POTENTIAL OF LUSI MUD AS GEOPOLYMER MATERIAL FOR ARTIFICIAL LIGHTWEIGHT AGGREGATE

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Potential of LUSI Mud as Geopolymer Material for Artificial Lightweight Aggregate

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LIST OF ABBREVIATIONS

LUSI	LUmpur SIdoarjo (Sidoarjo Mud)
CO_2	Carbon Dioxide
SiO_2	Silicon Dioxide
Al_2O_3	Aluminum Trioxide
OPC	Ordinary Portland Cement
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
Na_2SiO_3	Sodium Silicate
XRF	X-Ray Flourescence
XRD	X-Ray Diffraction
PSA	Particle Size Analysis
SEM	Scanning Electron Microscope
FTIR	Fourier Transform Infrared
m	Metre
km	Kilometre
°C	Degree celcius
m^3	cubic metre
%	percentage
M	Molar
MPa	Mega Pascal
Si	Silicon
Al	Aluminium
Ca	Calcium

CSH	Calcium silicate hydrate
SiO_4	Silicon tetraoxide
AlO_4	Aluminium tetraoxide
Na	Sodium
K	Potassium
Fe_2O_3	Iron oxide
ASTM	American Society for Testing and Materials
BS EN	British Standard (Eurocode)
ACI	American Concrete Institute
kg/m^3	kilogram per cubic metre
MnO_2	Manganese dioxide
h	Hour
rpm	revolutions per minute
GGBS	Ground granulated blast furnace slag
RHA	Rice husk ash
AIV	Aggregate Impact Value
MgO	Magnesium Oxide
CaO	Calcium Oxide
mm	millimetre
ALGA	Artificial lightweight geopolymer aggregate
L	Litre
LM/AA	LUSI Mud/Alkaline activator ratio
w/c	water/cement ratio
g	gram

Potensi Lumpur LUSI Sebagai Bahan Geopolimer untuk Agregat Buatan Ringan

ABSTRAK

Jumlah lumpur LUSI (LU-Lumpur, SI-Sidoarjo) yang banyak akibat daripada letusan berhampiran eksplorasi gas di Banjarpanji-1, Sidoarjo, Jawa Timur, Indonesia perlu ditukarkan kepada alternatif yang berguna. Geopolimer menjadi tumpuan kajian penyelidik kerana meningkatkan sifat-sifat konkrit, meningkatkan ketahanan, kos yang lebih rendah dan dapat memelihara alam sekitar. Geopolimer adalah istilah yang digunakan untuk menggambarkan polimer tak organik berasaskan aluminasilikat yang boleh dihasilkan melalui sintesis sebatian pozzolanik atau bahan sumber aluminasilikat dalam larutan beralkali tinggi. Permintaan yang tinggi terhadap agregat ringan dalam konkrit menggalakkan penyelidikan ini untuk meneroka lumpur LUSI sebagai agregat buatan ringan dengan sifat-sifat yang baik dalam konkrit. Kajian ini memberi tumpuan kepada penggunaan lumpur LUSI sebagai agregat buatan ringan geopolimer (ALGA) untuk diaplikasikan dalam konkrit. Kaedah pensinteran dipilih dalam kajian ini kerana sifat-sifat yang lebih baik dihasilkan dan keutamaan komersial. Proses penghasilan ALGA termasuk rekabentuk, pencampuran lumpur LUSI dan pengaktif alkali (natrium hidroksida, NaOH + natrium silikat, Na_2SiO_3), proses perpeletan dan pensinteran. Terdapat tiga parameter yang mempengaruhi agregat yang dihasilkan, i) suhu pensinteran; ii) kemolaran NaOH; iii) nisbah lumpur LUSI/pengaktif alkali dan nisbah Na_2SiO_3/NaOH. Pencirian lumpur LUSI dan sifat-sifat ALGA telah dianalisa dengan menggunakan analisis saiz partikel (PSA), analisis belauan sinar X (XRF), penyerakan sinar X (XRD), mikroskop imbasan elektron (SEM) dan spektroskopi inframerah jelmaan fourier (FTIR). Hasil kajian menunjukkan bahawa suhu pensinteran pada 950 °C, kemolaran NaOH 12M, nisbah lumpur LUSI/pengaktif alkali pada 1.7 dan nisbah Na_2SiO_3/NaOH pada 0.4 memberikan nilai impak agregat (AIV) yang optimum iaitu 15.42% dengan ketumpatan 1100 kg/m^3 dan penyerapan air rendah (4.7%). Fasa baru sodalite ($Na_4Al_3Si_3O_{12}Cl$), albite ($NaAlSi_3O_8$) dan kuarza (SiO_2) dalam ALGA memberi kesan kepada kekuatan tertinggi yang dihasilkan. Imej SEM menunjukkan taburan liang dalam ALGA yang dihasilkan dengan geopolimer adalah lebih baik dari segi struktur matrik. Jalur penyerapan pada 820-1250 cm^{-1} menunjukkan kepelbagaian sudut ikatan pada struktur ALGA. ALGA optimum kemudiannya dibandingkan dengan sampel kawalan (agregat dengan lumpur LUSI tanpa pengeopolimeran). ALGA optimum menunjukkan sifat yang lebih baik dari segi kekuatan dengan ketumpatan dan penyerapan air yang rendah berbanding dengan sampel kawalan. Kewujudan shell berkaca sekitar ALGA yang dihasilkan telah mengukuhkan struktur ALGA tersebut. Prestasi ALGA konkrit ringan menunjukkan keputusan yang baik dengan kekuatan tinggi 41.89 MPa pada 28 hari ujian dengan ketumpatan 1760.1 kg/m^3 yang boleh diklasifikasikan sebagai struktur konkrit agregat ringan mengikut ACI 213R (2003).

Potential of LUSI Mud as Geopolymer Material for Artificial Lightweight Aggregate

ABSTRACT

The abundant amount of LUSI (LU-Lumpur, SI-Sidoarjo) mud that began erupting near the Banjarpanji-1 exploration well in Sidoarjo, East Java, Indonesia need to convert onto useful and valuable alternatives. Geopolymer becomes an attractive research due to improving the concrete properties, increased durability, improved performance, lower cost and preserves the environment. Geopolymer is a term used to describe inorganic polymers based on aluminosilicates that can be produced by synthesizing pozzolanic compounds or aluminosilicate source materials with highly alkaline solutions. The high demand for lightweight aggregate in concrete encourages this research to explore new material of LUSI mud to be used as artificial lightweight aggregate with excellent properties and performance in concrete application. This study will focus on utilizing the LUSI mud as an artificial lightweight geopolymer aggregate (ALGA) to be used in lightweight concrete. Sintering method has been choosen in this study due to better properties produced and commercial priority. Production processes include design, mixing of LUSI mud and alkaline activator (sodium hydroxide, NaOH + sodium silicate, Na_2SiO_3), pelletizing and sintering process. There are three parameters that influence aggregate produced, i) sintering temperature; ii) NaOH molarity; iii) LUSI mud/alkaline activator ratio and Na_2SiO_3/NaOH ratio. The characterization of LUSI mud and properties of ALGA have been done by using Particle Size Analyzer (PSA), X-Ray Flourescence (XRF), X-Ray Diffraction (XRD), Scanning Electron Microscope (SEM) and Fourier Transform Infrared (FTIR). The results showed that the sintering temperature of 950 °C, NaOH molarity of 12M, LUSI mud/alkaline activator ratio of 1.7 and Na_2SiO_3/NaOH ratio of 0.4 gives the optimum Aggregate Impact Value (AIV) of 15.42% with low density of 1100 kg/m^3 and water absorption (4.7%). The new phases of sodalite ($Na_4Al_3Si_3O_{12}Cl$), albite ($NaAlSi_3O_8$) and quartz (SiO_2) were appearing at ALGA produced which might affect the highest strength produced. SEM image showed the distribution of pores in the ALGA produced with better geopolymer matrix structure produced. The broadness of the absorbance band at 820-1250 cm^{-1} showed the variability of the bond angles of the structures of ALGA. The optimum ALGA then compared with control sample (aggregate with LUSI mud and water without geopolymerization). The optimum ALGA showed better properties in terms of strength with lower density and water absorption compared to control sample. The existence of vetrified shell around the ALGA produced has strengthened the structure of ALGA. The performance of ALGA lightweight concrete shows excellent results with high strength of 41.89 MPa at 28 days of testing with a density of 1760.1 kg/m^3 which can be classified as structural lightweight aggregate concrete according to ACI 213R (2003).

CHAPTER 1

INTRODUCTION

1.1 LUSI Mud, Sidoarjo, Indonesia

The terms LUSI (LU- Lumpur 'mud' and SI- Sidoarjo), are referred to volcano mud from Sidoarjo, Indonesia which has started erupting on 29 May 2006. This eruption can be labelled as industrial disaster, resulted from a hydrocarbon exploration (Geoffrey et al., 2008; Hardjito & Antoni, 2013). LUSI has been classified as the largest volcano mud which cover an area of almost 3 square miles to a depth of 65 feet and submerging surrounding of not less than 640 hectares including productive land, housing, schools and infrastructure facilities (Cryanoski, 2007; Geoffrey et al., 2008) and the eruption is still continue until now. Furthermore, the eruption was predicted to last for several more decades (Rudolph et al., 2011).

LUSI mud is created through the formation of geo-exuded slurries (usually including water) and gases. LUSI mud is not true (igneous) volcanoes as they produce no lava. Hardjito et al., (2013) stated that the height of the cover dam to sustain the high volume of LUSI mud is about 12 meters. Some of the discharge has been channeled to the nearby river, causing a newly formed island in its mouth (Hardjito et al., 2013). Now, the daily

discharge was about 10,000-25,000 m^3 (Agustawijaya & Sukandi, 2012). With the high volume of LUSI mud available, the efforts have to be carried out to utilize this material.

The first research to utilize LUSI mud as pozzolanic material was reported by Januarti and Triwulan (2006) by combining wet LUSI mud with fly ash in geopolymer concrete. Then, Nuruddin et al. (2010) utilizes the LUSI mud by partially replace the use of cement in making mortar. Then, Hardjito et al. (2012) studied the calcined LUSI mud and successfully utilized the pozzolanic mortar at 40% of cement replacement, by mass. There is no other published work yet studying the artificial lightweight aggregate using LUSI mud. Thus, the contribution of this study is to develop the artificial lightweight aggregate by using LUSI mud, thus will be one of the alternatives to solve the high volume of LUSI mud in Sidoarjo, Indonesia.

1.2 Geopolymer

Geopolymer materials attracted a great deal of consideration to promote the use of pozzolanic materials such as metakaolin, fly ash, ground granulated blast furnace slag, and others to replace Portland cement (Yunsheng et al., 2010; Chindaprasirt et al., 2009; Davidovits, 2002; Malhotra, 1999; Palomo et al., 1999a). Geopolymer can be defined as cementitious materials produced from an aluminosilicate precursor activated in a high alkali solution (Duxson et al., 2007). Geopolymer possess good mechanical properties such as high compressive strength, long term durability (Komnitsas & Zaharaki, 2007), acid resistance (Duxson et al., 2007), fire resistance (Komnitsas & Zaharaki, 2007) and low thermal conductivity (Duxson et al., 2007; Zhang et al., 2010). The preparation of

geopolymer could reduce the environmental impact of cement manufacture compared to the production of Portland cement which releases large amounts of the carbon dioxide (CO_2) into the atmosphere (Habert et al., 2010).

Geopolymer requires raw materials with high content of SiO_2 and Al_2O_3, thus LUSI mud has high potential aluminosilicate source material for making geopolymers (Bondar et al., 2011) due to the significant amount of SiO_2 and Al_2O_3 in its composition. The efforts to explore the preliminary analytical of LUSI mud and its potential material used in geopolymer composites have been conducted by Ryuta and Kiyoshi (2009), Geoffrey et al. (2008), Cryanoski (2007), Davies et al. (2007), and Januarti and Triwulan (2006).

1.3 Artificial Lightweight Aggregate

Lightweight aggregate concrete is defined as concrete of low density using lightweight aggregates. Many types of aggregates are classified as lightweight that can be used to produce concrete with a wide range of densities and strengths (ACI 211.2, 2003). The need for lightweight structural design is increasing presently as it reduces the mass of the structure and reduces the total cost of the building. The structural lightweight concrete reduces the dead load on a structure, which the size of beams, columns and foundations can be reduced, and in turn cuts the amount of concrete and reinforcing steel required. Lightweight aggregate provides better insulation property due to low density (Yang et al., 2010). Artificial lightweight aggregate can be produced by using industrial by product such as sewage sludge, bottom ash, fly ash, palm shell and others (Chandra, 2002; Byung-wan et al., 2007; Almir et al., 2010). Most of the preparation methods of artificial lightweight

aggregate involve a sintering process for the hardening of pellets due to better properties produced (Niyazi & Turan, 2010, 2011a, 2011b, 2011c) and ready-used aggregates after they cool down.

Development of artificial lightweight geopolymer aggregate (ALGA) from LUSI mud has not been explored yet. The high demand for lightweight aggregate in concrete encourages this research to explore new material of LUSI mud to be used as artificial lightweight aggregate with excellent properties and performance in concrete application. Therefore, an optimization study needs to be done to determine the optimal ALGA properties using LUSI mud and geopolymer methods that would maximize the strength while keeping the minimum water absorption and density.

1.4 Problem Statement

The high volume of LUSI mud produced from the eruption of near the Banjarpanji-1 exploration well in Sidoarjo, East Java, Indonesia need to convert onto useful and valuable alternatives. This eruption impacted an area of almost 3 square miles to a depth of 65 feet and thirty thousand people has been displaced which cost Indonesia USD$3.7 billion in damages and damage control.

For 2012, the government has earmarked an initial amount of USD$80.01 million to pay compensation for 61 hectares of the victims' land and increasing year by year. The total cost of damage and damage control by Lapindo Brantas was achieved up to USD$488.0 Million in 2011 and increase to USD$730.7 Million in 2014 as shown in Fig. 1.1 (Lapindo Brantas Social Impact Report, 2011; 2014).