

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**

by

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TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	ii
ACKNOWLEDGEMENT	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	xi
LIST OF TABLES	xv
LIST OF ABBREVIATIONS	xvi
ABSTRAK	xviii
ABSTRACT	xix
CHAPTER 1 INTRODUCTION	
1.1 LUSI Mud, Sidoarjo, Indonesia	1
1.2 Geopolymer	2
1.3 Artificial Lightweight Aggregate	3
1.4 Problem Statement	4
1.5 Objectives of Study	6
1.6 Scope of Study	7
1.7 Organization of The thesis	8
CHAPTER 2 LITERATURE REVIEW	
2.1 Introduction	9
2.2 Eruption of LUSI, Sidoarjo, Indonesia	10
2.2.1 Current Utilization of LUSI mud	13

2.3	Geopolymer	13
2.3.1	Application of Geopolymer	15
2.4	Geopolymer Constituent	17
2.4.1	Source Materials	17
2.4.2	Alkaline Activator	20
2.5	The Geopolymerization Reaction Process	22
2.6	Characterization of LUSI Mud-Based Geopolymer	26
2.6.1	X-Ray Fluorescence (XRF)	26
2.6.2	X-Ray Diffraction (XRD)	27
2.6.3	Scanning Electron Microscope (SEM)	29
2.6.4	Fourier Transform Infrared (FTIR)	30
2.7	Factors Affecting Properties of Geopolymer	30
2.7.1	NaOH Molarity	30
2.7.2	Mix Design	31
2.7.3	Curing Temperature	33
2.8	Development of Artificial Lightweight Aggregate	34
2.8.1	Types of Lightweight Aggregate	36
2.8.1.1	Natural Aggregate	36
2.8.1.2	Artificial Aggregate	37
2.8.2	Methods of Producing Lightweight Aggregate	37
2.8.2.1	Mixing Process	37
2.8.2.2	Palletizing Process	38
2.8.2.3	Sintering Process	39
2.9	Properties of Artificial Lightweight Aggregate	43
2.9.1	Density	43

2.9.2	Water Absorption	44
2.9.3	Aggregate Impact Value (AIV)	45
2.9.4	Structure/Morphology	46
2.9.4.1	X-Ray Diffraction (XRD)	46
2.9.4.2	Scanning Electron Microscope (SEM)	48
2.9.4.3	Fourier Transform Infrared (FTIR)	50
2.10	Application of Artificial Lightweight Aggregate in Concrete	52
2.10.1	Workability	52
2.10.2	Density	52
2.10.3	Water Absorption	53
2.10.4	Compressive Strength	53
2.11	Summary	55
CHAPTER 3 METHODOLOGY		
3.1	Introduction	56
3.2	Raw Materials	58
3.2.1	LUSI Mud	58
3.2.2	Alkaline Activator Solution	58
3.2.2.1	Sodium Hydroxide (NaOH)	58
3.2.3	Sodium Silicate (Na ₂ SiO ₃) Solution	59
3.3	Preparation and Characterization of Raw Material	59
3.3.1	Preparation of Raw Material	59
3.3.2	Characterization of Raw Material	59
3.3.2.1	Particle Size Analysis (PSA)	59
3.3.2.2	X-Ray Fluorescence (XRF)	60

3.3.2.3	X-Ray Diffraction (XRD)	60
3.3.2.4	Scanning Electron Microscope (SEM)	60
3.3.2.5	Fourier Transform Infrared (FTIR)	61
3.4	Preparation of Sodium Hydroxide (NaOH) Solution	61
3.5	Preparation of Alkaline Activator Solution	62
3.6	Production of Artificial Lightweight Geopolymer Aggregate (ALGA)	63
3.6.1	Methods of Producing ALGA	63
3.6.1.1	Mixing	63
3.6.1.2	Palletizing	63
3.6.1.3	Sintering	64
3.6.2	Parameters of Producing ALGA	64
3.6.2.1	Sintering Temperature	65
3.6.2.2	NaOH Molarity	66
3.6.2.3	LUSI Mud/Alkaline Activator (LM/AA) ratio and $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio	67
3.6.3	Methods of Producing Control Samples	69
3.7	Testing for Artificial Lightweight Geopolymer Aggregate (ALGA)	69
3.7.1	Shape and Colour of Sample	69
3.7.2	Density	69
3.7.3	Water Absorption	70
3.7.4	Aggregate Impact Value (AIV)	70
3.7.5	Characterization of ALGA	72
3.8	Performance of ALGA in OPC Concrete	72
3.8.1	Method of Producing ALGA in OPC Concrete	72
3.8.2	Workability of ALGA Concrete	73
3.8.3	Density of ALGA Concrete	74

3.8.4	Water Absorption of ALGA Concrete	74
3.8.5	Compressive Strength of ALGA Concrete	75

CHAPTER 4 RESULTS AND DISCUSSION

4.1	Characterization of Raw Material	76
4.1.1	Particle Size Analysis of LUSI Mud	76
4.1.2	X-Ray Fluorescence (XRF) of LUSI Mud	77
4.1.3	X-Ray Diffraction (XRD) of LUSI Mud	78
4.1.4	Scanning Electron Microscope (SEM) of LUSI Mud	79
4.1.5	Fourier Transform Infrared (FTIR) of LUSI Mud	80
4.2	Effect of Sintering Temperature to the Properties of Artificial Lightweight Geopolymer Aggregate (ALGA)	82
4.2.1	Shape, Colour and Density of ALGA	82
4.2.2	Water Absorption of ALGA	84
4.2.3	Aggregate Impact Value (AIV) of ALGA	87
4.2.4	Relationship between Aggregate Impact Value (AIV) and Density of ALGA	88
4.2.5	Relationship between Aggregate Impact Value (AIV) and Water Absorption of ALGA	89
4.2.6	X-Ray Diffraction (XRD) of ALGA	90
4.2.7	Scanning Electron Microscope (SEM) of ALGA	93
4.2.8	Fourier Transform Infrared (FTIR) of ALGA	95
4.3	Effect of NaOH Molarity to the Properties of ALGA	99
4.3.1	Aggregate Impact Value (AIV) of ALGA	99
4.3.2	Density of ALGA	100
4.3.3	Water Absorption of ALGA	101

4.3.4	Relationship between Aggregate Impact Value (AIV) and Density of ALGA	102
4.3.5	The relationship between Aggregate Impact Value (AIV) and Water Absorption of ALGA	104
4.3.6	X-Ray Diffraction (XRD) of ALGA	105
4.3.7	Scanning Electron Microscope (SEM) of ALGA	106
4.3.8	Fourier Transform Infrared (FTIR) of ALGA	109
4.4	Effects of LUSI mud/Alkaline activator (LM/AA) ratio and $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio of ALGA	112
4.4.1	Aggregate Impact Value (AIV) of ALGA	112
4.4.2	Density of ALGA	113
4.4.3	Water absorption of ALGA	114
4.4.4	X-Ray Diffraction (XRD) of ALGA	116
4.4.5	Scanning Electron Microscope (SEM) of ALGA	117
4.4.6	Fourier Transform Infrared (FTIR) of ALGA	119
4.5	Comparison between optimum ALGA and control sample	122
4.5.1	Density, Water Absorption and Aggregate Impact Value (AIV)	122
4.5.2	X-Ray Diffraction (XRD)	124
4.5.3	Scanning Electron Microscope (SEM)	125
4.5.4	Fourier Transform Infrared (FTIR)	126
4.6	Performance of OPC-ALGA Concrete	127
4.6.1	Properties of ALGA	127
4.6.2	Properties of ALGA Concrete	127
	4.6.2.1 Workability	127
	4.6.2.2 Density	128
	4.6.2.3 Water absorption	129
	4.6.2.4 Compressive strength	129

CHAPTER 5 CONCLUSION

5.1	Conclusion	132
5.2	Recommendation	134
	REFERENCES	136
	APPENDIX A	149
	APPENDIX B	151
	LIST OF PUBLICATIONS	154

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LIST OF FIGURES

NO.		PAGE
1.1	Total cost for years 2011 and 2014 (Lapindo Brantas Social Impact Report, 2011; 2014)	5
2.1	The LUSI mud has immersed many villages (Geoffrey et al., 2008)	10
2.2	Satellite image of LUSI eruption site (Geoffrey et al., 2008)	11
2.3	The drain divert LUSI mud from the eruption site into the Porong River (Jennerjahn et al., 2013)	12
2.4	Application of geopolymeric based on the silica to alumina atomic ratio (Davidovits, 2011)	16
2.5	Geopolymerization reaction (Duxson et al., 2007)	23
2.6	Reaction mechanism of fly ash-based geopolymer (Duxson et al., 2007)	24
2.7	Geopolymerization process (Pacheco-Torgal et al., 2008)	25
2.8	XRD of LUSI mud (Antoni et al., 2013)	28
2.9	XRD patterns of volcanic ash from Mount Galim, West Region of Cameroon (Kouamo Tchakoute et al., 2013)	28
2.10	SEM micrograph of LUSI mud (Nuruddin et al., 2010)	29
2.11	FTIR spectra of volcano ash (Tchakoute Kouamo et al., 2012)	30
2.12	Illustration of palletizing artificial lightweight aggregate of fly ash before and after sintering (Monica et al., 2005)	40
2.13	SEM inner view of fly ash lightweight aggregate sintered at 1200 °C (Niyazi & Turan, 2011b)	41
2.14	Microscope picture of the cross section of (a) clay lightweight aggregate (Mueller et al., 2008); (b) expanded clay lightweight aggregate (Markus et al., 2013)	44
2.15	XRD of fly ash and bentonite pallet sample (Ramamurthy & Harikrishnan, 2006)	46
2.16	XRD of fly ash based geopolymer ●: sodalite, □: C-S-H, and ☆: hydrotalcite (Oh et al., 2011)	47

2.17	XRD patterns of volcano ash starting material and resulting geopolymer (Lemougna et al., 2011) ●: sodium aluminum silicate, ■: anorthite, ▲: ferroan forsterite, ★: augite	48
2.18	SEM micrograph of lightweight aggregate from combination of fly ash, expanded shale and kaolin (Shuguang et al., 2010)	49
2.19	SEM microstructure of lightweight geopolymer aggregate produced from fly ash ground granulated blast furnace slag and rice husk ash with alkaline activator (Le Anh-tuan et al., 2012)	50
2.20	FTIR spectra of volcano ash-based geopolymers (Tchakoute Kouamo et al., 2012)	51
2.21	Compressive strength of high performance alkaline activator lightweight concrete (Le Anh-tuan et al., 2012)	54
3.1	Flow chart of experimental procedure	57
3.2	Aggregate Impact Value Test	71
3.3	Casting of ALGA concrete	73
4.1	Graph of particle size distribution of LUSI mud	77
4.2	Colour of LUSI mud	77
4.3	XRD analysis of original LUSI mud	79
4.4	SEM images of original LUSI mud	79
4.5	FTIR spectra of LUSI mud	80
4.6	Colour, shape and density of sample at various sintering temperature	82
4.7	Graph of density of ALGA at various sintering temperature	84
4.8	Graph of water absorption of ALGA at various sintering temperature	85
4.9	Images of ALGA after sintered at (a) 900 °C (b) 950 °C, and (c) 1000 °C	86
4.10	SEM image of vitrified shell connected to inner part of ALGA	86
4.11	Graph of Aggregate Impact Value (AIV) for ALGA at various sintering temperature	87
4.12	The relationship between aggregate impact value (AIV) and density of ALGA	89

4.13	The relationship between aggregate impact value (AIV) and water absorption of ALGA	90
4.14	XRD pattern of ALGA produced at various sintering temperatures	91
4.15	SEM images of ALGA produced at (a) 500 °C, (b) 600 °C, (c) 700 °C, (d) 800 °C, (e) 900 °C, (f) 950 °C, and 1000 °C	94
4.16	FTIR spectra of ALGA produced at various sintering temperature	97
4.17	The aggregate impact value (AIV) of ALGA at various NaOH molarity	99
4.18	The density of ALGA at various NaOH molarity	101
4.19	The water absorption of ALGA at various NaOH molarity	102
4.20	The relationship between aggregate impact value (AIV) and density of ALGA	103
4.21	The relationship between aggregate impact value (AIV) and water absorption of ALGA	104
4.22	XRD pattern of ALGA produced at various NaOH molarity	106
4.23	SEM micrograph of ALGA produced at various NaOH molarity, (a) 6M, (b) 8M, (c) 10M, (d) 12M, (e) 14M, and (f) 16M	107
4.24	The FTIR spectra of ALGA produced at various NaOH molarity	110
4.25	The aggregate impact value (AIV) of ALGA produced at various LUSI mud/Alkaline activator (LM/AA) ratio and Na ₂ SiO ₃ /NaOH ratio	113
4.26	The density of ALGA produced at various LUSI mud/Alkaline activator (LM/AA) ratio and Na ₂ SiO ₃ /NaOH ratio	114
4.27	The water absorption of ALGA produced at various LUSI mud/Alkaline activator (LM/AA) ratio and Na ₂ SiO ₃ /NaOH ratio	115
4.28	XRD pattern of ALGA produced at various LM/AA ratio and Na ₂ SiO ₃ /NaOH ratio	117
4.29	SEM micrograph of artificial lightweight aggregate produced at (a) LM/AA = 1.7 and Na ₂ SiO ₃ /NaOH = 0.4, (b) LM/AA = 1.8 and Na ₂ SiO ₃ /NaOH = 0.4, (c) LM/AA = 1.9 and Na ₂ SiO ₃ /NaOH = 0.4	118
4.30	FTIR spectra of ALGA produced at LM/AA ratio of 1.7, 1.8, and 1.9 with Na ₂ SiO ₃ /NaOH ratio of 0.4	120
4.31	Images of control sample	123

4.32	XRD analysis of optimum ALGA compared with raw LUSI mud and control sample	124
4.33	SEM images of (a) optimum ALGA compared with; (b) control sample	125
4.34	FTIR spectra for optimum ALGA compared with control sample	126
4.35	The slump test for ALGA concrete	128
4.36	Compressive strength of OPC-ALGA concrete and OPC control concrete at various ages of testing	130
4.37	The interlocking of cement paste and ALGA	131

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LIST OF TABLES

NO.		PAGE
2.1	Raw materials for geopolymer	18
2.2	Chemical composition of LUSI mud	27
2.3	Density range of concrete (ACI 213R-03, 1998)	36
2.4	Various methods of manufacturing artificial lightweight aggregate from various sources	42
3.1	Properties of sodium hydroxide (NaOH)	58
3.2	Details preparation of NaOH solution	62
3.3	Details of parameters on producing ALGA using LUSI mud	65
3.4	Details of mix design for various ratios of LUSI mud/alkaline activator (LM/AA) and $\text{Na}_2\text{SiO}_3/\text{NaOH}$	68
3.5	The proportion of materials used in producing ALGA concrete	72
4.1	Chemical composition of LUSI mud	78
4.2	Main FTIR absorption peaks of LUSI mud	81
4.3	Main FTIR absorption peaks of ALGA produced at various sintering temperature	98
4.4	Main FTIR absorption peaks of ALGA produced at various NaOH molarity	111
4.5	Main FTIR absorption peaks of ALGA produced at LM/AA ratio of 1.7, 1.8, and 1.9 with $\text{Na}_2\text{SiO}_3/\text{NaOH}$ ratio of 0.4 and control sample	121
4.6	Comparison of optimum ALGA and control sample	123

LIST OF ABBREVIATIONS

LUSI	LUMPUR SIDOARJO (SIDOARJO MUD)
CO ₂	Carbon Dioxide
SiO ₂	Silicon Dioxide
Al ₂ O ₃	Aluminum Trioxide
OPC	Ordinary Portland Cement
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
Na ₂ SiO ₃	Sodium Silicate
XRF	X-Ray Fluorescence
XRD	X-Ray Diffraction
PSA	Particle Size Analysis
SEM	Scanning Electron Microscope
FTIR	Fourier Transform Infrared
m	Metre
km	Kilometre
°C	Degree Celsius
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 ₂ O 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 penyelidikan 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, Na₂SiO₃), 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 Na₂SiO₃/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 Na₂SiO₃/NaOH pada 0.4 memberikan nilai impak agregat (AIV) yang optimum iaitu 15.42% dengan ketumpatan 1100 kg/m³ dan penyerapan air rendah (4.7%). Fasa baru sodalite (Na₄Al₃Si₃O₁₂Cl), albite (NaAlSi₃O₈) dan kuarza (SiO₂) 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/m³ 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 chosen 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, Na₂SiO₃), 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 Na₂SiO₃/NaOH ratio. The characterization of LUSI mud and properties of ALGA have been done by using Particle Size Analyzer (PSA), X-Ray Fluorescence (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 Na₂SiO₃/NaOH ratio of 0.4 gives the optimum Aggregate Impact Value (AIV) of 15.42% with low density of 1100 kg/m³ and water absorption (4.7%). The new phases of sodalite (Na₄Al₃Si₃O₁₂Cl), albite (NaAlSi₃O₈) and quartz (SiO₂) 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/m³ 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 m³ (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 (CO₂) into the atmosphere (Habert et al., 2010).

Geopolymer requires raw materials with high content of SiO₂ and Al₂O₃, thus LUSI mud has high potential aluminosilicate source material for making geopolymers (Bondar et al., 2011) due to the significant amount of SiO₂ and Al₂O₃ 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).