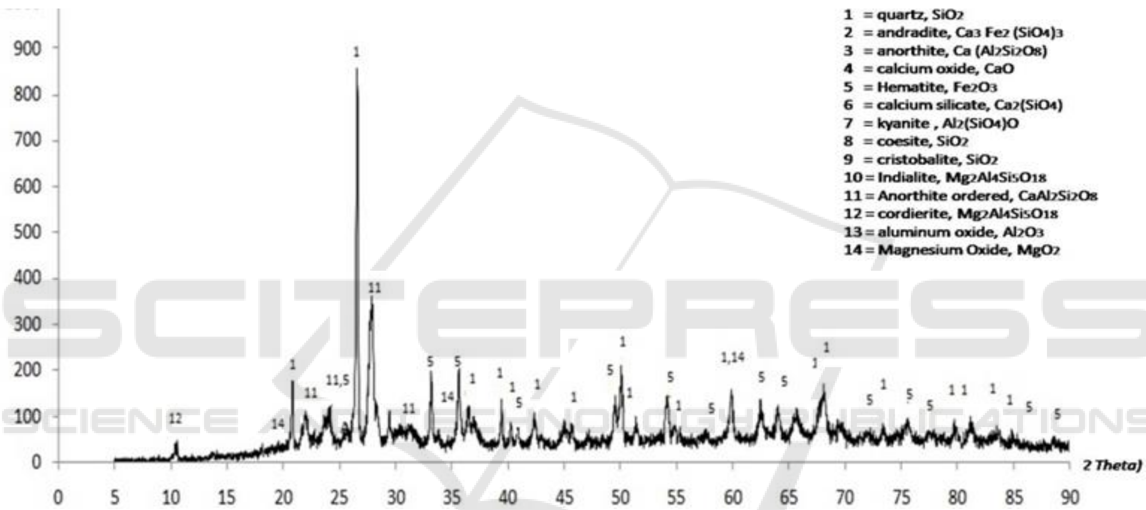


Figure 1: Xray Diffraction Calcined Sidoarjo-Mud 800°C-2 hours (Ekaputri & Triwulan, 2013).

From Figure 1, it is known that the dominant compounds in Calcined mud are Quartz (SiO_2), Anorthite ordered ($CaAl_2Si_2O_8$) dan Hematite (Fe_2O_3). (Rafiza, 2013) stated that the material (Sidoarjo-mud) changed from semi crystaline pattern in dry-mud to amorphous pattern in calcined-mud with domminant compound is SiO_2. SEM Analysis of dry Sidoarjo Mud and calcined Sidoarjo Mud are shown in Figure 2. The structure of Mud even in dry or calcined looks flat shape, similar to caolin. The bigger flat-layered structure (dry mud) changed to smaller flat-layered structur when calcined.

2.2 Fly Ash

Fly-ash is the finely divided residue resulted from the combustion of ground or powdered coal, which is transported by flue gasses. (ASTM & C618). Fly ash is devided into 3 classes: class N, Class F, and class C. The chemical compounds of fly ash are shown in table 2.

Table 2: Compound of fly Ash in 3 classification

Compound	Class		
	N	F	C
$SiO_2 + Al_2O_3 + Fe_2O_3$ (Min. %)	70	70	50
SO3,(Maks %)	4.0	5.0	5.0
Water content, (Maks %)	3.0	3.0	3.0
Lost material ((Maks %)	10.0	6.0	6.0

Scanning Electron Microscopy photo from fly ash class F, taken from Paiton Java Power Probolinggo is shown in figure 4. From figure 4, the structure of flyash looks spherical in a diameter of less than 45μm. (Ekaputri & Triwulan, 2013).

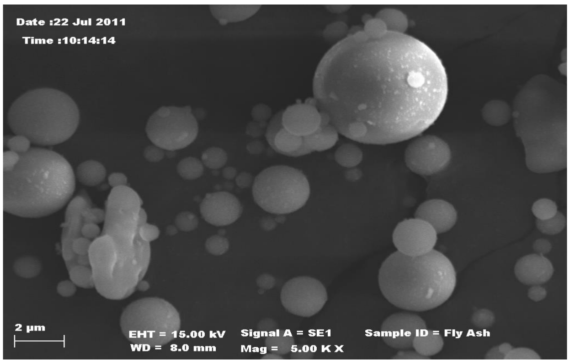


Figure 4: SEM Fly-ash class F (Ekaputri & Triwulan, 2013).

2.3 Producing ALWA

Fine ALWA was produced in various compositions. The first composition is 100% from Sidoarjo mud; the second is mix from 70% Sidoarjo mud and 30% fly ash; and the third is mix from 50% Sidoarjo mud and 50%. After the base material was blended perfectly, the material was burned for 240 and 360 minutes as presented in table 3.

Table 3: Sample of fine ALWA

Code	composition		Temperature (°C) /duration (hours)	
	Sidoarjo Mud	Fly Ash		
FA-0-x-z	100	0	1000/2	1050/6
FA-30-x-z	70	30	1000/2	1050/6
FA-50-x-z	50	50	1000/2	1050/6

2.4 Testing ALWA

2.4.1 Physical Properties

Fine ALWA analysis is adjusted to specifications on lightweight aggregates for structural lightweight concrete as required in ASTM C 330-03 as shown in table 4.

Table 4: Physics Requirement of lighweight aggregate for structural lightweigt concrete (ASTM C330)

Physical properties	Requirement
Density (gr/cm^3)	1,0 – 1,8
Maksimum Water absorption after 24 hours (%)	20
Maximum Dry Loose Bulk Density (kg/m^3)	1120

(ASTM, Standard Specification for Lightweight Aggregates for Structural Concrete, 2013)

2.4.2 Xray Diffraction

XRD testing is intended to determine the compounds contained in fine ALWA. XRD (X-ray Diffraction) tests carried out in the Energy laboratory - LPPM ITS. The XRD test was carried out at angle of 2Theta between 5 ° to 90 °. After getting the X-ray Diffraction pattern, the Xpowder program and Match! were used to find out the types of minerals and global amorphous fine ALWA, as well as to find out changes in minerals that occur due to the addition of fuel temperature, duration of calcination, and the addition of fly ash.

2.4.3 Scanning Electron Microscopy

SEM (Scanning Electron Microscopy) was done to obtain micrographs from fine ALWA.

3 RESULT AND DISCUSSION

3.1 Physical properties analysis of fine ALWA

Physical testing of fine ALWA included spesific gravity, density, and water absorption in every composition and calcination. Figure 5 shows the picture of fine ALWA : FA-0-1000-4, FA-30-1000-4, FA-50-1000-4, FA-0-1000-6, FA-30-1000-6, FA-50-1000-4, FA-0-1050-4, FA-30-1050-4, FA-50-1050-4, FA-0-1050-6, FA-30-1050-6, FA-50-1050-6.

As figure 5 indicates, the granules have different colours in each composition and calcination. The longer the duration of calcination, the colour became darker. The higher the temperation of calcination, the colour became darker.

Figure 5: Fine ALWA

3.1.1 Spesific Gravity

The table 5 showed the spesific gravity of fine ALWA when in saturated surface dry (SSD) condition.

Table 5: spesific gravity of fine ALWA (SSD)

Code (FA-x-y-z)	W_{SSD} (gr)	W_2 (gr)	W_1 (gr)	Spesific Gravity (SSD) (gr/cm^3)
FA-0-1000-4	200	1225	1345	2.500
FA-30-1000-4	200	1225	1340	2.353
FA-50-1000-4	200	1225	1340	2.212
FA-0-1050-4	200	620	735	2.353
FA-30-1050-4	200	1225	1335	2.222
FA-50-1050-4	200	620	725	2.105
FA-0-1000-6	200	1225	1335	2.262
FA-30-1000-6	500	1225	1480	2.119
FA-50-1000-6	200	1225	1320	1.916
FA-0-1050-6	200	1225	1330	2.105
FA-30-1050-6	500	1225	1480	2.041
FA-50-1050-6	200	1225	1320	1.905

Spesific gravity of fine ALWA in every composition and calcination showed that the fine ALWA was not in accordance with the requirement. ASTM C330 requires that spesific gravity of lighweight aggregate for structural lighweight concrete must be from 1.1 – 1.8 gr/cm^3. but, if comparing with lumajang sand, spesific gravity of fine ALWA in all sample was lighter than *lumajang* sands. Spesific gravity of lumajang sand is about 2700 kg/m^3. The lightest spesific gravity (1905 kg/m^3) of fine ALWA occured in 1050°C calcination for 6 hours with 50% sidoarjo mud and 50% fly ash. If we use fine ALWA code FA-50-1050-6, the spesific gravity of aggregate decreased for about 29.63%.

From the table 5, we can analyse the effect of adding fly ash on spesific gravity of fine ALWA. The addition of fly ash decreases the weight of the fine ALWA if it is burned with a duration of 4 and 6 hours. The addition of 30% fly ash decreases the spesific gravity by 3-6% while the addition 50% of fly ash reduces the specific gravity by 3-11%. It is because the specific gravity of the fly ash is lighter than the specific gravity of burnt sidoarjo mud. Fly ash's spesific gravity is 2500 kg/m^3. However, at the duration of calcination of 10 minutes, the addition of fly ash to 50% increases the specific gravity.

Based on table 5, we can also analyse the effect of adding temperature of calcination to spesific gravity of fine ALWA. Adding temperature (50°C) in all duration and all composition reduced spesific gravity of fine ALWA by 5-6%. According to the previous study, (Arioz, Karasu, Kilinç, & Kivrak, 2008), the LECA granules with spesific gravity between 1.5 and 2.0 can be produced in firing temperature at 1250°C. Firing temperature lower than 1250°C cannot produce lighter granules.

The effect of adding calcination's duration from 4 hours to 6 hours reduce the spesific gravity. The least spesific gravity loss occurs by 10% in 100% Sidoarjo Mud, and the biggest is 19% in fine ALWA with additional fly ash 50%.

3.1.2 Density

The density in every composition and calcination is shown in Table 6.

Table 6: Density of fine ALWA

Code (FA-x-y-z)	M (Kg/m^3)	Density (ASTM) (Kg/m^3)
FA-0-1000-4	1197.45	1120
FA-30-1000-4	1171.97	1120
FA-50-1000-4	1121.02	1120
FA-0-1050-4	1171.97	1120
FA-30-1050-4	1146.50	1120
FA-50-1050-4	1121.02	1120
FA-0-1000-6	1095.54	1120
FA-30-1000-6	1019.11	1120
FA-50-1000-6	993.63	1120
FA-0-1050-6	1070.06	1120
FA-30-1050-6	993.63	1120
FA-50-1050-6	968.15	1120

In the density testing, almost all variations in composition, calcination temperature, and duration of calcination met the requirements. The volume weight obtained ranged from 886-1197 kg/m^3 with ASTM C-330 maximum limit of 1120 kg/m^3.

The addition of fly ash to the fine ALWA reduced the density of fine ALWA. It aligns with the previous study by Huda and Astusti (2012), showing that adding greater hush ask at brick reduces the density. It is because of the silicate-alumna in husk ash evaporates when heated at high temperatures, so that more cavities occur in the brick.

The increase of temperature from 1000°C to 1050°C reduced the density for about 2%. It aligns with the previous study by Huda and Astuti (2012), showing that adding 20°C heating temperature reduced the brick density. The effect of adding duration of calcination temperature reduced the density.

3.1.3 Water Absorption

The density in every composition and calcination is shown in Table 7.

Table 7: Water Absorption of fine ALWA

Code (FA-x-y-z)	Water absorption (%)	Water absorption (ASTM) (%)
FA-0-1000-4	20.48	20
FA-30-1000-4	19.05	20
FA-50-1000-4	16.96	20
FA-0-1050-4	15.38	20
FA-30-1050-4	12.50	20
FA-50-1050-4	11.40	20
FA-0-1000-6	20.48	20
FA-30-1000-6	18.34	20
FA-50-1000-6	16.28	20
FA-0-1050-6	12.36	20
FA-30-1050-6	11.73	20
FA-50-1050-6	10.50	20

The water absorption value is shown in Table 7 shows that almost all of the values meet the requirement (ASTM C 330-04) less than 20%. The water absorption value is in the range of 11-20.5%. The smallest water absorption occurs at calcination temperature of 1050 °C for 6 hours by 11-12.5%.

The addition of fly ash to water absorption of fine ALWA reduces the water absorption of fine ALWA. The addition of calcination temperature from 1000°C to 1050°C reduces water absorption of fine ALWA. The addition of duration of calcination temperature reduces water absorption of fine ALWA

3.2 X-Ray Diffraction Analysis

Xray diffraction analysis for fine ALWA FA-0-1000-6, fine ALWA FA-0-1050-6, fine ALWA FA-30-1050-6, fine ALWA FA-50-1050-6, fine ALWA FA-0-1050-4, analysis fine ALWA FA-30-1050-4, fine ALWA FA-50-1050-4 discribe below.

The diffraction pattern is shown in figure 6 forms scattered and peaked. It shows that in temperature 1000°C duration 6 hours, the minerals that appeared are quartz (SiO_2), anorthite ($Al_2CaO_8Si_2$), hematite., calcite ($CaCO_3$), indialite ($Al_4Mg_2O_{18}Si_5$) and silimanite (Al_2SiO_5).

Xray diffraction of fine ALWA 100% Sidoarjo mud, with calcination temperature 1050°C for 6 hours is shown in figure 7.

The diffraction pattern presented in figure 7 shows that mineral occure are anorthite ($Al_2CaO_8Si_2$), quartz (SiO_2), hematite (Fe_2O_3), Indialite ($Al_2Mg_2O_{18}Si_5$), Calcite ($CaCO_3$). Silimanite has not been detected in this sample.

Xray diffraction of fine ALWA 70% Sidoarjo mud-30% Fly Ash, with calcination temperature 1050°C for 6 hours is shown in figure 8.

The diffraction pattern presented in figure 8 shows that minerals occuref in higher peak are quartz (SiO_2), anorthite ($Al_2CaO_8Si_2$) and hematite (Fe_2O_3). In the short peak, calcite, silimanie, and a little indialite can be found.

Xray diffraction of fine ALWA 50% Sidoarjo mud-50% Fly Ash, with calcination temperature 1050°C for 6 hours shown in figure 9.

Xray diffraction of fine ALWA 100% Sidoarjo mud, with calcination temperature 1050°C for 4 hours shown in figure 10.

The diffraction pattern shown in figure 10 show that mineral occure in higher peak are anorthite ($Al_2CaO_8Si_2$) quartz (SiO_2), and hematite (Fe_2O_3). The short peak occur calcite and indialite.

Xray diffraction of fine ALWA 70% Sidoarjo mud-30% Fly ash, with calcination temperature 1050°C for 4 hours shown in figure 12.

The diffraction pattern shown in figure 12 show that mineral occure in higher peak are anorthite ($Al_2CaO_8Si_2$) quartz (SiO_2), and hematite (Fe_2O_3). The short peak occur calcite, silimanite and indialite.

Xray diffraction of fine ALWA 50% Sidoarjo mud-50% Fly ash, with calcination temperature 1050°C for 4 hours shown in figure 13.

The diffraction pattern shown in figure 13 show that mineral occure in FA-50-1050-4 same with FA-30-1050-4.

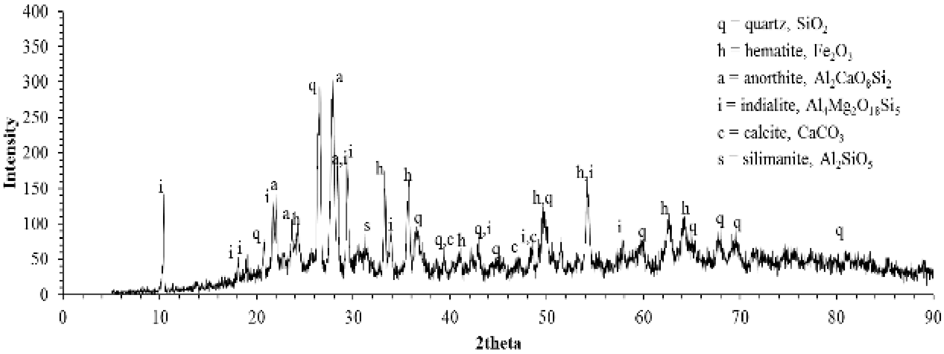


Figure 6: XRD analysis fine ALWA FA-0-1000-6

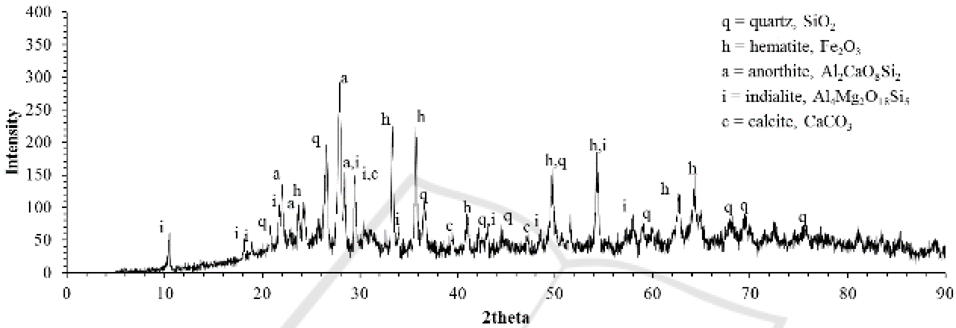


Figure 7: XRD analysis fine ALWA FA-0-1050-6

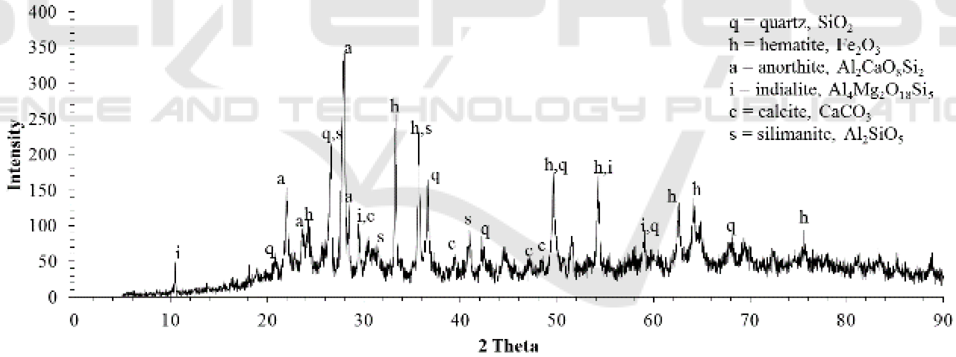


Figure 8: XRD analysis fine ALWA FA-30-1050-6

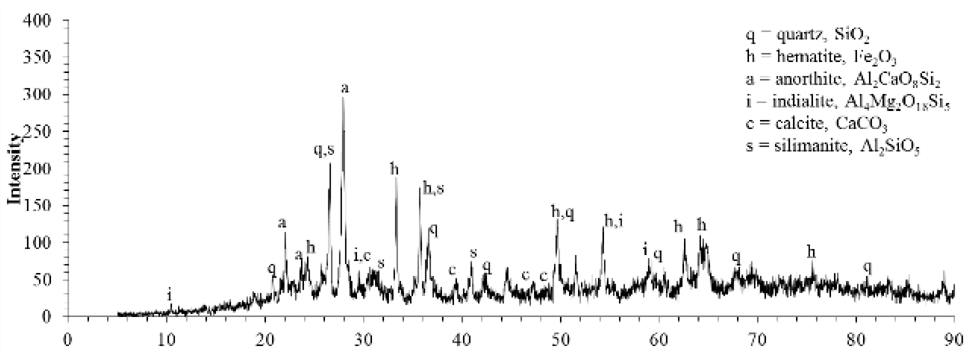


Figure 9: XRD analysis fine ALWA FA-50-1050-6

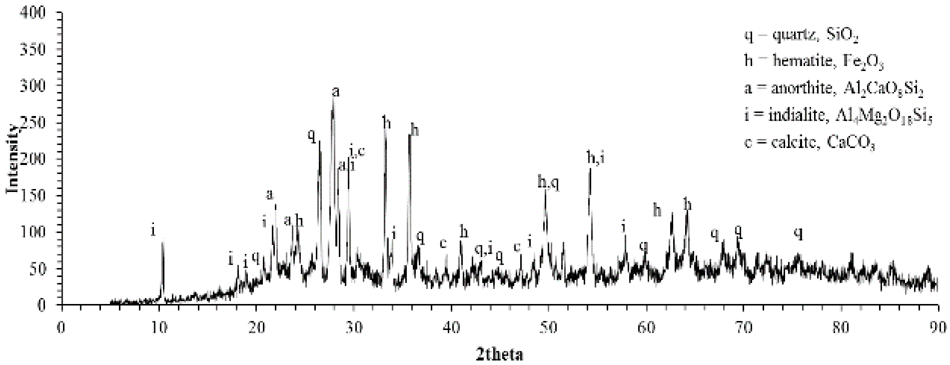


Figure 10: XRD analysis fine ALWA FA-0-1050-4

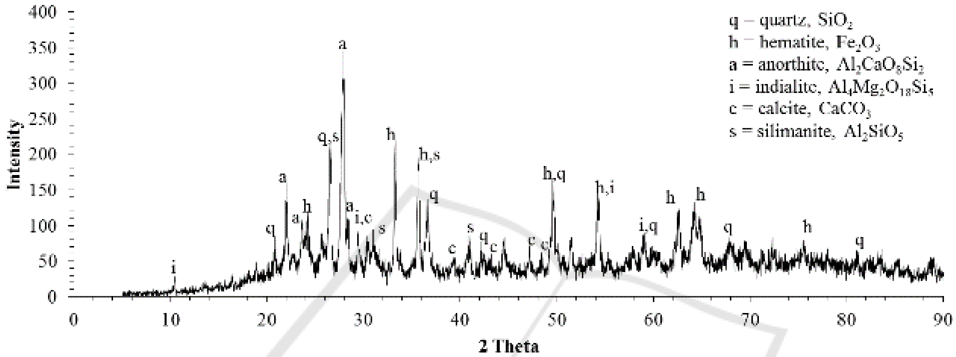


Figure 11: XRD analysis fine ALWA FA-30-1050-4

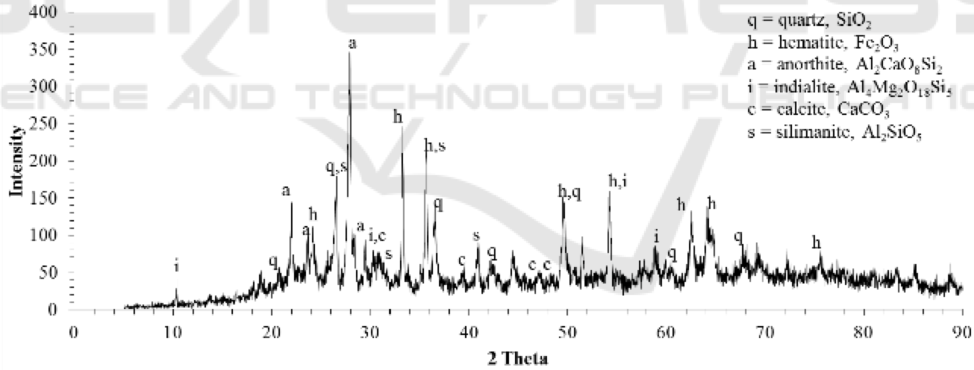


Figure 12: XRD analysis fine ALWA FA-50-1050-4

Xray diffraction analysis for fine ALWA FA-0-1000-6, fine ALWA FA-0-1050-6, fine ALWA FA-30-1050-6, fine ALWA FA-50-1050-6, fine ALWA FA-0-1050-4, fine ALWA FA-30-1050-4, fine ALWA FA-50-1050-4 mineral occure domminantly anorthite (Al2CaO8Si2), quartz (SiO2), and hematite (Fe2O3).

3.3 Scanning Electron Microscopy

Photo SEM (Scanning Electron Microscopy) aims to determine the shape of the microstructure found in the composition of fine ALWA. The fine ALWA composition carried out by SEM photos is without the addition of fly ash and 50% additional fly ash shown in figure 14.

From the figure 14 show micro structure of fone ALWA. Fine ALWA FA-0-1050-6 occur irregular particle and angled. Fine ALWA FA-50-1050-6 occur solid particle.

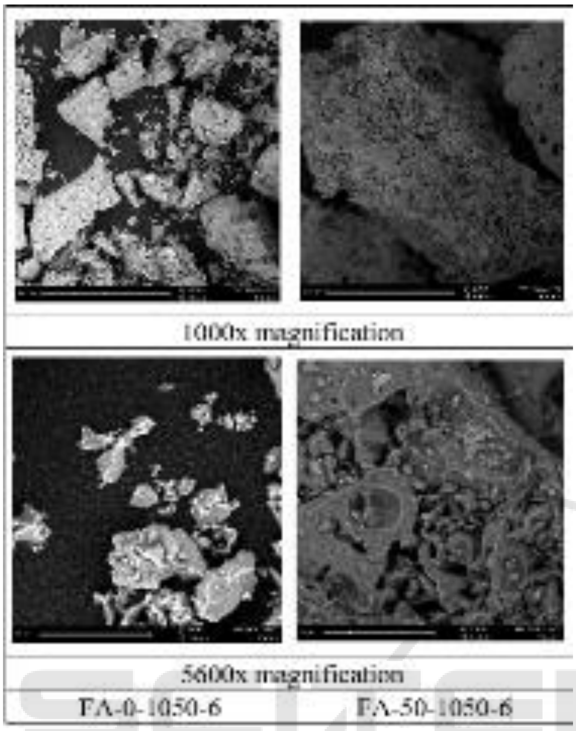


Figure 14: Photo SEM Fine ALWA FA-0-1050-6 and FA-50-1050-6

4 CONCLUSSION

Spesific gravity of fine ALWA in all variation (1,905-2,5gr/cm^3) not in accordance with the requirements of ASTM C 330 (1,1-1,8 gr/cm^3). Density of fine ALWA in all variation (886-1197 kg/m^3) meet with the requirement of ASTM C 330 (1120 kg/m^3). Water Absorption of fine ALWA in all variation meet with the requirement of ASTM C 330. (less than 20%). Xray diffraction analysis in all variation of fine ALWA domminantly quartz. Anorthide, and hematite, and Photo SEM of fine ALWA show that adding fly ash increase solidity of particle.

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